# JISDM 2019

## 4th Joint International Symposium on Deformation Monitoring

**15-17 May 2019**
Eugenides Foundation
Athens, Greece

www.jisdm2019.survey.ntua.gr

**GUIDE**

# JISDM 2019

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Local Organiser

National Technical University of Athens

School of Rural and Surveying Engineering

Scientific & Professional Commissions

INTERNATIONAL FEDERATION OF SURVEYORS

IUGG

IAG/AIG International Association of Geodesy

isprs Information from Imagery

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# EDITORIAL

Dear participants,

We are glad to welcome you in Athens for the 4th International Symposium on Deformation Monitoring (4th JISDM).

In the current state of development and increase of natural and man-made disasters worldwide, the intense advent in engineering, micro-electronics and computer sciences set a novel paradigm for new deformation monitoring and analysis solutions. Since the early years of the FIG and IAG joint symposia, and more recently their denomination JISDM, the symposia series has become a forum of excellence reuniting researchers and product developers in the field of deformation measurement, analysis and interpretation. Assembling nearly 200 of participants from more than 25 countries from the academia, the industry and public authorities, JISDM displays an active international community in the field. In the footsteps of our predecessors, we open the discussions on various scientific and industrial topics during the symposium. Our invited speakers introduce the latest tendencies in the field of deformation monitoring and share their vision on the evolution of technologies and methods for monitoring both natural phenomena and man-made structures.

Likewise to the previous organization, the 4th JISDM Scientific Committee called for two types of submissions - i.e., peer review and non-peer review papers. The authors of both types of papers will have the opportunity to send extended versions of their conference articles for publication to a number of special issues in scientific journals in the field. During the three days of the symposium 95 oral and 37 poster presentations are given. The topics relate to core methodological, technical and practical developments in the field of deformation monitoring. The program of the oral presentations is structured in two parallel tracks for the duration of the conference. Poster presentations split into three sessions, each one lasting one day, thus giving the opportunity to participants to discuss with authors without time pressure.

The 4th JISDM Organizing Committee attaches great importance to the active participation of young researchers in the symposium. In this regard, two awards are offered for the best oral and poster student presentations, while IAG grants a limited number of travel awards to young scientists participating in the symposium. The highly interesting topics of the symposium have attracted a large number of sponsorships, including contributions from the construction industry; highway, bridge, dam and renewable energy operators; service companies in the field as well as utility companies. In response, the organizing committee has allocated a special session for technical presentations by the sponsors.

We hope that besides the conference auditoriums you will also find the time to visit the wonderful city of Athens. Located at the crossroads of three continents, the capital of Greece has often been the hub of many civilizations spanning a recorded history over 3,400 years. During your promenades in the city you will discover that Athens is famous for its archeological sites and museums, culture, gastronomy, stunning seascapes and sandy beaches.

Last but not least, we thank you for your contribution to the 4th JISDM. We hope that you will enjoy your visit here and you will spend some quality and fruitful time.

May 2019

**Prof. Vassilis Gikas**
The 4th JISDM Organizing Committee

# JISDM 2019

## 4th Joint International Symposium on Deformation Monitoring

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# TOPICS

## Methods

Static and dynamic modeling of deformations, QC/QA and optimization techniques in deformation analysis, Photogrammetric and computer vision methods, Point cloud based spatio-temporal monitoring, Artificial intelligence and augmented reality for deformation monitoring, Innovative algorithms and data processing techniques.

## Sensors

Optical systems and total stations, GNSS-based monitoring, Laser scanning and LiDAR systems, Camera-based monitoring, Ground and spaceborne radar, Fiber-optics and geotechnical sensors.

## Integration & Automation

Sensor fusion, Geo-sensor networks, UAV and miniaturized sensors for change detection and SHM, New and low-cost sensors for deformation monitoring, Web-based smart sensing and monitoring solutions.

## Applications

Local and regional geodynamics, Deformation monitoring for construction engineering, Structural health monitoring, Vibration monitoring and dynamics, Big and tall structures monitoring, Monitoring of cultural heritage, Monitoring of geohazards, Ground settlements and landslides, Bridge and tunnel applications, Dam and mining applications, Metrology and industrial applications.

Technical sessions are organized in 13 thematic areas that include:

- QC/QA and optimization techniques in deformation analysis
- New concepts for GNSS-based monitoring
- Point cloud-based space-temporal deformations
- Reference frames and geodynamics
- Vibration monitoring and dynamics
- Ground and spaceborne radar
- Monitoring of cultural heritage
- Deformation monitoring for construction engineering
- Bridge monitoring
- Dam monitoring
- Multi-sensor systems and new concepts for deformation measurements
- UAV for change detection and deformation monitoring
- Monitoring of geohazards

# Local Organizer

National Technical University of Athens

School of Rural and Surveying Engineering

# Scientific & Professional Commissions

## International Federation of Surveyors, FIG

Commission 6: Engineering Surveys

WG 6.1: Deformation Monitoring and Analysis

Commission 5: Positioning and Measurement

## International Association of Geodesy, IAG

Commission 4: Positioning and Applications

## International Society for Photogrammetry and Remote Sensing, ISPRS

WG III/5: Information Extraction from LiDAR Intensity Data

FIG
INTERNATIONAL FEDERATION OF SURVEYORS

IUGG

IAG AIG
International Association of Geodesy

isprs
information from imagery

## SCIENTIFIC COMMITTEE

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## LOCAL ORGANIZING COMMITTEE

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**Telioni Elisavet**
**Tsini Demitra**
**Tsinis Demitris**
**Georgopoulos George**

**Carmelo Gentile**

**Politecnico di Milano, Italy**

Carmelo Gentile is a Full Professor of Structural Engineering in the Department of Architecture, Built environment and Construction engineering at the Politecnico di Milano. He is a Member of the Scientific Committee of the Laboratory of Testing Materials & Structures (LPM), Politecnico di Milano, and has served as the Director of the Laboratory of Vibrations & Dynamic Monitoring of Structures (*VibLab,* section of the LPM) from 2006 to 2013.

As the Director of the *VibLab,* he commited the full-scale testing and/or continuous dynamic monitoring of more than 100 bridges, including several arch and cable-stayed bridges. He is responsible of the continuous structural monitoring of the Milan Cathedral.

He has authored or co-authored about 300 technical and scientific papers in the main topics of Bridge engineering, Cultural Heritage structures, Earthquake engineering, Modal and structural identification, Structural Dynamics and Vibration-based damage assessment. He has participated in the Scientific Committees of major international conferences on experimental dynamics (such as EURODYN, EVACES, IOMAC) and has participated as an invited keynote speaker at several international conferences.

## Inspections and structural condition assessment of bridges: The role of ambient vibration testing and continuous monitoring

In recent years, ambient vibration testing and continuous monitoring have received increasing attention and the installation of dynamic monitoring systems, especially on bridges, has become more and more common. Among the many motivations for the raising interest on vibration testing and monitoring, the most relevant are: (a) the ageing of existing bridges, often accompanied by poor maintenance and harsh environmental conditions; (b) the possibility of performing the health condition assessment of a bridge from the analysis of its dynamic response to operational loads, with no need for artificial inputs; (c) the technological advances, allowing more economical installation of monitoring systems and fully computer-based operation.

The lecture firstly focuses on the technology of vibration-based Structural Health Monitoring (SHM) of bridges. Subsequently, the application of different SHM strategies (involving the continuous monitoring or the use of repeated tests and baseline FE modelling) is exemplified with reference to relatively simple and complex bridges.

**Charalampos (Haris) Kontoes**

**National Observatory of Athens, Greece**

Dr Kontoes Charalampos (Haris) holds the position of Research Director at the National Observatory of Athens. He leads a research team with active participation in Space Programs of EU/ESA, in the fields of EO. He leads the European Center of Excellence BEYOND for the monitoring of Natural Disasters in the SE Europe. He is responsible for the operations of the "ESA's CollGS" in Greece, and the "Copernicus Hubs for Sentinels" in support to ESA's operations globally. He is coordinating the implementation of GEOSS, and Copernicus in the N. Africa, M. East, and the Balkans. He assumed roles as National Delegate in Space Committees and Boards such as the EC/Space Program, ESA PBEO, GMES Steering Committee, COPERNICUS Task Force, EC Space Advisory Committee. He is member of the National Committee of the IUGG. He is author of more than 165 publications and an active member of the editorial boards of Scientific Journals as IJPRS, IJRS, SENSORS, IEEE Geoscience and RS.

## Big satellite data for ground deformation assessment at global scale

Displacement signals induced by geophysical phenomena are being systematically monitored with state-of-the-art time-series satellite SAR interferometry methodologies (SBAS, and PSI), and combining them with GPS measurements wherever these exist. Today we face the challenge to efficiently process big volumes of satellite data provided from ESA's Sentinel-1 SAR mission. Currently, more than 110 TiB of data are acquired per month, a volume that is equivalent to the entire 7-year archive of the Envisat mission. With the advent of High Performance Cloud Computing (HPC) resources, new capabilities have become available for the processing of big data to estimate with millimeter accuracy ground deformation. BEYOND/NOA addresses these challenges through the geObservatory service. This service offers to the communities of GEO and Copernicus a global observatory of ready-to-use differential interferograms, exploiting advanced data search and mining tools of Sentinel-1 data, and analyzing these data in an HPC environment.

**Dorota A. Grejner-Brzezinska**

**The Ohio State University, Columbus, USA**

Dorota A. Grejner-Brzezinska is the Lowber B. Strange Endowed Chair and Professor in the Department of Civil, Environmental and Geodetic Engineering, and serves as the Associate Dean for Research in the College of Engineering at The Ohio State University (OSU). She is also a Director of the Satellite Positioning and Inertial Navigation (SPIN) Laboratory. Her research interests cover GPS/GNSS algorithms, GPS/inertial and other sensor integration for navigation in GPS-challenged environments, sensors and algorithms for indoor and personal navigation, image-based navigation using artificial intelligence (AI) methods, and mobile mapping. She published over 350 peer reviewed journal and proceedings papers, numerous technical reports and five book chapters on GPS and navigation, and led nearly 60 sponsored research projects with the total budget of over $22mln.

Dr. Brzezinska is a member of the National Academy of Engineering (NAE), class of 2019, Fellow of the Institute of Navigation (ION), Fellow of the Royal Institute of Navigation (RIN), and the recipient of the 2016 ION Johannes Kepler Award, the 2005 ION Thomas Thurlow Award, the 2005 and 2015 United States Geospatial Information Foundation (USGIF) Academic Research Award, and the 2018 International Association of the Institutes of Navigation (IAIN) John Harrison Award. She served as President of the Institute of Navigation (2015-2017), and President of the International Association of Geodesy (IAG) Commission 4, Positioning and Applications (2011-2015), and is an IAG Fellow.

Dr. Brzezinska holds an M.S. and a Ph.D. in Geodetic Science from The Ohio State University, and an M.S. in Surveying Engineering and Land Management Systems from the University of Warmia and Mazury, Poland.

## On technological revolution in geospatial data acquisition, analysis and application

In recent years, geospatial data acquired by satellites, aircraft, UASs, LiDAR scanning systems, development of 3D city models, availability of GIS databases that overlay real-world imagery with database metadata, artificial intelligence (AI), machine learning and robotics are just a few examples of a technological revolution that impacted geospatial data acquisition, processing and applications. Widespread use of well-established sensor fusion methods, geo-sensor networks, availability of miniaturized sensors and Web-based smart sensing and monitoring solutions further improve the outcome of the geospatial engineering tasks, including deformation monitoring. Another example of a new technology entering geospatial data and application market is mixed reality, especially in areas where increased safety requirements are mandated. The scientists and engineers have the ability to manipulate models in the field and leverage the benefits of mixed reality into their projects. The Internet of Things (IoT) facilitates a fast information exchange and inclusion of various levels, sources and types of data.

This paper will discuss the evolution of technologies, instrumentation and methods used for geospatial data collection and analysis, and will demonstrate the benefits of sensor integration and broader adoption of modern technology to deformation monitoring.

# STUDENT AWARDS

## Student Travel Awards

A limited number of travel awards will be granted by the International Association of Geodesy (IAG) to young scientists for presenting their own research results (orally or as poster). In addition, the registration fees of travel award winners will be covered by the 4th JISDM organization. Applicants are required to inform the JISDM secretary at the time of application.

Further information can be found at https://iag.dgfi.tum.de/en/.

## Best student paper awards

School of Rural and Surveying Engineering

The School of Rural and Surveying Engineering (SRSE) of the host institution (NTUA) is pleased to offer two student awards for the best oral and poster papers respectively. All student papers will automatically be considered for the awards. The decision criterion will consider both the paper quality and the presentation quality. Candidates to paper awards should be exclusively presented by students, though authors may include senior members. The winners will be formally announced during the closing ceremony.

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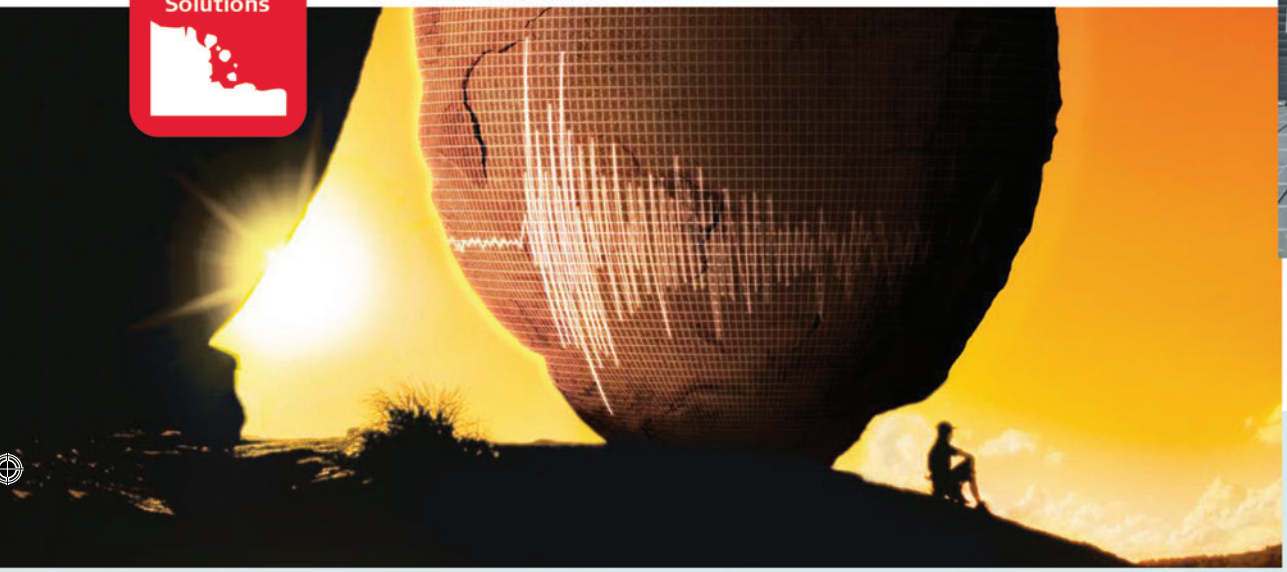

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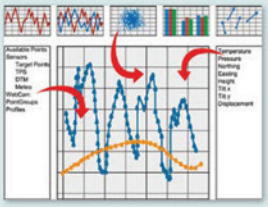

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- when it has to be **right**

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# PROGRAM OVERVIEW

## Wednesday, 15 May 2019

| | AMPHITHEATER | CONFERENCE HALL |
|---|---|---|
| 08:00 - 09:00 | Registrations | |
| 09:00 - 10:00 | **Opening ceremony** | |
| 10:00 - 12:00 | **Keynote Speeches** | |
| 12:00 - 13:00 | Lunch break | |
| 13:00 - 14:30 | Session 1.1 - QC/QA and optimization techniques in deformation analysis | Session 1.2 - New concepts for GNSS-based monitoring |
| 14:30 - 15:00 | Coffee break | |
| 15:00 - 16:30 | Session 1.3 - Point cloud-based space-temporal deformations - I | Session 1.4 - Reference frames and geodynamics - I |
| 16:30 - 17:00 | Coffee break | |
| 17:00 - 18:30 | Session 1.5 - Vibration monitoring and dynamics | Session 1.6 - Ground and spaceborne radar – I |
| 11:30 - 18:30 | Poster Session 1 (Hallway) | |
| 19:30 | **Welcome reception** | |

## Thursday, 16 May 2019

| | AMPHITHEATER | CONFERENCE HALL |
|---|---|---|
| 09:00 - 10:30 | Session 2.1 - Monitoring of cultural heritage | Session 2.2 - Deformation monitoring for construction engineering |
| 10:30 - 11:00 | Coffee break | |
| 11:00 - 12:30 | Session 2.3 - Bridge monitoring - I | Session 2.4 - Reference frames and geodynamics - II |
| 12:30 - 13:30 | Lunch break | |
| 13:30 - 15:00 | **SPONSORS PRESENTATIONS** | |
| 15:00 - 15:30 | Coffee break | |
| 15:30 - 17:00 | Session 2.5 - Multi-sensor systems and new concepts for deformation measurements - I | Session 2.6 - Dam monitoring |
| 09:00 - 15:00 | Poster Session 2 (Hallway) | |
| 19:30 | Dinner | |

## Friday, 17 May 2019

| | AMPHITHEATER | CONFERENCE HALL |
|---|---|---|
| 09:00 - 10:30 | Session 3.1 - UAV for change detection and deformation monitoring | Session 3.2 - Ground and spaceborne radar – II |
| 10:30 - 11:00 | Coffee break | |
| 11:00 - 12:30 | Session 3.3 - Multi-sensor systems and new concepts for deformation measurements - II | Session 3.4 - Monitoring of geohazards |
| 12:30 - 13:30 | Lunch break | |
| 13:30 - 15:00 | Session 3.5 - Point cloud-based space-temporal deformations - II | Session 3.6 - Bridge monitoring - II |
| 09:00 - 15:00 | Poster Session 3 (Hallway) | |
| | AMPHITHEATER | |
| 15:00 - 16:00 | **Keynote Speech** | |
| 16:00 | **Closing of the Symposium - Awards - Closing Ceremony** | |

# Wednesday, 15 May 2019

**08:00 - 09:00** **Registrations**

AMFITHEATER

**09:00 - 10:00** **Opening ceremony**

Chairs: *Wolfgang Niemeier, Vassilis Gikas*

**10:00 - 11:00** **Keynote Speech 1 - Inspections and structural condition assessment of bridges: The role of ambient vibration testing and continuous monitoring**

*Carmelo Gentile, Professor of Structural Engineering DABC, Politecnico di Milano, Italy*

**11:00 - 12:00** **Keynote Speech 2 - Big satellite data for ground deformation assessment at global scale**

*Charalampos (Haris) Kontoes, Research Director, National Observatory of Athens, Greece*

**12:00 - 13:00** **Lunch break**

AMFITHEATER

**13:00 - 14:30** **Session 1.1 - QC/QA and optimization techniques in deformation analysis**

Chairs: *Wolfgang Niemeier, Günther Retscher*

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CONFERENCE HALL

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AMFITHEATER

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CONFERENCE HALL

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**Multi-temporal InSAR analysis for monitoring ground deformation in Amorgos island, Greece** *[p.33]*
*Stavroula Alatza, Ioannis Papoutsis, Demitris Paradissis, Charalampos Kontoes*

**19:30** **Welcome Reception**

# Thursday, 16 May 2019

AMFITHEATER

**09:00 - 10:30** **Session 2.1 - Monitoring of cultural heritage**

Chairs: *Konstantinos Tokmakidis, Dionysios Balodimos*

**Multispectral monitoring of the successive phases of the Holy Aedicule rehabilitation** *[p.81]* Invited Lecture
*Antonia Moropoulou, Andreas Georgopoulos, Evangelia Lambrou, George Pantazis, Sofia Soile, Sevasti Tapeinaki, Elisavet Tsilimantou, Kyriakos Labropoulos*

**The significance of 3D network adjustment by using different least squares methods for the constructions' monitoring application on the monitoring network of the Holy Aedicule in Jerusalem** *[p.125]*
*Dimitrios Zachos, George Pantazis, Evangelia Lambrou*

**100 Years of Geodetic Measurements in the Piazza del Duomo (Pisa, Italy): Reference Systems, Data Comparability and Geotechnical Monitoring** *[p.38]*
*Gabriella Caroti, Andrea Piemonte,Nunziante Squeglia*

**Geodetic Monitoring and Structural Analysis on the Great Temple of Yeha, Ethiopia** *[p.76]*
*Klaus Mechelke, Simeon Burkhardt, Gerhard Eisele, Marcus Illguth, Mike Schnelle, Harald Sternberg*

CONFERENCE HALL

**09:00 - 10:30** **Session 2.2 - Deformation monitoring for construction engineering**

Chairs: *Alessandro Capra, Andrea Masiero*

**Static and Dynamic Interaction of Soil and Structures during the Design, Construction and Operation of various Engineering Projects** *[p.99]* Invited Lecture
*Prodromos Psarropoulos*

**A methodology for correcting refraction in vertical angles for precise monitoring in tunnels** *[p.85]*
*Konstantinos Nikolitsas, Evangelia Lambrou*

**Development and research of the methods for analysis of geodetic monitoring results for the subway tunnels** *[p.111]*
*Roman Shults*

**Geodetic monitoring of displacements and deformations for assestment of effect from suspend of exploitation of Pernik mines** *[p.68]*
*Ivan Kaltchev, Maria Kaltcheva*

**Re-discovering "big data" and "data science" in geodesy and geomatics** *[p.45]*
*Ioannis D. Doukas*

**10:30 - 11:00** **Coffee break**

AMFITHEATER

**11:00 - 12:30** **Session 2.3 - Bridge monitoring - I**

Chairs: *Gethin Wyn Roberts, Prodromos Psarropoulos*

**Bridge Monitoring & Assessment via OSMOS Optical Strands** *[p.39]*
*François-Baptiste Cartiaux, Sofia Koutsonika, Georgios Andrikopoulos, Patrice Marc Pelletier*

**Long-term Monitoring of a Multi-span Beam Bridge Using a Network of Digital Inclinometers: First Results and Perspectives** *[p.55]*
*Vassilis Gikas, Athanasios Mpimis, George Piniotis, Harris Perakis, Fanis Papadimitriou, Kostas Drimeris, Panos Sotiriou*

**Application of a Bayesian-based Neural Network on SHM of long-span bridges** *[p.83]*
*Dinh Tung Nguyen, Xiaolin Meng, John Owen, Yilin Xie, Panagiotis Psimoulis, George Ye*

**Assessment of bridges on the "Demir Kapija-Smokvica" motorway section on Pan-European Corridor X using loading test** *[p.34]*
*Toni Arangjelovski, Darko Nakov, Simona Bogoevska, Marija Docevska, Tilemachos Tsiknias, Goran Markovski*

**Performance analysis of bridge monitoring with the integrated GPS, BDS and GLONASS** *[p.122]*
*Ruijie Xi, Xiaolin Meng, Weiping Jiang, Qiyi He, Xiangdong An*

CONFERENCE HALL

**11:00 - 12:30** **Session 2.4 - Reference frames and geodynamics - II**

Chairs: *Daniel Roman, Christos Pikridas*

**The ups and downs of coast regions: The implications of vertical land motion on coastal hazards** *[p.43]*
*Paul H. Denys, Rob G. Bell, John Hannah, Chris F. Pearson*

**On the role of the length of GPS time-series in the accuracy of tectonic velocities' estimation: Examples from the HEPOS network** *[p.54]*
*Michail Gianniou, Eleni Mitropoulou, Dimitrios Mastoris*

**Recent Surface Deformation along the Carmel-Gilboa Fault System, Israel** *[p.49]*
*Gilad Even-Tzur, Jörg Reinking*

**Calculating a geoid model for Greece using gravity and GPS observations** *[p.91]*
*Nestoras Papadopoulos, Melissinos Paraskevas, Ioannis Katsafados, Georgios Nikolaidis*

**A model of vertical land movements along the German coast based on a combined solution of GNSS and InSAR data** *[p.115]*
*Dieter Tengen, Anika Riedel, Björn Riedel, Wolfgang Niemeier, Markus Gerke*

**12:30 - 13:30** **Lunch break**

AMFITHEATER

**13:30 - 15:00** **SPONSORS PRESENTATIONS**

*Chairs: Andreas Georgopoulos, Gilbert Ferhat*

**Non-intrusive technologies and solutions for Monitoring and Digital Reality models**
*Marco Di Mauro, Monitoring and Control Segment Manager, Leica Geosystems Ltd*

**Interoperability tools for deformation monitoring from UAS to road network change detection**
*Dimitris Stefanakis, CEO & Co-founder, UcanDrone PC, Greece*

**Infrastructure Assessment, Monitoring and Management under the heavy maintenance of Olympia Odos Concession Project**
*Michalis Bartzis, Alexandra Mavroeidi, Engineering Geologist, Olympia Odos, Greece*

**OSMOS Integrated Monitoring Solutions**
*Arnaud Surpas, OSMOS Hellas SA, Greece*

**Structural health monitoring-an essential tool in the maintenance strategy of the Rion-Antirion Bridge**
*Akis Panagis, GEFYRA S.A., Greece*

**Rheticus®: Monitoring from space geological transformations of earth surface for detecting instabilities of critical infrastructure**
*Yiota Spastra, Planetek Hellas E.P.E., Greece*

**Deformation monitoring using Laser Scanners. OPSIS, a unique solution for leaving no spot unattended**
*George Papastamos, Moniterra Ltd, Engineering Instrumentation & Monitoring, Cyprus*

**15:00 - 15:30** **Coffee break**

AMFITHEATER

**15:30 - 17:00** **Session 2.5 - Multi-sensor systems and new concepts for deformation measurements - I**

Chairs: *Werner Lienhart, Evangelia Lambrou*

**Benefits of strain and temperature monitoring of conventional tunnel cross sections using distributed fibre optic sensors** *[p.37]*
*Fabian Buchmayer, Christoph Martin Monsberger, Werner Lienhart*

**Sensor noise characteristics and error propagation: An educational approach based on collocated MEMS accelerometers** *[p.112]*
*Stathis Stiros, Georgia Fotopoulou, Christodoulos Glaros*

**A methodology for WSN deployment in 2D large-scale constraining environments, using computational geometry algorithms** *[p.66]*
*Athanasios Iliodromitis, Georgios Pantazis, Vassilios Vescoukis, Evangelia Lambrou*

**Fast track seismic assessment protocol based on a low cost structural health monitoring system** *[p.41]*
*Spyros Damikoukas, Stavros Chatzieleftheriou, Nikos D. Lagaros*

**Temporal and Spatial Analysis of GNSS network data for detection of anomalies** *[p.57]*
*Mohammed Habboub, Panos Psimoulis, Richard Bingley*

CONFERENCE HALL

**15:30 - 17:00** **Session 2.6 - Dam monitoring**

Chairs: *Maria João Henriques, Jens-André Paffenholz*

**Automatic follow-up of the tri-directional displacements of the Sainte-Croix arch dam (Verdon - France) by motorized total station** *[p.36]*
*Rémy Boudon, Simon Blin, Emilie Pons, Aurélie Ajzenberg*

**Investigation of the relationship between rainfall and long-term settlements of earthfill dams based on geodetic measurements: the case of Pournari I dam (Greece)** *[p.126]*
*Niloufar Zanganehazadabadi, Stella Pytharouli, Panagiotis Michalis*

**Polyphyton Dam: Monitoring of the Right Abutment Slide** *[p.101]*
*Spyridon Raftopoulos*

**Adaptive parametric identification in dam monitoring by Kalman filtering** *[p.50]*
*Sonja Gamse, Wan-Huan Zhou*

**19:30** **Dinner**

# Friday, 17 May 2019

## AMFITHEATER

**09:00 - 10:30** **Session 3.1 - UAV for change detection and deformation monitoring**

Chairs: *Charalabos Ioannidis, Stella Pytharouli*

**Small and low-cost navigation system for UAV-based emergency disaster response applications** *[p.51]*
*Yang Gao, Zhitao Lyu, Hamid Assilzadeh, Yang Jiang*

**Low cost UAV and image classification for monitoring the deterioration on building façades** *[p.75]*
*Andrea Masiero, Francesca Fissore, Antonio Vettore*

**Multitemporal Surface Deformation Analysis of Amyntaio Slide (Greece) using Remotely Piloted Airborne System and Structure-from-Motion photogrammetry** *[p.118]*
*Emmanuel Vassilakis, Michael Foumelis, Athanasia Erkeki, Evelina Kotsi, Issaak Parcharidis, Efthymios Lekkas*

**On the UAV based Analysis of Slow Geomorphological Processes: A Case Study at a Solifluction Lobe in the Turtmann Valley** *[p.72]*
*Lasse Klingbeil, Erik Heinz, Markus Wieland, Jana Eichel, Thomas Läbe, Heiner Kuhlmann*

**Estimating Climate Change-based Soil Loss Using Erosion Models and UAV Imagery in the Metsovo Mountain Region** *[p.80]*
*Loukas-Moysis Misthos, Lefkothea Papada, George Panagiotopoulos, Nikos Gakis, Dimitris Kaliampakos*

**Photo surveys with drones. The improvement of OSOM+, the systematic monitoring of maritime works programme** *[p.62]*
*Maria Henriques, Rui Capitão, Conceição Fortes, Rute Lemos, Teresa Reis, Hugo Silva*

## CONFERENCE HALL

**09:00 - 10:30** **Session 3.2 - Ground and spaceborne radar – II**

Chairs: *Michele Crosetto, Chris Danezis*

**Modeling and Monitoring of an Exploited Aquifer System in Northern Baja California, Mexico** *[p.109]*
*Christine Schottmüller, Anika Riedel, Björn Riedel, Markus Gerke, Wolfgang Niemeier*

**Multi-track N-SBAS Sentinel-1 Interferometry focused on opencast mine monitoring: The case study of the Ptolemaida-Florina coal mine in Greece** *[p.70]*
*Kleanthis Karamvasis, Vassilia Karathanassi*

**Monitoring ground deformation using Sentinel-1 PSInSAR and RTS measurements in the context of the Grand Paris Express project** *[p.82]*
*Abdeljalil Nahli, Elisabeth Simonetto, Maxime Tatin, Stéphane Durand, Laurent Morel, Vincent Lamour*

**Introduction to IBIS-ArcSAR: a circular scanning GB-SAR system for deformation monitoring** *[p.79]*
*Alberto Michelini, Federico Viviani, Lorenzo Mayer*

**The contribution of Sentinel-1 DInSAR to the determination of vertical deformation and height system monitoring** *[p.116]*
*Natasa Triantafyllou, Georgios Vergos, Ilias Tziavos*

**10:30 - 11:00** **Coffee break**

AMFITHEATER

**11:00 - 12:30** **Session 3.3 - Multi-sensor systems and new concepts for deformation measurements - II**

Chairs: *Hans Neuner, Maria Tsakiri*

**The 4th industrial revolution, how Monitoring and Risk Management in constructions is changing in the digital era** *[p.44]*
*Marco Di Mauro*

**A quick tool for the prediction of tunnel crown displacement using neural networks**
*Spyros Nsubuga, Maria Tsakiri, Vasiliki Georgiannou* *[p.86]*

**Deflection Monitoring and frequency response of a Ship using GPS and Fibre Optic based sensors** *[p.102]*
*Gethin Wyn Roberts, Craig Matthew Hancock, Ferdinand Klug, Werner Lienhart, Niko Zuzek, Huib de ligt*

**Machine learning meets deformation monitoring** *[p.88]*
*Tomasz Owerko, Szymon Walasik, Wojciech Karaś*

**The use of geodetic techniques in stability monitoring of floating structures** *[p.124]*
*Vangelis Zacharis, Sotiria Dimitrellou, Konstantinos Politis, George Livanos, Vassilios Pagounis, Orthodoxia Arabatzi, Maria Tsakiri*

**Evaluation of the application of radar and geodetic measurements in the monitoring of earth-filled structures** *[p.73]*
*Przemyslaw Kuras, Lukasz Ortyl, Tomasz Owerko, Aleksandra Borecka*

CONFERENCE HALL

**11:00 - 12:30** **Session 3.4 - Monitoring of geohazards**

Chairs: *Marco Scaioni, Ioannis Doukas*

**CyCLOPS: A Novel Strategic Research Infrastructure Unit for Continuous Integrated Spaced-based Monitoring of Geohazards** *[p.42]*
*Chris Danezis, Diofantos Hadjimitsis, Michael Eineder, Ramon Brcic, Athos Agapiou, Kyriacos Themistocleous, Evangelos Mendonidis, Marios Tzouvaras, Kleopas Hadjicharalambous, Sylvana Pilidou, Georgia Papathoma, Nana Mythilou, George Constantinou, Christiana Papoutsa, Marios Nikolaidis, Andreas Christofe*

**Establishment of a multi-purpose 3D geodetic reference frame for deformation monitoring in Cortes de Pallas (Spain)** *[p.52]*
*Luis García-Asenjo, Laura Martínez, Sergio Baselga, Pascual Garrigues*

**Ground Deformation Monitoring Techniques at Continuous Surface Lignite Mines** *[p.98]*
*Anthony Prokos, Christos Roumpos*

**Monitoring of Tempi Valley Critical Rock Masses: Establishment of Special Monitoring Network and Procedures in Aegean Motorway S.A. Concession Project** *[p.67]*
*Kostas Kalogirou, Efstratios Iliaskos*

**Sentinel -1 for geohazards monitoring** *[p.35]*
*Anna Barra, Oriol Monserrat, Lorenzo Solari, Marta Bejar-Pizarro, Michele Crosetto, Gerardo Herrera, Elena Gonzales-Alonzo, Roberto Sarro, Silvia Bianchini*

**12:30 - 13:30** **Lunch break**

AMFITHEATER

**13:30 - 15:00** **Session 3.5 - Point cloud-based space-temporal deformations - II**

Chairs: *Andreas Wieser, Antonio Vettore*

**Non-signalized Structural Monitoring using Scanning Total Stations** *[p.100]*
*Lukas Raffl, Wolfgang Wiedemann, Thomas Wunderlich*

**Numerical structural identification using 3D laser scanning – a simulation-based case study** *[p.110]*
*Eugenio Serantoni, Andreas Wieser*

**Random Sample Consensus vs Neural Network Analysis (RANSAC vs NNA) – a comparative evaluation on TLS point clouds** *[p.74]*
*Konstantinos Lakakis, Konstantinos Tokmakidis, Alexandros Naskos*

**Axial tomography as a tool for the estimation of constructions' deformations** *[p.53]*
*George Georgopoulos, Elisavet Telioni, George Antoniou, Efstathia Diakoumi*

**Large-volume photogrammetric deformation monitoring of the Bremen Cog** *[p.60]*
*Heidi Hastedt, Thomas Luhmann, Amandine Colson*

**Monitoring the planarity and subsidence of a motorway using kinematic laser scanning** *[p.61]*
*Erik Heinz, Christian Eling, Lasse Klingbeil, Heiner Kuhlmann*

CONFERENCE HALL

**13:30 - 15:00** **Session 3.6 - Bridge monitoring - II**

Chairs: *Stathis Stiros, Rémy Boudon*

**Identifying bridge deformation using laser scanning data** *[p.117]*
*Linh Truong-Hong, Roderik Lindenbergh*

**Spatio-temporal monitoring of a bridge based on 3D point clouds - A comparison among several deformation measurement approaches** *[p.89]*
*Jens-André Paffenholz, Daniel Wujanz*

**Diagnostic surveys of displacements of a rotating pedestrian bridge during its movement** *[p.119]*
*Ireneusz Wyczałek, Michał Wyczałek, Elżbieta Wyczałek*

**Monitoring of the static and dynamic displacements of railway bridges with the use of the total station and set of the electronic inclinometers** *[p.120]*
*Ireneusz Wyczałek, Piotr Olaszek, Damian Sala, Marek Kokot*

AMFITHEATER

| | |
|---|---|
| **15:00 - 16:00** | **Keynote Speech 3 - How research and technology convergence is shifting the deformation monitoring paradigm**<br>Chairs: *Andreas Wieser, Vassilis Gikas*<br>*Dorota Grejner-Brzezinska, Lowber B. Strange Endowed Chair, Professor, Associate Dean for Research, The Ohio State University, Colombus, United States* |
| **16:00** | **Closing of the Symposium - Awards - Closing Ceremony** |

11:30 - 18:30

## Wednesday, 15 May 2019

**Empirical influence functions of different robust estimation methods applied in displacement analysis** *[p.139]*
*Robert Duchnowski, Patrycja Wyszkowska*

**The method of detecting outliers, jumps and breaks in measurement data from a structural monitoring system** *[p.157]*
*Wojciech Sowa, Bernard Kontny*

**Processing strategy of Continuous GPS (cGPS) observations for the French Landslide Observatory OMIV** *[p.140]*
*Gilbert Ferhat, Mohammed Benbachir, Jean-Philippe Malet, Pierre Boetzlé, Paul Maisse, Maurin Vidal, Benjamin Vial, Patrice Ulrich*

**Specific procedures for monitoring geotectonic recent movements in the Košice Basin, Slovakia** *[p.156]*
*Vladimír Sedlák*

**Linear and Non-Linear Deformation Effects in the Permanent GNSS Network of Cyprus** *[p.137]*
*Chris Danezis, Miltiadis Chatzinikos, Christopher Kotsakis*

**A strategy for the monitoring of tall structures in urban area using GNSS technology** *[p.159]*
*Luca Tavasci, Luca Poluzzi, Stefano Gandolfi*

**Undisputable, Objective and Reliable Geodetic Dam Monitoring with FRM Standardization** *[p.144]*
*Stelios P. Mertikas, Xenofon Frantzis, Achilles Tripolitsiotis*

**Investigation of the Optimum Minimum Input data for the Forecasting of 3D Point Position Changing, Using Non-Linear Autoregressive Neural Networks** *[p.132]*
*Eleni-Georgia Alevizakou, Evangelia Lambrou*

**Monitoring applications by using the Remote Survey Method** *[p.145]*
*Charalampos Molyvas, Evangelia Lambrou*

**Investigation of the dependence between digital height readings and the meteorological parameters by using a stand-alone set up and repeatable short-term measurements** *[p.141]*
*Anastasios-Grammatas Kampouris, Evangelia Lambrou, George Pantazis*

**Long-term geodetic monitoring of seasonal deformations of earth dams and relevant finite element verification** *[p.148]*
*George Pantazis, Dimitrios Skarlatos, Loizos Pelecanos*

**Geodetic and geophysical approach of the gravitational field in santorini volcanic group** *[p.93]*
*Melissinos Paraskevas, Dimitrios Paradissis, Konstantinos Raptakis, Paraskevi Nomikou, Emilie Hooft, Dimitrios Papanikolaou*

09:00 - 15:00

# Thursday, 16 May 2019

**Efficacy of Msplit estimation in displacement analysis** *[p.162]*
*Zbigniew Wiśniewski, Andrzej Dumalski, Robert Duchnowski*

**Method for confirming Monitoring System Accuracy** *[p.135]*
*Marthinus Briers, Yuriy Stopkhay*

**Noise analysis of BDS coordinate time series based on dynamic positioning** *[p.143]*
*Jun Ma, Chengdu Cao, Yang Min, Lv Zhou*

**Accuracy assessment of multi-GNSS Precise Point Positioning** *[p.131]*
*Duygu Akyürek, Serdar Erol, Asude Meryem Karaç, Bihter Erol*

**2014 Mw 6.5 Gökçeada earthquake deformation analysis with geodetic and geophysical methods** *[p.130]*
*Duygu Akyürek, Serdar Erol, Murat Merdivan, Bihter Erol*

**Determination of the tectonic plate motion parameters for the Eurasian plate based on the VLBI station positions** *[p.148]*
*Miłosława Rutkowska, Marcin Jagoda, Czesław Suchocki*

**The Aitolo-Akarnania (Western Greece) GNSS network PPGNet – first results** *[p.142]*
*Epameinondas Lyros, Jakub Kostelecky, Vladimir Plicka, Filler Vratislav, Efthimios Sokos, Konstantinos Nikolakopoulos*

**High rate GPS and seismological data to monitor coseismic deformation of the Peninsula of Baja California, Mexico** *[p.146]*
*Carlos Moraila, Gilbert Ferhat, Clara de Lacy*

**Deformation Monitoring and Analysis of Super High-rise Building Based on GB-RAR** *[p.163]*
*Lv Zhou, Xuelin Wen, Fei Yang, Jun Ma, Xianjian Lu*

**Study the Deformation of Elevated Water Storage Tank** *[p.160]*
*Sara Sameh, Zaki Zeidan, Ashraf Beshr*

**Preliminary results on potential deformations occurring on slopes of major Highways by analyzing Sentinel 1 images** *[p.136]*
*Elissavet Chatzicharalampous, Constantinos Loupasakis, Issaak Parcharidis, Manolis Charalampakis, Michaela-Maria Karathanou-Nicholaidi*

**Monitoring ground deformation of cultural heritage sites using SAR and geodetic techniques: The case study of Choirokoitia, Cyprus** *[p.160]*
*Kyriacos Themistocleous, Chris Danezis, Evangelos Mendonidis, Vassilis Gikas*

**Seismic Instrumentation and Monitoring systems in large Hydroelectric Infrastructure in Greece** *[p.152]*
*Christos Roilos, Spyridon Raftopoulos*

09:00 - 15:00

# Friday, 17 May 2019

**A new GPS-derived database for co-seismic displacements in the Aegean area and its geodynamic significance** *[p.133]*
*Nikoletta Andritsou, Athanassios Ganas, Chrysanthi Kosma, Panagiotis Argyrakis, Varvara Tsironi, George Drakatos, Efthymios Lekkas*

**Determination of local active tectonics regime in central and northern Greece, using primary geodetic data** *[p.150]*
*Christos Pikridas, Ilias Lazos, Alexandros Chatzipetros, Spyros Pavlides*

**Investigation for mining-induced deformation in Upper Silesia Coal Basin with multi-GNSS in Near Real-Time** *[p.161]*
*Damian Tondaś, Jan Kapłon, Witold Rohm, Maya Ilieva*

**Radar Remote Sensing Based Assessment of Land Deformation due to construction of Airport in Hilly Area: A case study of Pakyong, India**
*Vishal Mishra, Kamal Jain*

**Comparison of several geomatic techniques for rockfall monitoring** *[p.147]*
*M. Amparo Núñez-Andrés, Felipe Buill, Càrol Puig, Nieves Lantada, Albert Prades, Marc Janeras, Josep A. Gili*

**Surface Rupture Mapping using Sub-Pixel Correlation of SPOT Satellite Images**
*Syed Zaheer Hussain, Tazeem Khan, Mirza Muhammad Waqar*

**Unmanned Aerial Vehicle (UAV) based mapping in engineering surveys: Technical considerations for optimum results** *[p.151]*
*Stella Pytharouli, Jock Souter, Olympia Tziavou*

**A methodology investigation for a semi-kinematic datum realization in Greece combining geodetic and geological data** *[p.134]*
*Stylianos Bitharis, Christos Pikridas, Aristeidis Fotiou*

**An example of using the OptD method to optimization of point clouds in the buildings diagnostics** *[p.158]*
*Czesław Suchocki, Wioleta Błaszczak-Bąk, Marzena Damięcka-Suchocka, Marcin Jagoda, Andrea Masiero*

**Deformation Monitoring using LiDAR data sets** *[p.149]*
*Georgios Papastamos*

**Application of merging model based on MEA+BP in dam deformation analysis** *[p.138]*
*Yanfeng DONG, Wusheng HU*

**i²MON - Integrated monitoring for the detection of ground and surface displacements caused by coal mining** *[p.155]*
*Daniel Schröder, Jörg Klonowski*


# Oral presentations
## abstracts

# ANALYSIS OF DEFORMATIONS AFTER THE BODRUM-KOS EARTHQUAKE (JULY 20, 2017 Mw6.6) USING GEOSENSORS DATA

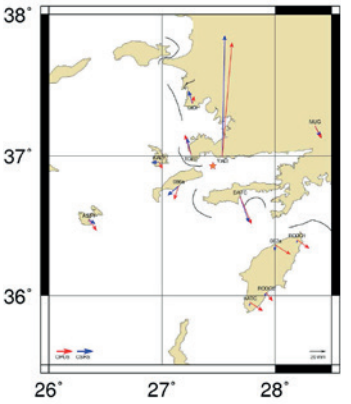
**Duygu Akyürek[1], Serdar Erol[1], İrem Köz[1], Bihter Erol[1]**

[1] *Istanbul Technical University, Geomatics Engineering Department, Maslak, 34469, Istanbul, Turkey, (akyurekd@itu.edu.tr)*

For ages, in the Aegean Sea, there have been a lot of earthquakes occurred due to the active faults in the area such as Gökova (G), Büyük Menderes Graben (BMG) and so on. On 21 July 2017 01:31 in local time of Turkey, Mw6.6 earthquake and tsunami occurred offshore the island of Kos and Bodrum, SE Aegean Sea (Gökova Gulf). Additionally, nine aftershocks were recorded and the largest one was Mw4.7. Turkey and Greece were affected from this earthquake materially and morally.

In this study, Interferometric Synthetic Aperture Radar (InSAR) and Global Navigation Satellite System (GNSS) positioning measurement techniques were used to detect deformation after Bodrum-Kos earthquake. In the case of detection of crustal deformation, InSAR technique provides surface deformation map of large areas with high spatial resolution and vertical deformation with high accuracy. Besides, GNSS technique provides more precise measurements and deformations in three-dimension. The SAR datasets of Sentinel-1 (before and after earthquake with 1-month interval) and GNSS data (three days before and after earthquake) of eleven permanent GNSS stations located in Turkey and Greece and also acceleration and velocity values obtained from database of The National Strong Motion Network of Turkey (TR-NSMN) were used for deformation analysis. Furthermore, GNSS data were evaluated by using internet based GNSS processing services by means of static and kinematic solutions. The deformation analyses results have been represented by comparing the Sentinel-1 displacements with the permanent GNSS data processing outputs. The GNSS and InSAR techniques were compared and evaluated over the processing results as a conclusion, and it was seen that the results from the two techniques confirmed each other

***Keywords:*** *Bodrum-Kos Earthquake; Crustal Deformation; InSAR technique; Sentinel-1; GNSS technique*



# MULTI-TEMPORAL INSAR ANALYSIS FOR MONITORING GROUND DEFORMATION IN AMORGOS ISLAND, GREECE

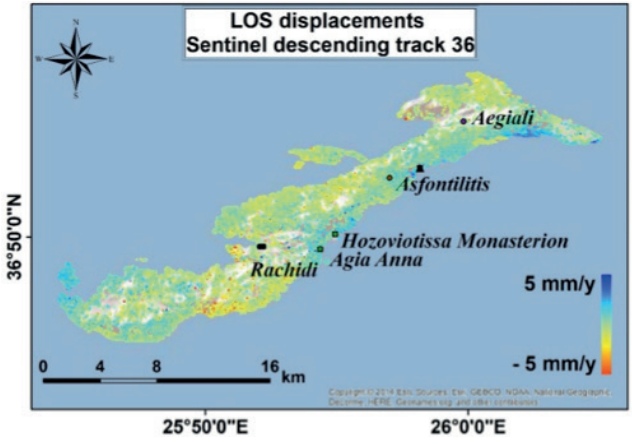
**Stavroula Alatza[1], Ioannis Papoutsis[2], Demitris Paradissis[1], Charalampos Kontoes[2]**

[1] *National Technical University of Athens, School of Rural and Surveying Engineering, Higher Geodesy Laboratory and Dionysos Satellite Observatory, 9 Iroon Polytechniou str, 15780 Zographos, Greece, (ralatza@central.ntua.gr)*

[2] *National Observatory of Athens, Institute for Astronomy, Astrophysics, Space Applications & Remote Sensing, Vas. Pavlou & I. Metaxa str, 15236 Penteli, Greece*

Amorgos island lies to a very active tectonic zone, in the Aegean Sea Plate, between the South Aegean Volcanic Arc and the North Anatolian Fault . On 9 July 1956, one of the strongest earthquakes of the 20th century in the area of South Aegean, occurred in Amorgos, with a magnitude of Ms=7.4. The objective of this research is to map ground deformation in Amorgos island, using InSAR techniques, through geodetic observations of more than a decade. Radar Interferometry is a widely used method, for estimating ground deformation, as it provides millimeter accuracy and at the same time, a wide spatial coverage of the study area. Persistent Scatterer Interferometry (PS) and Small Baseline Subset (SBAS), are two of the most prevalent methods, for time series analysis in SAR Interferometry. We conducted a multi-temporal analysis on all available data from 2003 to 2018, by exploiting historical ENVISAT SAR imagery, as well as the dense archive of Sentinel-1 SLC imagery. The multi-temporal interferometry (MTI) using PS and SBAS techniques, as well as the combination of the above methods, was implemented on Envisat data and the PS method was implemented on Sentinel-1 data. A multi-track analysis was implemented on Sentinel data, to decompose the line of sight displacements, to vertical and horizontal. Results of both datasets indicate a small-scale deformation on the island. The central south coast is experiencing horizontal movement, while the southeastern coast is uplifting with a maximum velocity of 5mm/y. The combination of the good spatial coverage achievable via InSAR, with GPS measurements, is suggested as an important tool for the seamless monitoring of Amorgos island, towards tectonic hazard estimation.

***Keywords:*** *SAR Interferometry; Amorgos earthquake; Sentinel-1; timeseries analysis; LOS decomposition*



# ASSESSMENT OF BRIDGES ON THE "DEMIR KAPIJA-SMOKVICA" MOTORWAY SECTION ON PAN-EUROPEAN CORRIDOR X USING LOADING TEST

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This paper presents the results obtained by the loading test performed on 12 new bridges along the "Demir Kapija-Smokvica" motorway section on Pan-European Corridor X. Four (2x2) of them are simply supported post tensioned beams bridges and the other eight (4x2) are balanced cantilever. Static loading test was performed with a certain number of identical trucks applied in pre-defined positions. For the dynamic loading test, one truck, moving with different velocities, was used. The purpose of the loading test was to assess the quality of the newly built bridges by comparing the real behavior of the structures with the theoretical assumptions in the structural design. Deflections as well as strains were measured at several measurement points of specific cross sections of the decks. The measurement was performed by deflect meters, however for the sections over the rivers a proper survey equipment was used. Strains were measured with strain gauges for concrete and data acquisition units DATALOG8. Acceleration time histories were recorded in a single cross section of the smallest span. Accelerometers of the type Digitexx D110-T with portable compatible data acquisition system were used. Estimation of the dynamic amplification factor was the main purpose of the dynamic loading test. Prior the testing, structural finite element analysis of the bridges, using the actual loading test schemes, geometry and material data, was performed. This analysis defines the intensity of the gross-weight of the vehicles in order to obtain threshold values of internal forces and deflections within limits of 50 to 100% from the designed values. Analysis of the results shows good agreement between measured performance and numerically calculated values.

***Keywords:*** *assessment; prestressed bridges; loading test; static test; dynamic test*

# SENTINEL-1 FOR GEOHAZARDS MONITORING

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This work is aimed at presenting the potentialities of Sentinel-1 as a supporting tool for geological risks prevention and management, showing the main results achieved in the framework of two European ECHO Projects: Safety (2016-2017) and U-Geohaz (2018-2019). In the last 25 years, the satellite Synthetic Aperture Radar Differential Interferometry (DInSAR) has given a great contribution in the monitoring of geohazards like landslides, subsidence or volcanos. A great step forward has been done with the satellites Sentinel-1 (S1) A and B, launched respectively in 2014 and 2016 by ESA. Ensuring a regular worldwide acquisition, over wide areas (250x250 km$^2$), with a high temporal sampling (6-12 days) and providing free data, S1 represents an innovation in the use of DInSAR, allowing accomplishing long term monitoring planning, at a regional to local scale. By the way, the potentialities of S1 are under-exploited: DInSAR is not easy and intuitive for what concern both the data processing and the results interpretation and use. In this context, a methodology has been implemented with the aims of both fully exploit the 6-days repeatability of S-1 end making the DInSAR results suitable to be used by any actor involved in the risk management activities. Nowadays, approaches based on the presented methodology have been integrated in the activities of the Geographical Institute of Spain (IGN), within the Volcano Monitoring System (VMS), and of the University of Florence (UNIFI), within a project of deformations monitoring of the Tuscany Region, involving the Italian Civil Protection. The methodology and the main results in Italy and Spain will be presented.

***Keywords:*** *Sentinel-1; DInSAR; Monitoring; Geohazards; U-Geohaz*

# AUTOMATIC FOLLOW-UP OF THE TRI-DIRECTIONAL DISPLACEMENTS OF THE SAINTE-CROIX ARCH DAM (VERDON - FRANCE) BY MOTORIZED TOTAL STATION

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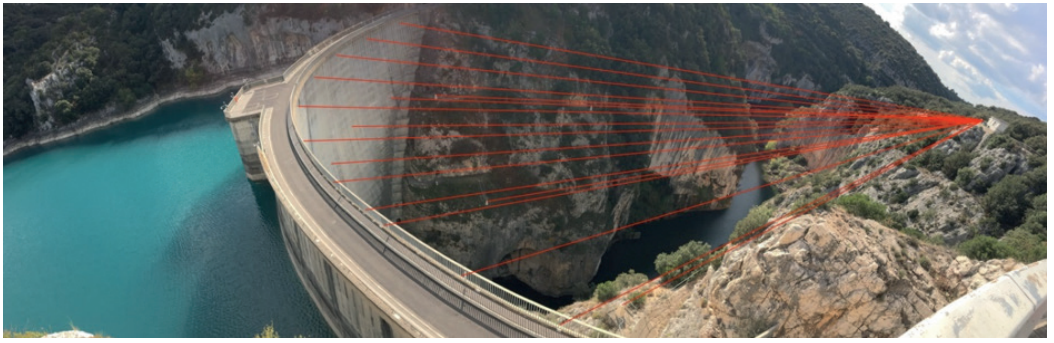
The dam of Sainte Croix is a 61.5 m high arch dam with double curvature, built in the Verdon Gorges in France from 1973 until 1975. Since its construction, the follow-up of its mechanical behaviour is based on planimetric measurements realized on 32 lava rosettes distributed on its downstream facing. The grid reference consists of 9 survey columns among which 5 are considered and verified fixed. The qualitative assessment of the arch dam mechanical behaviour is very accurate with biannual measurements but the operator wished to improve it in case of particular operating conditions with the possibility of a close follow-up. Among the techniques currently used for dam's surveillance (ICOLD, Bulletin 158, 2018), a solution by motorized total station, completely integrated into the information system, was thus proposed and implemented in July 2016 after numerous tests were realized on all the processing chain. These tests led to an increased reliability of the permanent on-site installation, its connection to the information system called KOALA with features equivalent to those of a classic remote instrumentation (measurements on request or preset, automatic data processing including elaborate topographic calculations, etc.) and the operational maintenance of the system.

The advantages of this measuring system are the continuity of the horizontal displacements time series with the addition of the vertical displacements, a behaviour analysis based on a larger sample of measurements under variable hydrostatic/thermal loads, a lower cost than other alternatives (pendulums and GNSS stations for example) and the possibility offered to add marks for a minor cost.

This paper presents this technological evolution chronologically in a simple and instructional manner for the different parts: material, software, and in particular modelling and validation of the obtained data with historical one.

***Key words:*** *dam monitoring; behaviour analysis; hydrostatic and thermal loads; modelling; instrumentation*



# BENEFITS OF STRAIN AND TEMPERATURE MONITORING OF CONVENTIONAL TUNNEL CROSS SECTIONS USING DISTRIBUTED FIBRE OPTIC SENSORS

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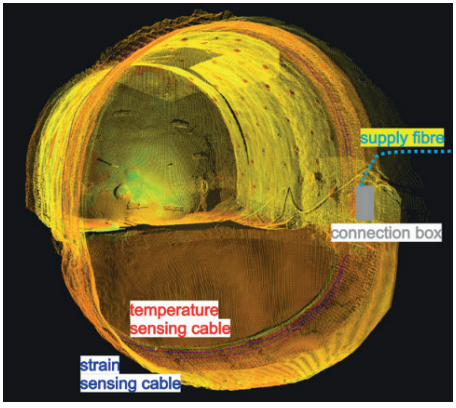
Nowadays tunnel safety and predictive maintenance of tunnel structures become more and more important. Due to longer service lifetimes, the condition of a tunnel is more degrading and therefore, tunnel structures must be monitored to guarantee the safety as well as to enable predictive maintenance. However, conventional methods are usually time consuming, expensive and partially require an interruption of the tunnel traffic.

This paper reports about a tunnel monitoring approach based on distributed fibre optic sensing (DFOS), which allows in-situ strain and temperature measurements along the installed sensor line with a spatial resolution of 0.5 m. The distributed method delivers hundreds of sensing points inside the tunnel lining and completely new information can be gathered to characterize the inner behaviour of the shotcrete. In addition, measurements can be performed automatically without the need of access to the tunnel cross section and hence, the tunnel construction and the operating phase are not disturbed.

The developed system was installed within a shotcrete lining directly at the tunnel face at a construction section of the Semmering Base Tunnel. Continuous monitoring started immediately after the installation and was performed over several weeks during the curing of the shotcrete and the further excavation of the tunnel. In this paper, we describe the system installation process, show the most significant monitoring results and compare them to conventional measurements. The outcome demonstrates the high potential of distributed fibre optic sensing in tunnel monitoring with respect to SHM, concrete curing and fire surveillance. The DFOS measurement results showed that it is possible to derive reliable strain and temperature changes with a resolution of half a meter, even in rough environments like a tunnel. Compared to geodetic measurements, DFOS results give much more details about the behaviour of the tunnel lining.

***Keywords:*** *distributed fibre optic sensing; tunnel monitoring; strain distribution; SHM*



# 100 YEARS OF GEODETIC MEASUREMENTS IN THE PIAZZA DEL DUOMO (PISA, ITALY): REFERENCE SYSTEMS, DATA COMPARABILITY AND GEOTECHNICAL MONITORING

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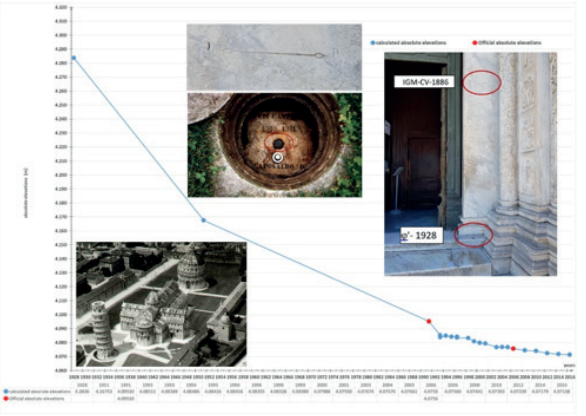
The entire Pisa plains is subjected to subsidence movements, including the world-renowned Piazza dei Miracoli. This phenomenon, as a whole, has long been investigated, but over time the value of the site has commanded specific and steady focus. Early geodetic observations, dating back to 1908-1912, included the monitoring of the inclination of the Torre Pendente (Leaning Tower). Only in the 1960s, geodetic and topographical measures were extended to the entire site, using as altimetric reference a benchmark, placed at the Baptistery. In 1989, a specific committee for the consolidation and restoration of the Leaning Tower was established, and in 1990 the Tower was closed to public access. The ensuing reconnaissance and executive planning provided the restoration and redesign of the levelling network for monitoring vertical movements of the site, also revealing that reference benchmark was in fact subjected to subsidence. This issue was overcome by instating benchmark #999, which was anchored to the deep sands layer and acted as altimetric reference for any successive survey. Since 2012, monitoring of the vertical movements in the Piazza has been entrusted to ASTRO Laboratory of Pisa University. Lately, some interest has developed for investigating the evolution over time of subsidence in the site, thus requiring the use of a shared reference for different data sets.

These uncertainties have had relevant consequences on monitoring of monuments, in particular about the tower, which has been subjected to important stabilization measures during the last decade of XX century. Since the observational method has been applied to the tower, levelling surveys became mandatory; a thorough discussion about reference points has also been carried out.

The present paper has primarily historic connotations and describes the procedures followed to attune the diverse data sources in order to ensure their usability after roughly 100 years.

***Key words:*** *Levelling; Historical Survey; Measure Comparability; Geotechnical Monitoring; Structural Monitoring*



# BRIDGE MONITORING & ASSESSMENT VIA OSMOS OPTICAL STRANDS

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Knowing the actual level of traffic on a road bridge and its consequences in terms of stress cycles in the bridge structure is of great value in the scheme of a resilient asset management. A solution is proposed in the case of different types of road bridges in Europe, based on continuous strain monitoring by the mean of Optical Strands sensors and of dedicated analysis tools provided by OSMOS Group.

The choice of performing continuous strain measurements on critical parts of the bridge deck is discussed, as a relevant solution in order to provide the control of the actual effects of exceptional convoys on the structure, the automatic detection of heavy vehicles with an estimation of their actual weight, and the assessment of the structural elements in terms of strain and stress, both under the effects of the live loads and over the long term.

As the monitoring device is conceived as a permanent solution for these bridges, the accumulated data over several months allow a statistical analysis of the effects of heavy traffic in order to perform a fatigue analysis from comprehensive data instead of sampled ones. By considering some assumptions on the long-term growth rate of the traffic, an estimation of the lifespan of the asset is then performed.

The heavy traffic monitoring of road bridges through continuous strain measurements over long periods as proposed by OSMOS is an integrated solution which answers to several different problematics, both for the daily management through detection of overweight vehicles, and for the long-term assessment through lifespan estimation.

***Keywords:*** *Structural Health Monitoring; Bridge Assessment; Load Rating; Weigh-in-Motion; Fatigue; Optical Strand*

# URBAN DEFORMATION MONITORING USING SENTINEL-1 SAR DATA: A CASE STUDY

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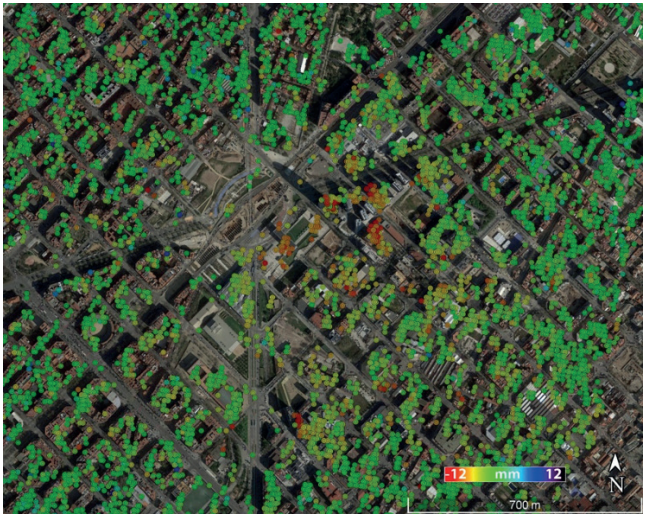
Urban deformation monitoring is a key tool for city management and asset maintenance. An important application is the monitoring of the deformation caused by construction works that involve lowering the water table. In this work we focus on this type of application: the monitoring of the deformation associated with the construction works related to the transformation process of the Glories Square, located in the centre of Barcelona (Spain). The construction works are monitored with a set of in situ measurements (inclinometers, levelling, etc.) which are mainly located in the area of the Glories Square. Such measurements are complemented with Persistent Scatterer Interferometry (PSI) observations, which aim at achieving a global view of the deformation phenomena occurring in the square and, especially, its surroundings, where in-situ measurements are not available. The PSI monitoring is based on C-band data acquired by the Sentinel-1 sensors. These sensors offer an improved data acquisition throughput with respect to previous C-band sensors, increasing considerably the deformation monitoring potential. In its standard data acquisition mode (Interferometric Wide Swath), Sentinel-1A and 1B acquire images covering 250 by 250 km, with a revisiting cycle of 6 days. This paper will describe the data processing and analysis procedure implemented by the authors in the case study.

***Keywords:*** *Radar; interferometry; DInSAR; subsidence; uplift.*



# FAST TRACK SEISMIC ASSESSMENT PROTOCOL BASED ON A LOW COST STRUCTURAL HEALTH MONITORING SYSTEM

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During the past few decades, the merits and benefits of Structural Health Monitoring (SHM) are demonstrated in numerous technical and scientific applications all over the world. The possibility of enhanced structural assessment stemming from sensor measurements is appealing. The fact that our infrastructure ages and uncertain factors play substantial role in proper structural assessment, forces us to use the latest technology in order to prevent future disastrous consequences from extreme events that are bound to happen. The challenge now is to make these technologies cheap enough for extensive application. In this work we present a new SHM implementation methodology that can lead to extensive application. The proposed methodology is based on two crucial factors. The first one is home-developed low cost version of SHM monitoring system that is also presented here. The system is comprised of sensor-logging-data forwarding units that are installed permanently or semi-permanently on structures and has been so far tested with success in extracting the dynamic characteristics of buildings and bridges. The second factor is the way installation, data processing and data forwarding is done. These activities along with structural performance assessment can be done by totally different parties with the aid of internet technology. In this way all the interested parties can interact and provide a low cost extensive SHM application. In the context, we present installation, processing and assessment protocols that can simplify the SHM procedure. The instrumentation installation methods protocols are such that can provide accurate measurements along with ease of implementation. The data extraction can be done locally by commercial memory units, or with the aid of internet based protocols like TCP/IP, Lora or other. The computer systems of the involved parties can be used for the first data parsing reducing the need of memory requirements and preparing the data to be sent to the next party for processing. We also introduce simplified seismic assessment protocols as an extension of the described SHM implementation that can provide a rapid seismic performance estimation based on the measured dynamic characteristics.

***Keywords:*** *Structural health monitoring; internet based protocols; reduced model; structural integrity; vibration data; denoising; nonlinear correction; performance based earthquake engineering*

# CyCLOPS: A NOVEL STRATEGIC RESEARCH INFRASTRUCTURE UNIT FOR CONTINUOUS INTEGRATED SPACED-BASED MONITORING OF GEOHAZARDS

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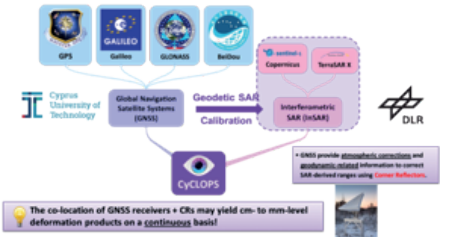
Cyprus, being located on the Mediterranean fault zone, exhibits a unique geodynamic regime since its tectonic evolution is driven by the interaction of the Eurasian and the African plate. Besides its seismological interest, Cyprus exhibits many active landslides and slope instabilities in areas of steep topography that pose an imminent threat for entire settlements, critical infrastructure, and cultural and natural heritage landmarks. To address these challenges, a novel strategic research infrastructure unit, abbreviated CyCLOPS, is being developed and established by Cyprus University of Technology in cooperation with the German Aerospace Center (DLR). CyCLOPS will utilize novel space technologies, including cutting-edge European space missions, such as Galileo, Copernicus Sentinel and TerraSAR-X along with state-of-the-art processing techniques to monitor the effects of geohazards, such as earthquakes and landslides, and assess their impact on the built environment, cultural heritage landmarks and geodetic infrastructure. Specifically, novel multi-sensor co-located configurations will be established throughout Cyprus, which include permanent GNSS reference stations, weather stations, tiltmeters along specifically designed Corner Reflectors. Consequently, CyCLOPS will enable robust and continuous estimation of ground deformation and its velocity gradients at the national and regional level. The latter will be carried out by means of novel integrated GPS/GNSS and SAR techniques rendering Cyprus a dedicated calibration and validation site for European space missions. Consequently, the unit will provide accurate, country-wide products that shall be used to generate valuable risk assessment information. CyCLOPS will also augment the national geodetic GNSS infrastructures and promote the positioning accuracy and integrity of GNSS services. Finally, the derived information along with a multitude of heterogeneous data (weather, geology, structural health, demographics etc.) will be utilized in a contemporary early warning system to promote awareness, prevention and, eventually, public safety, with utmost objective to further align the National Risk Assessment Strategy with the UNISDR 2015-2030 global targets.

***Keywords:*** *GNSS; SAR; Natural Hazards; Infrastructures; Cyprus*



# THE UPS AND DOWNS OF COAST REGIONS: THE IMPLICATIONS OF VERTICAL LAND MOTION ON COASTAL HAZARDS

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More than 10% of the world's population (~600 million people) live in the coastal zone that is within 10 metres of sea level. The combination of global sea level rise (SLR) of 2-3 mm/yr, and late 20th century sea level acceleration, makes coastal communities in many parts of the world vulnerable to gradual inundation that will, in the future, require either adaptation or retreat from affected coastlines. Although the measurement and monitoring of SLR is well established through a combination of globally distributed tide gauge sites and altimeter measurements; what is not well understood is local and regional geodynamical process that result in vertical land motion (VLM) that has the potential to increase coastal hazard.

Often the VLM trend is slow and imperceptible. For example, VLM associated with glacial isostatic adjustment (Scandinavia, North America) are predictable while VLM associated with water and gas extraction (Australia, USA, Malaysia) are not. In the case of seismic activity, VLM associated with an earthquake event can be unpredictable and cause vertical displacements of up to several metres. Other types of seismic activity, such as postseismic deformation or periodic slow slip events may result in gradual subsidence or uplift VLM over extended periods of time.

New Zealand straddles the Australian/Pacific plate boundary and we are just starting to realise the spatial and temporal complexities associated VLM. GPS/GNSS measurements have been used to monitor the Hikurangi subduction zone (east coast of the North Island) that has resulted in a combination of subsidence (2-5 mm/yr) and slow slip events (1 mm/yr uplift). The recent Kaikōura 2016 earthquake resulted in spatially coherent coseismic displacements that caused subsidence in the Wellington region of 30 mm followed by ongoing postseismic deformation that has uplifted the region by up to 50 mm. In low lying areas of Christchurch we have measure subsidence of 10 mm/yr following the Christchurch 2011 earthquake events. In seismically activate regions and especially coastal zones close to tectonic plate boundaries, VLM needs to be monitored and included in SLR studies to understand the geodynamics that is affecting the coastal regions hazard and risk assessments.

***Keywords:*** *tectonic deformation; vertical land motion; coastal hazard; GNSS*

# THE 4TH INDUSTRIAL REVOLUTION, HOW MONITORING AND RISK MANAGEMENT IN CONSTRUCTIONS IS CHANGING IN THE DIGITAL ERA.

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Modern monitoring systems are nowadays more and more good examples of "Internet of Things" where sensors can be smart and communicate to each other and share results over the web using interfaces that are focused to present computed and already filtered data as useful information to allow the human element to take the best decision.

This optimization of the risk management is the same reason of the proven effectiveness of embracing the digital revolution in the construction lifecycle with the aim to reduce to the minimum the risks of delivery a project not on time or on budget implementing a more connected data strategy.

Real-time data before, during and after construction from a monitoring solution can play a critical role to en-rich the data model and increase efficiency.

Automated monitoring solutions innovations have been traditionally driven not only by advancements in measuring technology but also by the availability of new telecommunications or computing solutions.

Thanks to the computation power of modern hardware and new software algorithms, automated scanning processing and the real-time surface comparison are now possible.

High-resolution imaging for monitoring is as well now possible thanks to faster telecommunications infrastructures saving time and money for site inspections and visual checking that can now be done remotely.

Measurements from different sensors can now be integrated in the field via wireless mesh and computed securely in the cloud with no risk of hardware failures or data loss.

From the cloud, the measurements are shared in real time through powerful interfaces that allow data to be presented as useful information for people in charge and site engineers.

The latest monitoring innovations and real case studies, examples and projects from the U.K. and different countries in the world will be described and discussed in the article and presentation.

***Keywords:*** *Monitoring; Imaging; IoT; Scanning; Automation*

# RE-DISCOVERING "BIG DATA" AND “DATA SCIENCE” IN GEODESY AND GEOMATICS

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In late years, a dramatic increase in data across the globe is happening. “Data science”, in parallel with the so-called "big data", monopolize the press, the internet, the public interest (via: text, applications, technology, public and private sector, offering-finding jobs...). Geodesy/Geomatics has traditionally been about data, dealing with a lot of data. Consequently, by considering: data inference, algorithm development, related technology, and their blending multidisciplinarity which characterizes these sciences, it is not difficult to say that both geodesy and geomatics have also always been about the multidisciplinary field of “data science”. From the appearance of computers, on the one hand the data surrounding geodesy (and later, geomatics) and, on the other hand the geodetic problems-requirements of each era, were frequently resulting into heavy-duty tasks that tested (even surpassed) existing analytic methods and computers. In terms of modern methods of (geodetic) data-analysis, as well as computing power and speed requirements, the bar was always being set higher.

In the present paper, the "re-discovery" / "re-revelation" of the perpetual relationship among geodesy/geomatics (and their branches e.g. remote sensing, engineering geodesy, etc.) and “data science” - “big data”, is attempted. It is an old and fundamental relationship that we must always remember, revisit and refresh it, in the light of modern scientific and technological developments. After all, the new methodologies concerning “data science” - “big data”, their new tools and possibilities, their various solutions that circulate (directly or indirectly related to the branches of geodesy/geomatics), and their future trends, are very serious development-levers that have a permanent key-role in the evolvement of geodesy/geomatics in the 21st century. In this regard, some thoughts are paid about the necessary and permanent participation of “data science” in the curricula related to geodesy and geomatics.

***Keywords:*** *geodesy; geomatics; (geo-) big data; data science; data analytics*

# PREDICTING DISPLACEMENT DEFORMATION OF BRIDGE BASED ON CEEMDAN-KELM MODEL USING GNSS MONITORING DATA

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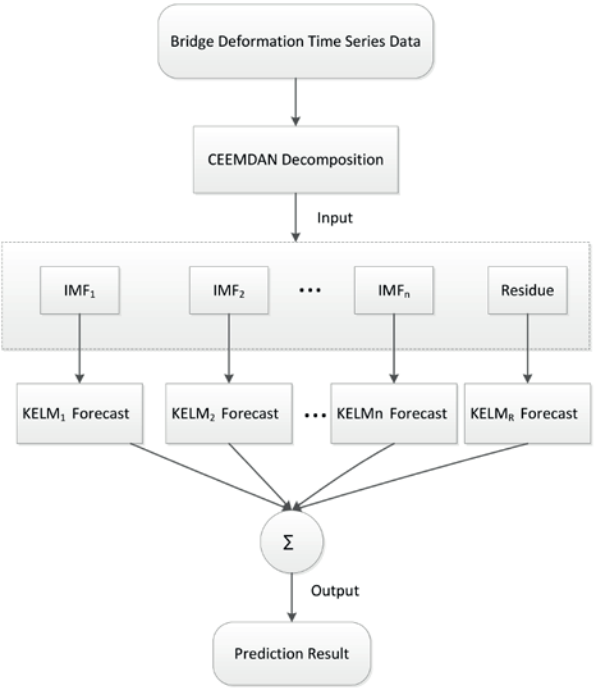
Bridges are critical to economic and social development of a country. In order to ensure the safe operation of bridges, it is of great significance to accurately predict displacement of monitoring points from bridge Structural Health System (SHM). In the paper, a CEEMDAN-KELM model [complete ensemble empirical mode decomposition with adoptive noise (CEEMDAN) based kernel extreme learning machine (KELM) ensemble learning strategy] is proposed to improve the accuracy of displacement deformation prediction of bridge. Firstly, the original displacement deformation monitoring time series of bridge is accurately and effectively decomposed into multiple components named intrinsic mode functions (IMFs) and one residual component using CEEMDAN. Then, these components are forecasted by establishing appropriate KELM prediction models, respectively. At last, the prediction results of all components including residual component are summed as the final prediction results. A case study using global navigation satellite system (GNSS) monitoring data is used to illustrate the feasibility and validity of the proposed model. Practical results show that prediction accuracy using CEEMDAN-KELM model is superior to BP neural network model, EMD-ELM model [mode decomposition (EMD) based extreme learning machine (ELM) ensemble learning strategy] and EMD-KELM model in terms of the same monitoring data.

***Keywords:*** *deformation prediction; CEEMDAN; KELM; GNSS monitoring data*



# EXPERIMENTAL VALIDATION OF A PROTOTYPE PHOTONIC PHASE OPTICAL TIME DOMAIN REFLECTOMETER FOR SHM IN LARGE-SCALE INFRASTRUCTURES

**Massimo Leonardo Filograno[1], George Piniotis[1], Vassilis Gikas[1], Vassilis Papavassiliou[1], Charis Gantes[1], Maria Kandyla[2], Christos Riziotis[2]**

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Extensive dynamic characterization and continuous Structural Health Monitoring (SHM) are crucial tools for the assurance of reliable and safe operation of large infrastructures. This trend is expected to accelerate in the near future, as the percentage of aging infrastructure is steadily increasing. In this work, we develop a minimally invasive and synchronous fiber optic monitoring technique for SHM, and we assess its applicability and performance in large-scale infrastructures, such as bridges. The study presents characterization tests on a scaled steel bridge, a laboratory model of a modular Bailey-type bridge on a 1:2.5 scale. Structural characterization is implemented by a hybrid approach, combining geodetic monitoring techniques, such as Ground-based Microwave Interferometry (GBMI), as reference methods in conjunction with fiber optic techniques. Specifically, we deploy multipoint fiber optic Bragg Grating (FBG) strain transducers on the bridge, to rigorously assess the performance of a new prototype Phase Optical Time Domain Reflectometer (Phase-OTDR), also deployed on the bridge. Phase-OTDR systems have already demonstrated value for SHM applications by recognizing dynamic patterns as well as detecting and locating vibrations along the fiber. Because the required complexity of these systems heavily limits their applicability, this study proposes efficient instrumentation with a balanced trade-off between performance and cost. The study includes the analysis of the effect of adjustable structural elements, which enable damage simulation and tuning of the bridge's structural behavior. Finite-element modeling and simulation are employed to predict the bridge's behavior and interpret the experimental measurements. The results of the study demonstrate an excellent agreement between geodetic and photonic methods, drawing useful conclusions on their synergistic use, which is transferrable to full-scale infrastructures.

**Keywords:** *Ground-based Microwave Interferometry; Laser Tracking; Sensors; Optical Fibers; Bragg Gratings; Phase-OTDR; Structural Health Monitoring*

# INFLUENCE OF ATMOSPHERIC REFRACTION ON TERRESTRIAL LASER SCANNING AT LONG RANGE

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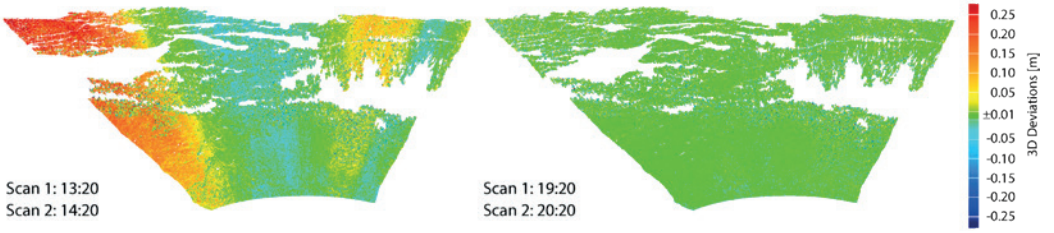
Terrestrial laser scanning is already being used for geomonitoring where typically long-range scanners have to be deployed to cope with distances up to a few kilometers. Point clouds obtained from scanning over such distances are affected by time-varying artifacts that are usually not visible or not relevant in close range scans. These are in particular deviations due to slight instabilities in scanner setup and to atmospheric refraction. While the former can be avoided or mitigated by providing a stable scanner setup, the latter is unavoidable and can cause apparent surface displacements exceeding a few decimeters. The resulting deformations of the point clouds are systematic because the density distribution within the air, driving the atmospheric effects on both time of flight and line-of-sight curvature, varies temporally and spatially during the time needed for taking an individual scan. However, they lead to non-linear point cloud distortions, which cannot be removed with a rigid body transformation and are thus not compensated through registration.

We present an experimental study, carried out in summer 2018 in an alpine valley in Switzerland, clearly showing these artifacts. A landslide area and stable surroundings were scanned hourly from a distance of 800 to 2500 m using a Riegl VZ-4000 for 48 h. Simultaneously, four total stations continuously tracked prisms in stable areas to provide data for directly exposing the influence of refraction on the vertical angle and the measured distance at well-defined stable points. Additionally, barometric pressure, relative humidity, wind speed and direction, together with a dense vertical temperature profile over the first three meters from the ground were continuously measured at the scanner site. Finally, inclination sensors were attached to the scanner setup to directly observe potential scanner instabilities.

Using the data from the mentioned campaign, we analyze the relation between apparent surface changes and atmospheric variations showing how decimeter-level deviations result from the combination of measurement ray curvature on the one hand and distance and terrain inclination on the other. We draw conclusions about opportunities for mitigating the effects by choosing appropriate configurations, measurement times and data processing. We support the analysis by extensive numerical simulations.

***Keywords:*** *terrestrial laser scanning; long range TLS; atmospheric refraction; geomonitoring; scanning artifacts*



# RECENT SURFACE DEFORMATION ALONG THE CARMEL-GILBOA FAULT SYSTEM, ISRAEL

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The Carmel-Gilboa Fault System is one of the major geological structures of northern Israel. It is a northwestern branch of the Dead Sea Fault. Tectonic activity and crustal deformation occur along the Carmel Gilboa Fault System. The fault system region is covered by a monitoring geodetic network consisting of 24 sites. In this paper we analyze GPS data which were measured eight times between 1999 and 2016 and derive regional velocities for the network sites. The site velocities were estimated with respect to a local datum. In order to define a correct datum and ensure stability of the datum we assume that GPS vectors are not immune to changes in their datum content of orientation and scale. The GPS vectors from each campaign are stripped from their datum content using the extended free network adjustment constraints. The datumless measurements are used to define the datum by preliminary coordinates and linear constraints, which remain constant for all monitoring campaigns, as well as to define the position of the network points and their velocities. The use of extended S-transformation enables transition from one datum to another and calculates the velocities in relation to the chosen datum.

We use principles from continuum mechanics to extract the horizontal site velocities field into surface deformation parameters. The results show deformations of about 1 mm/yr sinister along the Carmel Gilboa Fault System accompanied with extensions and shear strain.

***Keywords:*** *Carmel-Gilboa Fault System; Velocity field; Extended free Network; GPS*

# ADAPTIVE PARAMETRIC IDENTIFICATION IN DAM MONITORING BY KALMAN FILTERING

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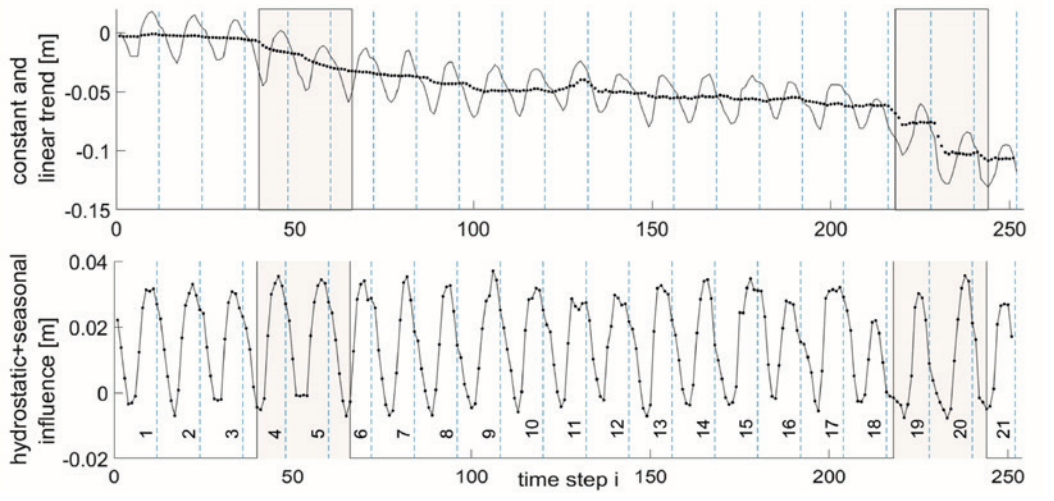
The contribution presents an implementation of Kalman filtering (KF) for an adaptive estimation of unknown parameters of a hydrostatic-seasonal-time model which is used in dam safety procedures. The unknown parameters present the components of the KF system state vector, which is iteratively improved by new information entering with new observations. In the case study, time series of measured relative displacements and water level in impounding reservoir of a rock-fill embankment dam for a period of 21 years were used to test the proposed algorithm. Measurements were captured with a fully automatized monitoring system based on tachymetric observations in a geodetic deformation network. The analyses showed that the KF can detect statistically significant changes according to the previous dam behaviour by testing measurement innovations after a successful initialization phase and stabilisation of the parameters. The statistically significant changes are strongly correlated with the changes in the water level and changes in the long-term trend of relative displacements. Namely, a drawdown of the water level below the planned minimal water level within the operating year or even for several adjacent years can cause changes in the trend of irreversible deformations, since there is a less back-pressure on the dam induced by the water masses. The algorithm enables detrending of reversible and irreversible deformations, and an assessment of a long-term trend for each measurement epoch. The whole process is strongly influenced by the process noise intensity scalar which defines weighting between the process and the measurement noise. Defining an appropriate value of the process noise intensity scalar is the main challenge of the algorithm, where the convergence of a posteriori error covariance matrix was used as the main criterion in the tuning process for the case study.

***Keywords:*** *dam monitoring; hydrostatic-seasonal-time model; Kalman filter; parametric identification; tachymetric observations*



# SMALL AND LOW-COST NAVIGATION SYSTEM FOR UAV-BASED EMERGENCY DISASTER RESPONSE APPLICATIONS

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Emergency disaster response and analysis rely on the timely availability of data acquired from the event site. Traditionally acquisition of such data requires the dispatch of ground personnel to the scene which however is often either inaccessible or dangerous. In the past few years, unmanned aerial vehicles (UAVs) have found more and more uses in environmental monitoring, pipeline inspection, search and rescue, and disaster assessment etc. UAVs can fly at a lower elevation and slower speed than manned systems which allows them to capture data with higher resolution, and they can operate in adverse weather and dangerous environments and acquire data autonomously, making UAVs an optimal platform for rapid-response applications.

Continuously available precise location information of the unmanned system by means of measurements from satellite and inertial navigation systems and other enabling sensors is advantageous. For small UAVs which dominate civilian applications including disaster and emergency management, the navigation system must be small size, light-weight, and low-cost due to UAV space, payload and cost constraints. Further, precise satellite positioning without ground base station is preferred for emergency response applications in order to reduce the operational cost and complexity in the field. These challenges are driven to the design of a small size, light-weight, and low-cost navigation system through integration of the latest satellite and inertial navigation technologies. The development of a small low-cost UAV and its navigation system as well as fly tests with respect to emergency disaster response applications are described.

Nedjati A., Vizvari B., and Izbirak G. Post-earthquake response by small uav helicopters. Natural Hazards, 80(3):1669–1688, 2016.

***Key words:*** *GNSS; MEMS inertial sensor; UAV; navigation; emergency disaster response*

# ESTABLISHMENT OF A MULTI-PURPOSE 3D GEODETIC REFERENCE FRAME FOR DEFORMATION MONITORING IN CORTES DE PALLAS (SPAIN)

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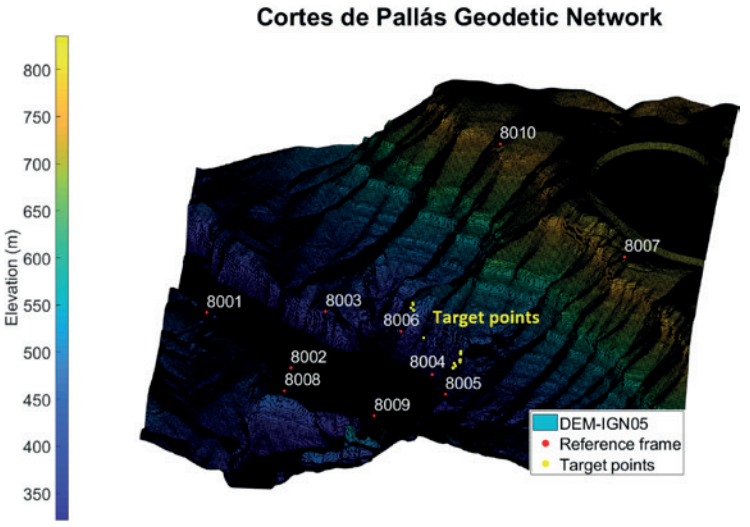
La Muela cliff partially collapsed near Cortes de Pallás in Valencia (Spain) in 2015. After the refurbishment and consolidation works the Universitat Politècnica de València was commissioned by the Diputació de València to undertake a three-year deformation monitoring project based on discrete geodetic surveys by using high-precision distance meter techniques. This solution was planned to establish a 3D high-precision reference frame, to monitor the possible deformation of 15 target points of interest on the cliff, and to provide precise ground control to image-based techniques or other techniques that might be used in the future. The measurements were carried out using a Mekometer ME5000, a 3D network of data loggers for temperature, humidity and air pressure, and the submillimetric GNSS-Based Distance Meter approach as developed by the UPV. The absolute scale of the network is guaranteed by the calibration of the instruments at the UPV calibration baseline, which is metrologically traced to the SI-metre, as well as laboratory calibration of meteorological sensors. This contribution describes the methodology and processes that were applied to determine the coordinates of the first geodetic campaign which was carried out in June 2018. The results show that the 3D coordinates were obtained with an accuracy of some tenths of a millimeter for the reference frame pillars and some millimeters for the target points. The comparison with other techniques confirms the importance of using metrologically sound reference frames as a crucial tool for a proper integration of different deformation monitoring techniques.

***Keywords:*** *Deformation monitoring; geodetic survey; length metrology; EDM; Kern ME5000 Mekometer*



# AXIAL TOMOGRAPHY AS A TOOL FOR THE ESTIMATION OF CONSTRUCTIONS' DEFORMATIONS

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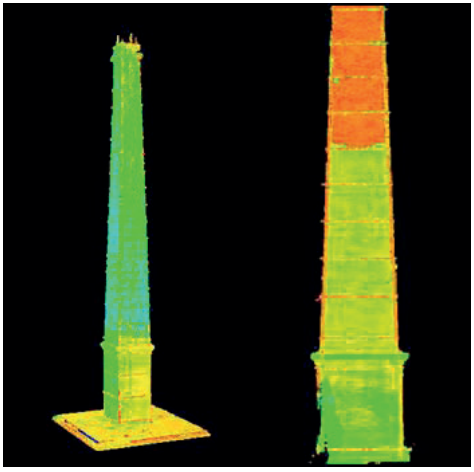
Constructions' deformations are, traditionally, estimated through the displacements of the discrete control points of a geodetic control network, established for this purpose. Nowadays, however, modern technology, and specifically 3D terrestrial scanning technology, can provide detailed information about the way the construction has deformed. This information is obtained through the exploitation of the point cloud that provide a holography of the construction under consideration. Dense sections of this 3D model, perpendicular to a specified axis, produce a tomography of the construction. From these sections, all the information, that describes the way the construction has deformed, is derived. In this paper the above method is described in detail. The detection and estimation of the deformations of two brick chimneys, situated at the old gas factory of Athens, nowadays known as Technopolis, is presented. The chimneys were scanned from the points of a horizontal network, oriented to the Hellenic Geodetic System (G.G.R.S). From the tomography of the two chimneys, with respect to the plumb line, significant horizontal displacements ranging up to 22cm were estimated. Moreover, since the point clouds of the chimneys are referenced to the same reference system, relations between the chimneys' deformations are derived and the possible cause of these deformations is investigated.

***Keywords:*** *deformation monitoring; constructions' response; terrestrial laser scanning technology; point cloud*



# ON THE ROLE OF THE LENGTH OF GPS TIME-SERIES IN THE ACCURACY OF TECTONIC VELOCITIES' ESTIMATION: EXAMPLES FROM THE HEPOS NETWORK

**Michail Gianniou[1], Eleni Mitropoulou[1], Dimitrios Mastoris[1]**
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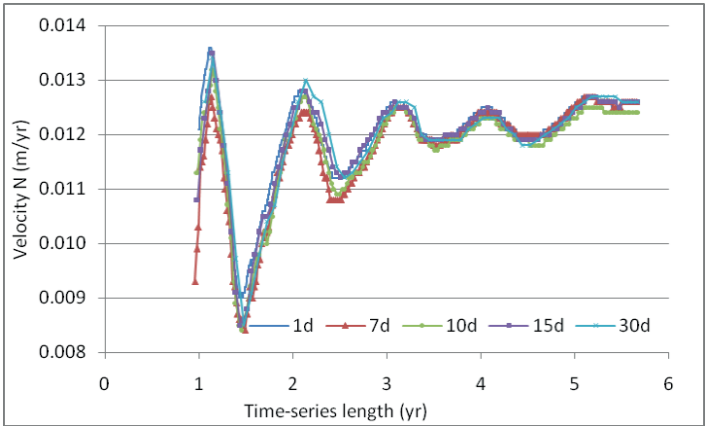
Permanent GPS reference stations are used since many years worldwide for a variety of purposes ranging from positioning services to realization of reference frames and scientific research. Permanent reference stations provide an excellent opportunity to estimate reliable tectonic velocities. Especially in cases that a reference station remains at its initial site for a long time-period, highly accurate velocities can be estimated. Today, there are many examples of stations that are operating on the same point for longer than 10 or even 20 years. These stations offer a good possibility to study the role of the length of GPS time-series in the accuracy of the estimation of tectonic velocities. In this work, we use data from the Hellenic Positioning System (HEPOS) to investigate the relationship between the length of the time-series and the accuracy of the resulting velocities. GPS observations from selected HEPOS stations are processed using the Precise-Point-Positioning (PPP) technique to obtain daily solutions. The velocities of each station are estimated multiple times using variable data length and the results are compared to each other in order to reveal the impact of the length of the time-series to the accuracy of the estimated velocities. The analysis indicates that a minimum of 3 years of data should be used for velocity estimation and that 4 or more years can lead to horizontal velocity estimations accurate to a few tenths of mm/yr. We also investigate the role of the sampling rate of the GPS time-series in the accuracy of the results. The results are discussed in conjunction with the different reference frames of the PPP solutions and the noise characteristics of each time-series.

***Keywords:*** *permanent reference stations; GPS time-series; tectonic velocities; Precise-point-positioning; HEPOS*



# LONG-TERM MONITORING OF A MULTI-SPAN BEAM BRIDGE USING A NETWORK OF DIGITAL INCLINOMETERS: FIRST RESULTS AND PERSPECTIVES

**Vassilis Gikas[1], Athanasios Mpimis[1], George Piniotis[1], Haris Perakis[1], Fanis Papadimitriou[2], Kostas Drimeris[3], Panos Sotiriou[1]**

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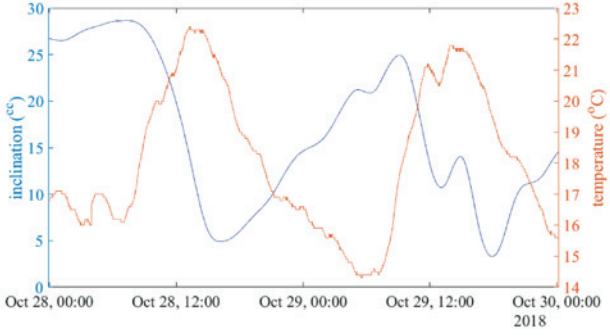
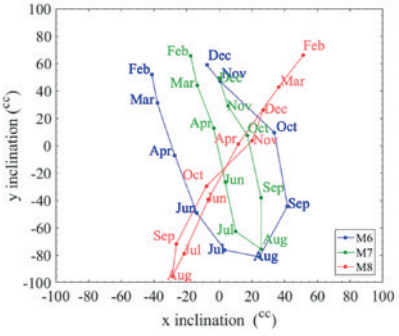
This paper presents the continuous, multi-sensor monitoring system installed on a multi-span beam bridge of the Athens toll-way (Greece) for capturing, analyzing and understudying its structural condition and, ultimately, for evaluating its structural integrity status. Particularly, the focus of this work is placed on field data acquisition and analysis of the tilt (inclination) sensor system mounted on the cap of the taller (> 17m) piers, used for extracting the pattern of the long-term, quasi static inclinations of the bridge complex and for constructing an envelope of typical safe operation. The tiltmeter monitoring system setup including raw data transfer, manipulation and pre-processing procedures are fully detailed. Moreover, the signal processing techniques, the data filtering types and statistical analysis tools developed are also discussed.

From the data analysis obtained for the first 9½ months of continuous operation of the system the dynamic and static deformations of the bridge are evident. More specifically, the dynamic response of the structure due to heavy passing vehicles is apparent and in conformance to traffic records. Also, the daily and seasonal effects found in the data are consistent and in conformance with the variations in meteorological readings as well as with independent monitoring techniques, such as the displacements obtained using continuous Robotic Total Station (RTS) observations. Finally, a proposal for further analysis of the long-term, multi-sensor measurements combining structural modeling information towards structural integrity identification is also provided.

***Keywords:*** *bridge monitoring; inclinometers; meteorological sensors; digital filtering*



# ROBUST POINTWISE CORRESPONDENCES FOR POINT CLOUD BASED DEFORMATION MONITORING OF NATURAL SCENES

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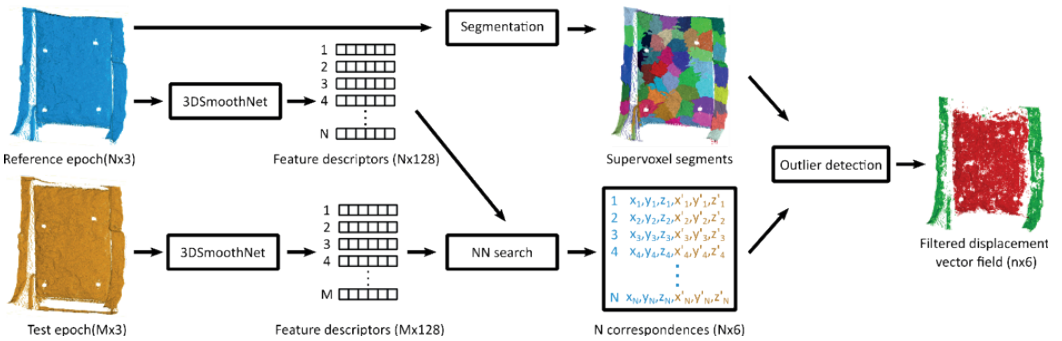
Areal-based deformation monitoring based on point clouds can be a very valuable alternative to the established point-based monitoring. However, due to naively establishing the pointwise correspondences, established deformation analysis approaches for point clouds do not expose the true 3D changes in parts, which actually did change. Herein we extend the recently proposed algorithms that establish pointwise correspondences in the feature space, with a neural network based outlier detection algorithm capable of classifying the putative pointwise correspondences into inliers and outliers based on information only extracted from the point clouds. We demonstrate the proposed approach on two data sets, including a real case data set of a landslide located in the Swiss Alps. We show that while the traditional approaches greatly underestimate the magnitude of the displacements, our approach can correctly estimate the true 3D displacement vectors.

***Keywords:*** *terrestrial laser scanning; deformation monitoring; deep learning; outlier detection; supervoxel*



# TEMPORAL AND SPATIAL ANALYSIS OF GNSS NETWORK DATA FOR DETECTION OF ANOMALIES

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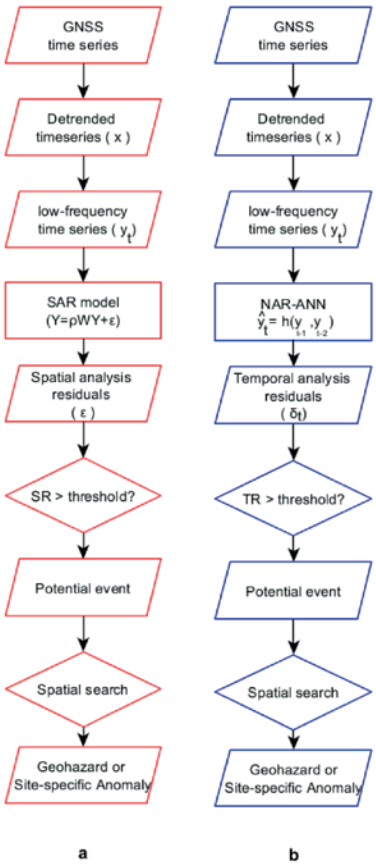
The development of high-rate permanent GNSS networks has led to the application of the GNSS network data for monitoring phenomena related to geohazards and ground motion. In this research, a novel approach for the analysis of GNSS network time series was developed for detecting anomalous behaviours, which can be related to geohazards. The GNSS time series are analysed in both time and space domains using Artificial Neural Network (ANN), to model the time-dependency of the GNSS time series of each station, and Spatial Autoregressive Models, to model the spatial dependency between the GNSS stations for each epoch. The developed approach was examined using (i) GNSS coordinate time series of the GEONET network in Japan, corresponding to the Tohoku-Oki MW9.0 2011 earthquake and (ii) the Integrated Water Vapour (IWV) time series from the GNSS records analysis of the NERC British Isles continuous GNSS Facility (BIGF) network, corresponding to periods of significant meteorological events (i.e. storms). The results show that this approach effectively detects anomalous behaviours that could be related to geohazards (i.e. earthquakes and severe storms). The temporal GNSS data analysis leads to more effective results in detecting rapid large anomalous behaviours as earthquakes and dynamic changes of the meteorological front. On the contrary, the spatial GNSS data analysis leads to a more effective detection of slowly-developed geohazards related to longer period events (e.g. local and low-pace meteorological events). However, the approach of using both the temporal and spatial analysis can cover a broad range of geohazards: sudden large anomalies or slow small local anomalies.

***Keywords:*** *GNSS network; geohazards; Artificial Neural Network; Spatial Regression Models*



# ON THE IMPROVEMENT OF PRECISE POINT POSITIONING AUGMENTED WITH TROPOSPHERIC ZWD USING CORS NETWORKS APPLIED TO BRIDGE MONITORING

**Xu Tang[1], Craig Matthew Hancock[3], Gethin Wyn Roberts[2], Shuanggen Jin[1], Hongwei Li[4], Huib de Ligt[3]**

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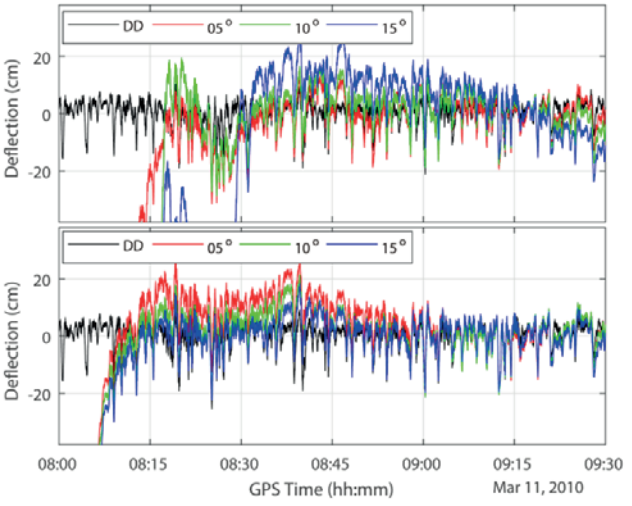
In Scenarios where GNSS Double Differencing, using a permanent base station located close to a structure, is not appropriate or during periods where such a base station experiences failure then Precise Point Positioning (PPP) is quickly developing into a viable alternative option for structural monitoring applications. However, Precise Point Positioning still has limitations in terms of the accuracy and precision that can be achieved. These limitations in quality restrict the types of applications that PPP is suitable for in Structural Health Monitoring. In this paper the PPP processing algorithm is augmented using a tropospheric correction method that improves that quality of PPP positioning and is then applied to structural monitoring of large bridges. Local Continuously Operating Reference Stations (CORS) are used to estimate the troposphere correction from the undifferenced observations. These tropospheric corrections are then interpolated to provide corrections for the PPP processing at the bridge surveying point. The results show an improvement in the terms of RMSE and correlation coefficient obtained after the PPP augmentation by tropospheric correction is applied, compared with regular PPP. GPS double differenced time series are treated as the truth to assess the regular and augmented PPP solutions with various cutoff angle configurations. The experimental results reveal that the deflection precision of regular PPP severely depends on the satellite geometry. Tropospheric correction augmented PPP can improve standard PPP algorithms position time series due to poor satellite geometry and expedite the carrier phase ambiguity convergence.

***Keywords:*** *CORS; PPP; structure monitoring; troposphere correction augmenting*



# EVALUATING THE PERFORMANCE OF A SPACE- AND TIME-CONTINUOUS DEFORMATION MODEL

**Corinna Harmening**[1], **Hans Neuner**[1]

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The establishment of terrestrial laser scanning in engineering geodesy provides new possibilities, but also presents new challenges. An appropriate utilization of the huge amount of information contained in laser scanning point clouds requires the development of areal analyzing approaches. Currently, especially the development of a point cloud-based deformation analysis receives much attention.

In this contribution, a space- and time-continuous deformation model is introduced. The basis of this approach is formed by the initial object's geometry of the first measuring epoch, which is represented by a trend surface in terms of a best-fitting B-spline surface. The deviations of the point clouds measured in the subsequent epochs with respect to the trend surface reflect the deformations. These deviations are interpreted to be caused by a locally stationary and locally homogeneous stochastic process and, thus, they are modelled by means of stationary and homogeneous correlograms as well as slowly varying variances. The combination of the deterministic trend surface with this stochastic signal leads to an adjustment problem similar to a least squares collocation.

The focus of this contribution lies in the application of the deformation model to a deformed surface acting like a first-order system which follows the step response. Simulated data sets of five measuring epochs are used in order to analyze the approach's performance by investigating the filtering's residuals and by comparing the filtered data sets to nominal surfaces.

***Keywords:*** *B-spline surfaces; Correlation structure; Laser scanning; Least squares collocation; Locally stationary/homogeneous stochastic process; Space- and time-continuous deformation analysis; Step response*

# LARGE-VOLUME PHOTOGRAMMETRIC DEFORMATION MONITORING OF THE BREMEN COG

**Heidi Hastedt**[1], **Thomas Luhmann**[1], **Amandine Colson**[2]

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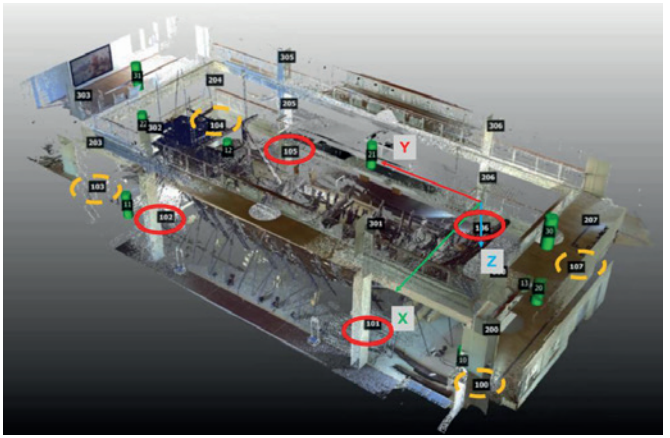
Long-term monitoring of processes on archaeological artefacts is an important issue in preserving their history and enabling their future presentation. The monitoring can be separated into 1) conservation and preservation aspects, 2) geometric deformation estimation and analysis and 3) documentation and long-life retention. Focussing on the geometric deformation estimation and its analysis of the conserved medieval ship "Bremen Cog" (size of ~25m*8m*8m) at the German Maritime Museum (see figure), two main aspects of deformation have to be distinguished: rigid-body motion and the determination of strain, torsion or bending. For the Bremen Cog it is unknown which size and kind of deformation has to be expected. With knowledge from the Vasa ship monitoring at the Vasa museum in Stockholm, deformations of a mm within a year are detected. Therefore, the museum identified a deformation of ≥1mm to be estimated with the monitoring of the Bremen Cog. Based on geodetic theory, a significant movement can be detected by a signal-to-noise ratio of $q > 5$ if the movement is large relative to the techniques single point precision, which then has to be lower than 0.15mm. A large-volume photogrammetric measurement is therefore chosen to be applied to the monitoring concept. The photogrammetric measurements are based on a ground control network which is established to the museums building structure and measured by a lasertracker network (see figure). For photogrammetry, reflective targets are glued to the Cog which represent the object points to be monitored. This article will give an overview on the large-volume photogrammetric monitoring concept. Results are given for the ground control network with its limitations due to tidal changes of the museums location and for the photogrammetric measurements by a feasibility study. The findings of detectable deformation will be given with respect to the applied methods and the environmental conditions.

***Keywords:*** *deformation; photogrammetry; accuracy; cultural heritage; ground control network*



# MONITORING THE PLANARITY AND SUBSIDENCE OF A MOTORWAY USING KINEMATIC LASER SCANNING

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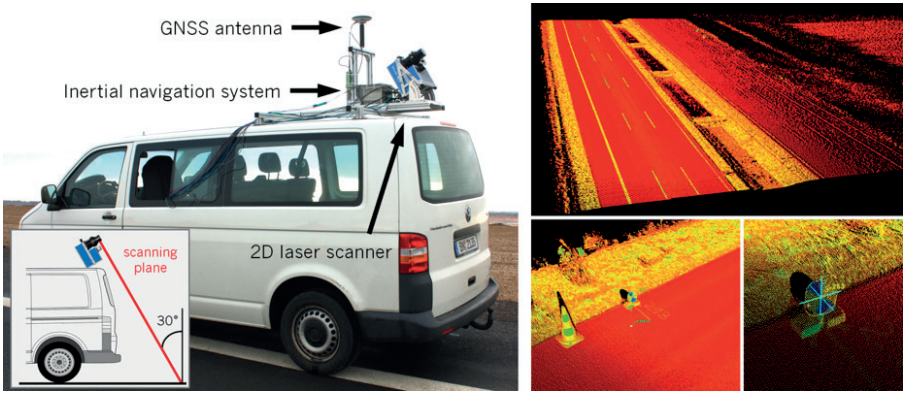
Mobile Mapping is extensively used for the fast and accurate acquisition of the transportation infrastructure. Regarding this, the inspection of the road surface is important, because deficiencies caused by non-planarity and subsidence pose a risk to the traffic. Recently, a scan-based Mobile Mapping System (MMS) has been developed at the University of Bonn. The goal of this paper is to evaluate this MMS, where the height component is of main interest. Following this, the applicability of the MMS for monitoring the planarity and subsidence of road surfaces is investigated. The test area is a 6 km long section of the A44n motorway in Germany. For the evaluation of the MMS, leveled control points along the motorway were utilized. The control points are provided with physical heights, thus, undulations from a geoid model were used for the transformation of the ellipsoidal heights of the MMS. Moreover, a tilt correction for the geoid was determined based on GNSS measurements and leveling. This correction improves the accuracy of the MMS by 40 %, leading to physical heights with an accuracy of < 10 mm (route mean square error). The height precision of the MMS was found to be 5 mm (standard deviation). As a result, a potential subsidence of the road surface in the order of a few cm is detectable. In addition, the cross fall of the motorway was extracted from the point clouds describing the planarity of the road surface. In this respect, no deficiencies of the motorway were detected.

***Keywords:*** *kinematic laser scanning; mobile mapping; evaluation; monitoring; road surface; subsidence; planarity; pilot study*



# PHOTO SURVEYS WITH DRONES. THE IMPROVEMENT OF OSOM+, THE SYSTEMATIC MONITORING OF MARITIME WORKS PROGRAMME

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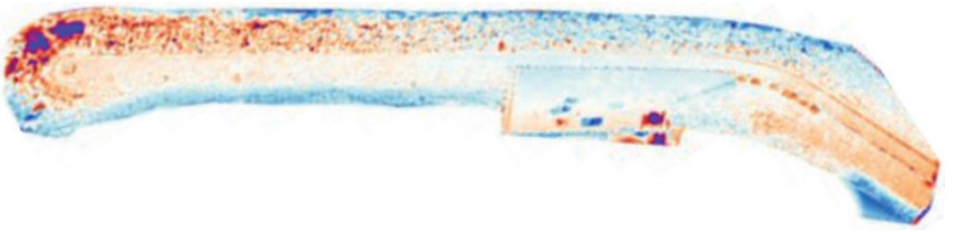
OSOM - SYSTEMATIC MONITORING OF MARITIME WORKS- is a monitoring programme developed by the National Laboratory for Civil Engineering (LNEC) to support the decision making process relative to the timing of the maintenance, or even repair, of maritime works. The main goal of this programme is the monitoring of the structure's behaviour, through the analysis of the data collected during monitoring campaigns performed by LNEC. In recent years the programme has being enhanced (now is called OSOM+) and one of the most important contributions was the integration of photogrammetric surveys, with drones, to improve visual inspections. Although the stage of testing this new source of information has already been overcome, and for this reason drones and photogrammetric methods are fully incorporated in the programme OSOM+, there is still place for new studies that will help, in a near future, to make the drone surveys more efficient. This paper presents some of the studies that are underway and some conclusions that are emerging.

***Keywords:*** *UAV; drone; photogrammetry; monitoring; breakwater*



# KOBE EARTHQUAKE MONITORING – REAL TIME GEODETIC NETWORKING

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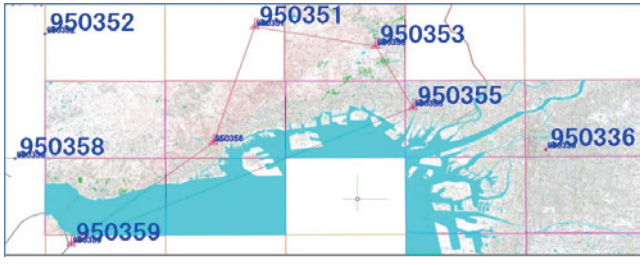
In 1995 Kobe earthquake innovated geodetic networking with GPS observations, and in 2018 Geospatial Information Authority of Japan (GSI) has been monitoring more than 1200 electronic control points nationwide in Japan. GeoNet introduced Parameter Estimation approach in geodetic networking using GEONAP since 2000, and now proceeded to integrated geodetic networking among GNSS, levelling and gravity measurement, using PANDA. Kobe harbor is now preparing for tsunami disaster caused by Nankai Trough Earthquake. For this purpose GeoNet, Septentrio and Kobe University set up Kobe pentagonal reference stations for 1second adjustment monitoring (Kobe GNSS networking). As for the preparatory procedures, GEONAP nationwide network adjustment and Kumamoto and Kyoto-Osaka regional adjustments were successfully completed along with active faults lines. As deformation monitoring is closely related with cadastral system for reconstruction projects, author presented provisional specifications for public cadastral survey projects with 4 major approaches of GNSS networking and helicopter and satellite photogrammetry. Kobe GNSS networking could confirm an authentic specification for earthquake prediction and alert as substantial measure against natural disasters.

***Key words:*** *Kobe GNSS Networking, GEONAP; Parameter Estimation satellite surveying*



# GEOHAZARD DETECTION BASED ON HIGH-PRECISION ESTIMATES OF THE INSTANTANEOUS VELOCITY OF AUTONOMOUS GNSS STATIONS

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This paper deals with the detection of small movements of a GNSS station/receiver, based on estimates of its instantaneous velocity. The epoch-wise velocity estimates are at a level of accuracy of a few millimeters per seconds; recent results also revealed that for the most precise component few tenths of mm/s are attainable. In order to detect a movement, the estimated velocity and the covariance information form the basis for the statistical tests, and the assessment of significance. An advantage of this algorithm is its real-time capability, furthermore it runs on a stand-alone GNSS station. Thus, no network connections are required, and the GNSS stations can be considered as independent and stand-alone movement detection sensor. Experimental data demonstrate that this algorithm has the potential to detect movements on the mm/s level, and below. Furthermore, we highlight its capability for the detection and localization of strong-sized earthquakes: With receiver velocity estimates for densely deployed GNSS stations, prominent seismic phases can be identified, and with a simple inversion model, the earthquake hypocenter coordinates and the source time can be estimated with remarkable quality. We conclude that the presented method might considerably contribute to a GNSS-based earthquake or landslide early warning system.

***Keywords:*** *GNSS Instantaneous Velocity Estimation; Significance Testing; Geohazard Detection; Seismic Monitoring; Early Warning Systems*

# ANALYZING SHAPE DEFORMATION AND RIGID BODY MOVEMENT OF STRUCTURES USING COMMONLY MISALIGNED TERRESTRIAL LASER SCANNERS: THE RADIO TELESCOPE CASE

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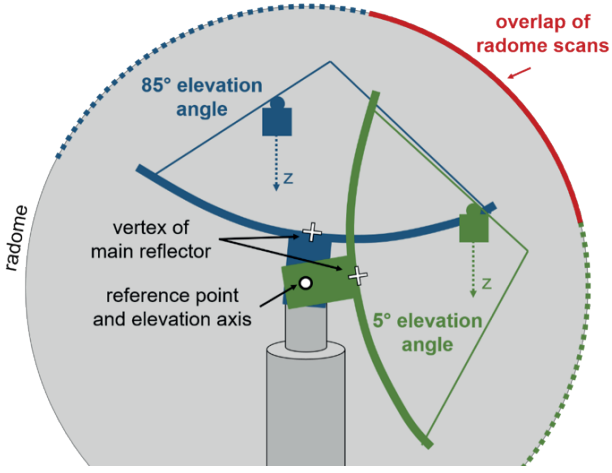
In general, terrestrial laser scanners suffer from internal misalignments leading to systematic measurement errors. In most cases, these systematic errors outnumber the magnitude of random errors. Hence, we need to account for systematic errors within the deformation analysis to get unbiased results. We present and compare several strategies for dealing with these laser scanner misalignments without the need of an accurate previous calibration. These strategies are based on two-face measurements, an in-situ calibration of the laser scanner and a combination of both in a bundle adjustment. We also analyze if changing measurement geometries, i.e., by varying the station of the laser scanner, improve the sensitivity regarding the estimation of the calibration parameters.

We investigate these strategies based on a specific example: The elevation-dependent deformation analysis of radio telescopes that are used for geodetic very long baseline interferometry (VLBI). Within one measurement campaign, the radio telescopes rotate around their elevation axes. For this rotation, we need to know if the telescopes' reference points are stable and if the radio telescopes' main reflectors deform. While the first possible deformation equals a rigid body movement, the second ones equals a shape deformation.

As result, the shape deformation as well as the rigid body movement are least affected by the laser scanner misalignments if measuring in two-faces, calibrating the scanner in-situ and varying the measurement geometry. Although we only draw our conclusions based on the empirical results of this specific example, they are transferable to other deformation analyses using terrestrial laser scanners.

***Keywords:*** *deformation analysis; terrestrial laser scanner; calibration; systematic errors; two-face measurements; bundle adjustment*



# A METHODOLOGY FOR WSN DEPLOYMENT IN 2D LARGE-SCALE CONSTRAINING ENVIRONMENTS, USING COMPUTATIONAL GEOMETRY ALGORITHMS

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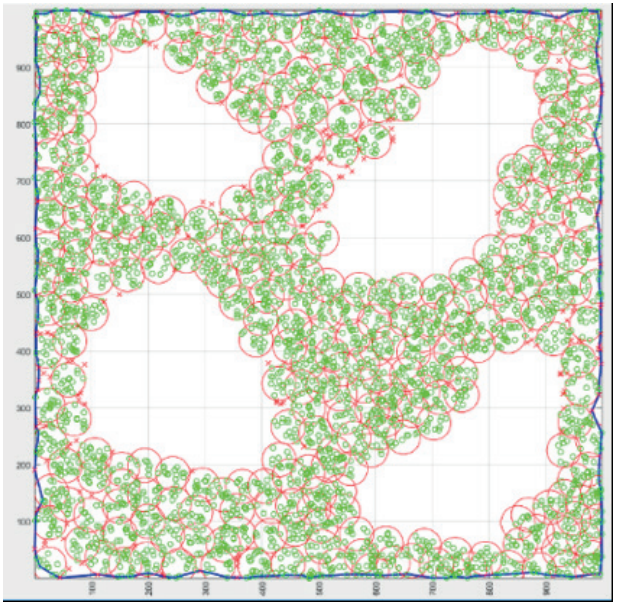
In the past few years, the evolution of the Wireless Sensor Networks made them a powerful tool for monitoring and observing the natural environment. WSNs are adopted in various applications, e.g. geohazards monitoring or deformation detection in large scale areas. The equilateral triangle grid leads to the maximum coverage with the minimum number of sensors. Nevertheless, in most large-scale outdoor applications, achieving the ideal deployment geometry is hard or even impossible. In such environments the positions of the sensors have to be chosen among a list of possible points, which in most cases are randomly distributed. In order to achieve a geometry as near as possible to the theoretical optimum, an algorithm has been proposed. It uses the Centroidal Voronoi Tessellation. Although the case studies had the desired results, their simulation took place in the continuous space. There are cases, in which may be impossible to cover the whole area with sensors due to natural constraints. This paper evaluates the effectiveness of the proposed method in an area with holes. Alternative scenarios are examined, by changing the values of the parameters that affect the final result.

***Keywords:*** *WSN; wireless sensor networks; computational geometry; geosensors; CVT; Centroidal Voronoi Tessellation; geohazards monitoring*



# MONITORING OF TEMPI VALLEY CRITICAL ROCK MASSES: ESTABLISHMENT OF SPECIAL MONITORING NETWORK AND PROCEDURES IN AEGEAN MOTORWAY S.A. CONCESSION PROJECT

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The paper aims to describe the installed monitoring network of critical rock masses and the procedures that are followed by the Concessionaire to ensure the safety of users along the National road in Tempi valley. The road runs between the mountains of Olympus and Ossa in a canyon characterized by steep rock slopes on both sides, parallel to Pinios River that streams through it. The intense discontinuity systems of the rock slopes are expected to activate planar slide of large rock masses, rock wedges as well as individual rockfall events concluding on the pavement during the roadway operation and therefore may cause accidents and relevant traffic jam.

The concessionaire Aegean Motorway S.A. (AMSA) is responsible for the Operation and Maintenance of this road. For that reason, an extensive rockfall protection and stabilization design for the mitigation of rockfall risks along the National road through Tempi valley was realized in the years 2009 and 2010. Supplementary to the original design, special focus areas (SFA) were identified and treated with appropriate methods such as scaling and elimination, stabilization and rockfall barriers.

Subsequently, a procedure was established as outlined in detail in the Rockfall Protection Inspection and Maintenance Manual (RIMM) setting out the necessary actions for the continuous inspection of the areas of increased rockfall risks within the Concession Project and for the operation and maintenance of the rockfall protection systems. All rockfall measures as well as rock slopes of the valley are inspected systematically with any new rockfall event and/ or damage to the protection measures documented in designated forms. Moreover, a special geodetic monitoring network has been established in critical rock masses with specific warning and alarm thresholds. The monitoring system of critical rockmasses in Tempi valley is enhanced with grout bridges applied to rock discontinuities where movement is supposed to occur prior to failure. All the collected data are the subject of interpretation by rockfall experts in line with the established procedure.

***Keywords:*** *Tempi valley; RIMM; critical rock masses; geodetic network; grout bridges*

# GEODETIC MONITORING OF DISPLACEMENTS AND DEFORMATIONS FOR ASSESTMENT OF EFFECT FROM SUSPEND OF EXPLOITATION OF PERNIK MINES

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The Pernik Coal Basin is the oldest in Bulgaria - its operation starts on 17.08.1891. Depth of bedding of coal beds is small (10-130m). In the last years, after the mining operations were stopped on 2000, emergency situations occurred on the territory of the town of Pernik, which are directly related to the mining activity carried out in the Pernik basin. Risky and emergency situations potentially affect all types of engineering facilities on the terrain of the city of Pernik (buildings, streets, roads, railways, bridges, stadiums, other facilities) as well as elements of the underground engineering infrastructure (water mains, sewerage, cable routes, etc.). The main goal of the project is to carry out studies and analyzes and to propose design solutions for the development of the geodetic network for surveying of the movements and deformations of the land surface and the mining mass with objects in order to organize specialized monitoring as a preventive measure for the purpose of conservation of objects and facilities from the harmful influence of the mining works and the consequences of stopping their operation in region of Pernik Mining. The territory covered by the project is about 213ha in the center of City of Pernik, Bulgaria. Different methods and instruments were applied for performing of precise geodetic measurements for deformation monitoring for last 9 years. Some results and conclusions are presented in the report based on collected 4D data base.

***Keywords:*** *Deformations and movements monitoring; Precise geodetic measurements - methods and instruments*

# DISTANCE LIMITATIONS WHEN USING CORS NETWORKS AND GNSS RECEIVERS FOR DEFORMATION MONITORING

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Global Navigation Satellite Systems (GNSS) are currently widely used for deformation data collection.

Numerous of receivers are installed on structures like bridges and dams, in order to monitor their operation and health conditions.

The technological advancement of GNSS receivers and the installation of many networks of permanent and continuously operated reference stations (CORS) have resulted in their extensive use for monitoring purposes.

Each one of the GNSS receivers is connected with a reference station, to perform the measurements.

Although the use of GNSS receivers and a proper reference station has been scientifically proved that horizontal and vertical accuracies of about ±10-15 mm can be achieved, the distance limitations of using a permanent reference station for deformation monitoring, is a crucial parameter.

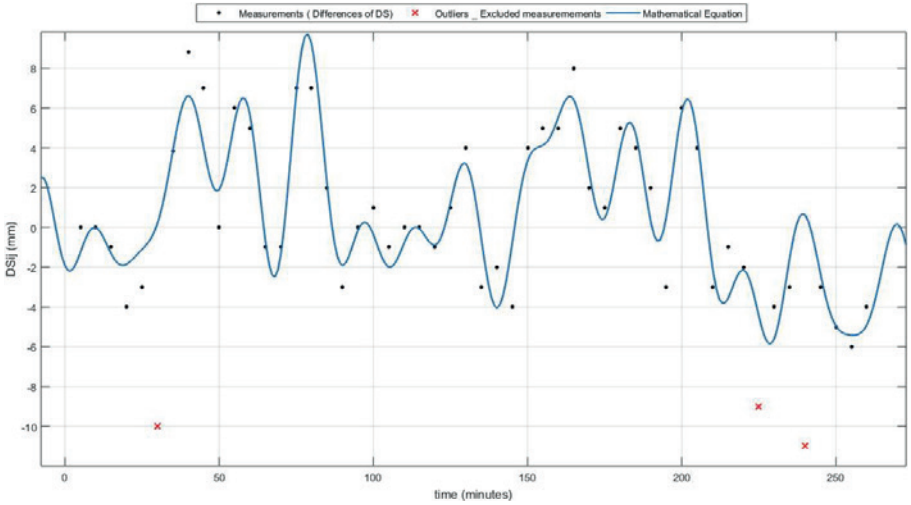
In this paper, the influence of the distance, between a monitor receiver and the reference station, to the achieved accuracy is investigated.

The study involves measurements by single and dual frequency receivers at various conditions. These refer to the methodology being used for the measurements (Single Base and VRS), and the distance between the reference station and GNSS receiver, which fluctuates from 50m to 25km.

Regarding the results, the values of these distances are studied in order to examine the necessity and usefulness of using virtual stations, which are every time created at a different close distance to the monitored facility. Also, the least time between each measurement (occupation time) and the different sets of measurements, in order for the deformation time series to be created, is concluded.

Finally, the relation between the distance and the achieved accuracy is determined, through mathematical modelling. The results contain the mathematical equations formed and are visually presented with diagrams.

***Keywords:*** *Global Navigation Satellite Systems; VRS Methodology; Single Base Methodology; CORS Network; Measurements' Time Series; Single / Dual Frequency GNSS receivers*



# MULTI-TRACK N-SBAS SENTINEL-1 INTERFEROMETRY FOCUSED ON OPENCAST MINE MONITORING: THE CASE STUDY OF THE PTOLEMAIDA-FLORINA COAL MINE IN GREECE

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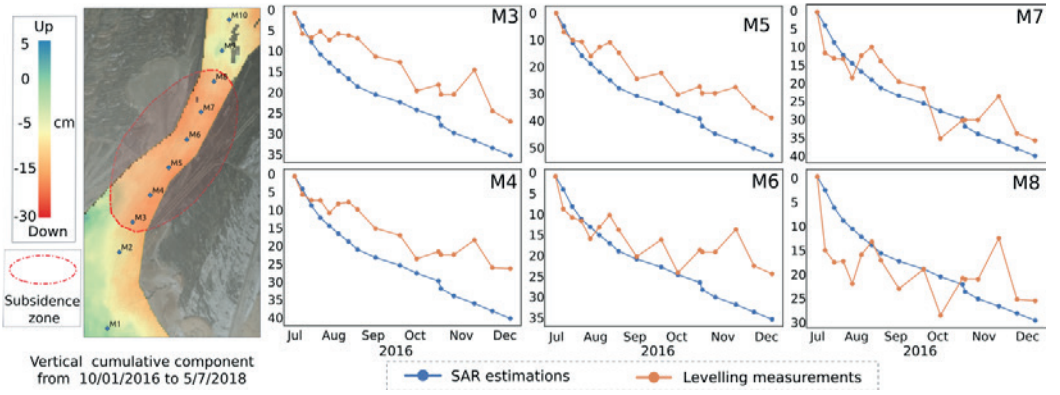
This paper illustrates the capabilities of distributed scatterer satellite Synthetic Aperture Radar Interferometry (InSAR) to monitor time-varying land deformation on mines. Due to continuous mining activities, monitoring ground deformation in and around mine areas has great importance to prevent possible slope instabilities that may lead to considerable casualties and cause several environmental issues. InSAR is considered a unique and well-established technique able to measure and monitor subtle surface displacements and deformation patterns over large areas. One of the main limitations of the aforementioned technique on the monitoring of opencast mining regions is the ambiguity of one dimensional line-of-sight measurements. In order to obtain insights on this limitation and optimally to transcend them, a multi-track Normalized Small Baseline Subset (N-SBAS) InSAR approach was applied. This technique is a modified SBAS approach that exploits the complementary information from multiple acquisition geometries of Sentinel-1 interferometric datasets. The combined use of ascending and descending Sentinel-1 geometries allowed to retrieve 3D deformation.

In this study, the open-pit coal mine located southern of town of Ptolemaida, Greece, has been successfully monitored by obtaining long-term time series ground displacement information. The study uses Sentinel-1 data collected over a period of 2.5 years (January 2016 - June 2018). The estimated deformation was in accordance with field observations. The qualitative comparison of the produced results with ground measurements revealed the capabilities as well as the limitations of the proposed methodological approach. The results of this work indicate that the generated deformation maps can be a useful complementary data source for operational mining planning and risk assessment in the mining environment.

***Keywords:*** *Deformation Monitoring; Sentinel-1; Small BAseline Subset (SBAS); Synthetic Aperture Radar Interferometry (InSAR); Ptolemaida-Florina coal mine*



# IMPACT OF MATHEMATICAL CORRELATIONS ON THE STATISTIC OF THE CONGRUENCY TEST CASE STUDY: B-SPLINES SURFACE APPROXIMATION FROM BRIDGE OBSERVATIONS

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B-spline surfaces possess attractive properties such as a high degree of continuity, which is important for computing curvature. Since the local support of the basis functions allows to control the shape of the estimated surface, they are increasingly used in the field of geodesy, where their main application is the fitting of surfaces to, e.g., 3D point clouds obtained from terrestrial laser scanners (TLS), see Koch (2009). By comparing different epochs, deformation can be detected more easily for nearly all kind of objects by using test statistics such as the congruency test.

The concept of surface approximation is similar to a regression problem where the model is the surface representation and the data are the sampled points on the surface. Consequently, besides improving the functional model with new strategies to determine the knot vector, the stochastic model of the underlying observations has to be correctly specified. Otherwise, biases in test statistics are unavoidable and compromise the detection of small deformations when the congruency test is used. Unfortunately, measurements from TLS are not as simple as point clouds for Computer Aided Graphics: the raw observations are not directly Cartesian coordinates but polar coordinates, i.e. range and angles, which additionally possess different variances. A transformation from polar to Cartesian coordinates is mandatory to determine the weighting functions or control points of the B-splines approximation by a least-squares adjustment. Mathematical correlations are thus introduced in the already heteroscedastic transformed observations. As they lead to fully populated variance covariance matrices, they remain mostly neglected and an oversimplified stochastic model is used assuming homoscedasticity and independency of the transformed observations. In this contribution, the impact of neglecting mathematical correlations in deformation analysis with the congruency test will be studied. It will be shown that these correlations can eventually be reduced to an inflation variance factor, which allows for their simplified handling in matrix products. In a case study with real data from a bridge under loading, the impact of neglecting them will be investigated, highlighting in which cases considering mathematical correlations in the congruency test is necessary or not for a trustworthy deformation detection. Heteroscedasticity will be taken into consideration using an intensity-based model accounting for geometry and object properties.

***Keywords:*** *B-spline; Terrestrial Laser Scanner; congruency test; mathematical correlations; heteroscedasticity*

# ON THE UAV BASED ANALYSIS OF SLOW GEOMORPHOLOGICAL PROCESSES: A CASE STUDY AT A SOLIFLUCTION LOBE IN THE TURTMANN VALLEY

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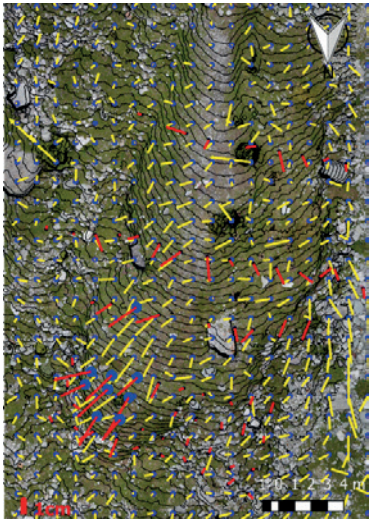
In this paper, we investigate the usage of unmanned aerial vehicles (UAV) to access the geometry and the deformation of a geomorphological phenomenon, which is called a 'solifluction lobe'. Solifluction is the slow downslope movement of soil mass in mountain areas resulting from freeze-thaw processes, which occurs widely in Arctic, Antarctic and Alpine regions. This movement can reach velocities in the order of mm or cm per year. The solifluction lobe under investigation has a size of about 10mx30m and is located in the Turtmann Valley in the Swiss Alps. We performed two UAV flight campaigns in two consecutive years, generating 3D point clouds and orthomosaics from aerial images using photogrammetric methods. We also recorded a high precision terrestrial laser scan (TLS) in one epoch, which serves as a validation method for the UAV based measurements. Additionally, a number of total station measurements of distinct recognizable points have been measured for validation. We show that in this study it is not possible to discover a deformation of a few centimeters using point cloud comparison methods, as the motion of the lobe is mainly along its surface. However, we were able to show this motion with an optical flow based method using the orthomosaics. We confirmed this using the total station measurements.

***Keywords:*** *Geomorphology; Solifluction Lobe; UAV; Structure From Motion; Terrestrial Laser Scanning; total Station Measurements; Optical Flow; Deformation Analysis*



# EVALUATION OF THE APPLICATION OF RADAR AND GEODETIC MEASUREMENTS IN THE MONITORING OF EARTH-FILLED STRUCTURES

**Przemysław Kuras[1], Łukasz Ortyl[1], Tomasz Owerko[1], Aleksandra Borecka[1]**

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The subject of the paper is the assessment of the displacement monitoring referred to the earth-filled structure using radar and geodetic measurement techniques. The investigations has been carried out on the earth-filled flood embankment.

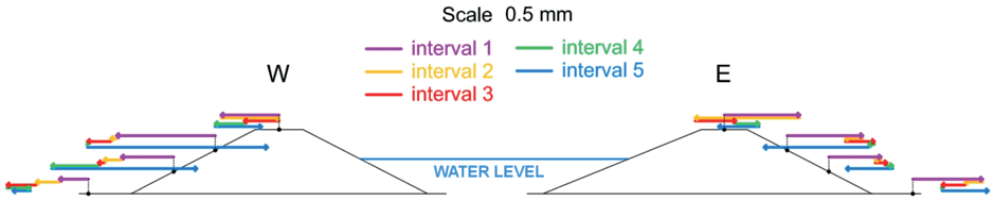
As part of the tests, a check of the embankment reaction to the flood wave was assumed. In addition, long-term monitoring was carried out, which was aimed to determine the behaviour of the newly built embankment.

In order to monitor the deformation of the embankment, it was necessary to develop the proper methodology. For the needs of research works, an appropriate geodetic network consisting of reference points and survey markers has been designed and established. Moreover, a permanent foundation was built for continuous monitoring using interferometric radar, and survey markers were equipped with radar reflectors.

The final results allow to reveal the reaction of the embankment to external loads. The displacement values were referred to the course of the water level to indicate the relationship between them. In the field of testing the embankment reaction to the flood wave, the reliable results could be obtained thanks to high-accuracy measurements performed by radar and geodetic techniques. A sizable number of points allows to perceive some tendencies, even if the displacement values were at the level of their determination errors. As a result, the relation between embankment soaking and its movement directions can be noticed.

In the field of long-term monitoring, which was conducted by geodetic techniques in the period of 1.5 years, the results clearly imply the dominance of displacements outside the reservoir for points located on the embankment, in contrast to points on the crest and foreground, which do not show significant movements.

***Keywords:*** *radar interferometry; geodetic monitoring; earth-fill embankment*



# RANDOM SAMPLE CONSENSUS VS NEURAL NETWORK ANALYSIS (RANSAC VS NNA) – A COMPARATIVE EVALUATION ON TLS POINT CLOUDS

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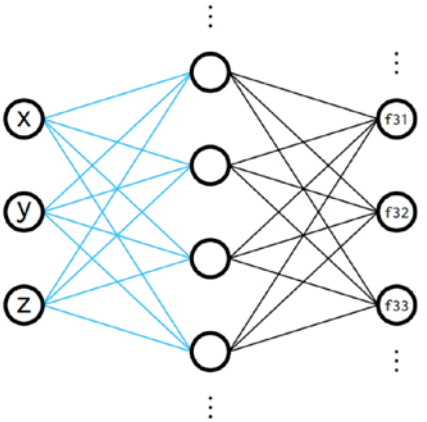
Laser scanning is one of the most common techniques for the geometric documentation of objects as well as buildings. In the last decades, laser scanning has replaced or complemented traditional topographic methods to a significant degree. The main advantages of laser scanning that have led to its high appreciation by the scientific community are the fact that it is a fast and simple method of geometric documentation, while it combines the accuracy of topographic methods and the wholeness of photogrammetric methods. The data that a laser scanner provides to the user is a large set of XYZ coordinates that is called a point cloud. Point clouds obtained by laser scanning need to be processed before the information that they contain can be available and measurable. In this paper, the Random Sample Consensus (RANSAC) algorithm is being implemented to detect geometric shapes in point cloud data. RANSAC is an iterative method that estimates the parameters of a model by random subsampling of data and fitting of the model on the selected subset. In addition, Neural Networks (NNs), Machine Learning (ML) and Deep Learning methods have been used to implement a point cloud classification model as well as a point cloud segmentation model. These models have been trained with the use of supervised learning techniques, using algorithmically generated training and testing datasets. A comparative evaluation of the accuracy and flexibility that these methods provide has been performed.

***Keywords:*** *RANSAC method; Machine Learning; Neural Networks; Deep Learning; TLS point clouds*



# LOW COST UAV AND IMAGE CLASSIFICATION FOR MONITORING THE DETERIORATION ON BUILDING FAÇADES

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Due to aging, weathering, infiltration, solar radiation and other factors, building and human infrastructures are subject to deterioration and, consequently, they periodically need to be monitored in order to determine whether they need any maintenance or restoration action. Traditionally, deterioration monitoring is done by means of on-site inspection performed by a human specialized operator. Despite being a reliable monitoring approach for small buildings, it becomes a not so affordable monitoring method for large buildings and infrastructures, where a human operator needs the use of external facilities for a careful visual inspection. The high costs related to such kind of inspection motivate the search for alternative monitoring methods. In particular, the availability of low cost drones, embedded with high resolution cameras, represent a viable way for a visual inspection of areas otherwise difficult to reach by human operators. Actually, this paper aims at investigating the use of low cost drones combined with artificial intelligence recognition methods, which recently proved to reach state of art classification performance in many applications. Such approach is applied for the detection of damaged bricks on the façade of a university building, reaching a good recognition performance.

***Keywords:*** *monitoring; UAV; deep learning; classification; deterioration detection; image processing*

# GEODETIC MONITORING AND STRUCTURAL ANALYSIS ON THE GREAT TEMPLE OF YEHA, ETHIOPIA

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The Great Temple of Yeha is an appr. 2700 years old building located in the village of Yeha, northern Ethiopia. It served as the main sanctuary of the Ethio-Sabeean Community of Di´amat and is nowadays still visible with walls of up to 14m height. In 2016, the German Archaeological Institute erected a steel frame in the interior of the building to support the fragile upper parts of the remaining walls.

Preliminary monitoring surveys have shown that the walls of the temple are subject to deformations, mainly caused by heat impact of sunlight. The structural design of the steel frame was based on detailed 3D laserscans. The main task of the steel frame is to absorb any loads implied to the building such as strong winds and to support instable parts of the walls.

After mounting the frame, a monitoring survey within a time period of one week has been carried out, including measurements by total station, strain gauges, temperature gauges and 3D laserscanner.

The objective of the monitoring survey was to find out wether the supporting frame has an effect on the deformation behaviour of the walls of the temple. Secondly, the question arose if and up to which extend traditional geodetic measurements and strain gauge measurements lead to similar conclusions. Thirdly, does the mounted steel structure follow the assumptions of the structural design?

***Keywords:*** *structural monitoring; structural analysis; geodetic monitoring; strain gauge; steel supporting frame; temple; 3D Laserscanner*

# MULTI-GNSS IMPLEMENTATION AND ASSESSMENT OF THE PHASE RESIDUAL METHOD FOR STRUCTURES DYNAMIC LOAD AND NATURAL FREQUENCY ESTIMATION

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Continuous monitoring of the dynamic displacement of structures, especially bridges, is usually accomplished with the use of traditional displacement measurement dedicated equipment, such as accelerometers and displacement transducers. During the past decade, following the increase in quality of GNSS equipment, new methodologies were developed to provide equivalent types of measurements at a lower cost. One of these methods is the phase residuals method (PRM), where the double-difference phase residuals from a relative static GPS positioning are assessed in the frequency domain. With this scenario in mind, this paper investigates the limitations imposed to the method and how the use of modernized GNSS signals may improve the reach of applications of the PRM. It is known that amongst constellations and between satellites of the same constellation, different system characteristics will generate phase observables of different qualities, but the effects on such a sensitive method remain unknown. After performing two experiments, being one for reference and noise-floor analysis, and one for displacement frequency analysis, this study concludes that the multipath frequency influence in the power spectrum is less prominent in modernized GNSS signals, thus, extending the reach of the method for sub-Hz natural and displacement frequencies estimation. This study also provides recommendations for choosing the system and sampling rate for a dynamic load and natural frequency estimation. Finally, for frequencies above the multipath-induced frequency threshold, and under the Nyquist frequency limitation for spectral analysis, all available GNSS constellations and signals performed equivalently on the proposed experiment, being able to track a 2 Hz oscillation (approximately the natural frequency of a 50 m span bridge) with high accuracy without the need of accelerometers or transducers.

***Key words:*** *GNSS, Phase-Residuals, Double-Difference, Multipath, Natural Frequency, Structure Monitoring*

# INTRODUCTION TO THE NEW MONITORING SYSTEM FOR LONG-SPAN BRIDGES - FROM GEOSHM TO ISHM

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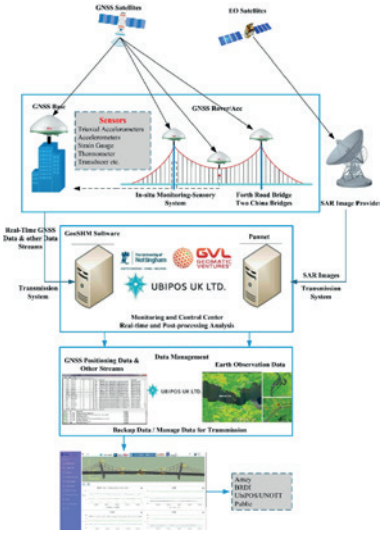
In 2013, the University of Nottingham as a leading organisation was awarded a grant from the Integrated Application Promotion (IAP) scheme of the European Space Agency (ESA) for a feasibility study (FS) called GeoSHM. The GeoSHM project uses integrated GNSS and Earth Observation technologies for the structural health monitoring of large bridges. During the GeoSHM FS period a small monitoring system was installed on the Forth Road Bridge in Scotland and the consortium have gathered huge data sets and gained rich experience regarding the design and implementation of the innovative GeoSHM service according to essential user needs. To fully explore the opportunities of the GeoSHM FS project ESA decided to further sponsor its second phase development which is a €2.3 million demonstration project and led by UbiPOS UK Ltd. The GeoSHM Demo Project focuses on addressing the major drawbacks of the GeoSHM FS Project and developing a smart data strategy to fully reflect the end user needs.




However, during the two-year GeoSHM Demo Project, it has still been very difficult to find the right methods to extract the useful information from the enormous amount of data collected by the sensors to support a smart decision-making process. In 2017, a China-UK consortium applied and was awarded the further funding from a joint Infrastructure Systems Programme supported by Jiangsu Province in China and Innovate UK. The iSHM project (Cloud-based Intelligent Structural Health Monitoring Platform for Long-span Bridges) is developing an innovative SHM data strategy empowered with Big Data analytics and artificial intelligence to extract essential deformation information from a novel sensory system and build precise models for the understanding of deformation mechanism from a cluster of large bridges of different types. Bridge health status and operational behaviors are precisely determined through these established precise models that define external/internal loading and bridge response using machine learning and cloud computing technologies.

This paper together with other accompanying papers of this same conference will introduce the results of the GeoSHM Demo Project and the new design of the iSHM Project. The difference between these two projects will be discussed. It will provide useful information regarding the efforts of our SHM work in the past four years.

***Keywords:*** *structural health monitoring; GNSS; Earth Observation; Big Data Analytics; Machine learning; Cloud computing*

# INTRODUCTION TO IBIS-ArcSAR: A CIRCULAR SCANNING GB-SAR SYSTEM FOR DEFORMATION MONITORING

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In the last decade, Ground-Based Synthetic Aperture Radar (GB-SAR) Interferometry has become a well-established technique for deformation monitoring of several scenarios, including landslides, glaciers, dams and open pit mines. This goal has been achieved thanks to the GB-SAR specific advantages, such as remote sensing, high sensitivity to small deformations, long range of measurements, imaging capability and fast scan time.

The GB-SAR systems synthesize an aperture along azimuth direction by moving the radar head on a linear rail while transmitting a Frequency Modulated Continuous Wave (FMCW) signal. A 2D range-azimuth image can be produced through proper signal processing, and repeated acquisitions in time of the same scenario can be processed through differential interferometry techniques, obtaining 2D range-azimuth displacements maps.

However, especially in open pit mine geometries, the 80° azimuth field of view of a typical GB-SAR system can be a limiting factor in comparison to other monitoring technologies (e.g. Real Aperture Radar). Recently, to overcome this limit, IDS GeoRadar developed IBIS-ArcSAR: an innovative circular scanning GB-SAR system with 360° horizontal coverage capability, at constant angular resolution.

In this paper, the differences between the standard linear scan and the new circular scan applied to GB-SAR systems are reviewed. In particular differences in synthetic aperture geometry, antenna pattern role and the focused 2D image properties, are analyzed. Then the IBIS-ArcSAR system is presented, describing the hardware setup and the technological solutions implemented to improve GB-SAR systems' performances. Finally, some real dataset results acquired during the last year, are reported and analyzed.

***Keywords:*** *GB-SAR; Interferometry; Radar Imaging; Geohazard monitoring; Open pit mine monitoring*

# ESTIMATING CLIMATE CHANGE-BASED SOIL LOSS USING EROSION MODELS AND UAV IMAGERY IN THE METSOVO MOUNTAIN REGION

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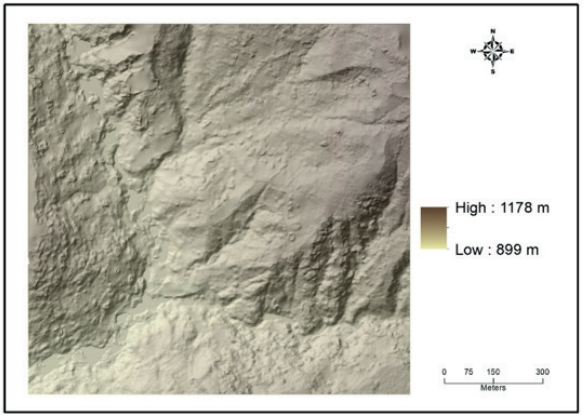
Soil erosion is a natural process involving soil loss rates of about 2 t ha-1 year-1. This process can be heavily intensified due to human activity, inducing losses of up to 100 t ha-1 year-1, further leading to significant land cover alteration and soil productivity decrease. Climate change is a human-induced agent that affects several factors underlying soil erosion in various ways. In mountain areas, climate change may be significantly detrimental to the landscape and soil productivity, especially for the upper convex hillslope parts (summits, shoulders etc.), where soil displacement is not frequently counterbalanced by soil formation. In this paper, a methodology for estimating and mapping soil loss by water erosion in a mountainous region (Metsovo, Greece) is developed. To this end, an effective erosion model (RUSLE – Revised Universal Soil Loss Equation) is utilized by combining and fine-tuning data from climate models, geospatial data, and UAV imagery: the climate models are downscaled providing input data; the UAV, equipped with a multispectral sensor, supports precise land cover classification, DEM generation and the computation of suitable indices. The results show that both the enhanced land classification scheme derived from the UAV imagery, and the future scenarios regarding climate and rainfall erosivity change affect the estimated soil loss rates. The aggravated soil loss rates are meant to deform more seriously the more elevated and rugged parts of the landscape, while the subsequent land degradation poses environmental and socio-economic concerns for the mountainous but productive and active region of Metsovo, under the influence of climate change.

***Keywords:*** *accelerated water erosion; soil loss estimation; climate change; UAV imagery; geospatial modelling*



# MULTISPECTRAL MONITORING OF THE SUCCESSIVE PHASES OF THE HOLY AEDICULE REHABILITATION

**Antonia Moropoulou[1], Andreas Georgopoulos[2], Evangelia Lambrou[3], George Pantazis[3], Sofia Soile[2], Sevasti Tapeinaki[2], Elisavet Tsilimantou[1], Kyriakos Labropoulos[1]**

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The Holy Aedicule of the Holy Sepulchre, an emblematic monument that has survived throughout the centuries, recently underwent a major and demanding rehabilitation under the responsibility of the National Technical University of Athens Interdisciplinary Team. The requirement for reinstating structural integrity to the Holy Aedicule, for preservation of the values it represents and for achieving a sustainable rehabilitation in a demanding environment, demanded a multidisciplinary approach utilizing multispectral monitoring techniques of the successive phases of the Holy Aedicule, prior, during and after the completion of the rehabilitation interventions. Specifically, a thorough geometric documentation was realized involving laser scanning and photogrammetric techniques, in order to obtain a 3D textured model of the Holy Aedicule, prior to the initiation of the works. At this phase, in parallel a diagnostic study was implemented, regarding the building materials and their decay phenomena, utilizing non-destructive techniques that document the surface of the monument and its state of preservation, while providing prospection of its internal structural layers. This information was crucial for the design of the restoration materials and rehabilitation interventions. The next phase involved dismantling of the exterior stone slabs from the facades. The revealed masonry was geometrically documented, to record the morphology of this internal layer and to optimize the design of the required interventions. The geometrical products verified the non-destructive prospection of the Aedicule. During the strengthening interventions the Tomb of Christ was opened, along with an "observation window" within the Tomb Chamber; their interiors were digitally documented, including materials information. Upon completion of the strengthening interventions (grouting, titanium elements, etc.), the columns were reset and the stone facades were reinstalled, and the Aedicule was "freed" from the British metal frame installed seventy years earlier. The final phase involved an interdisciplinary documentation of the rehabilitated structure.

***Keywords:*** *Holy Aedicule; monitoring; interdisciplinary documentation; successive phases; rehabilitation*

# MONITORING GROUND DEFORMATION USING SENTINEL-1 PSInSAR AND RTS MEASUREMENTS IN THE CONTEXT OF THE GRAND PARIS EXPRESS PROJECT

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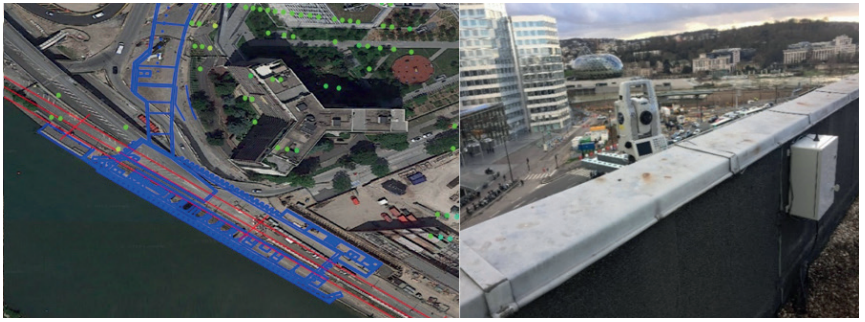
The Grand Paris Express project consists in the construction of new tunnel sections, stations and additional structures. Like all underground works, this can cause ground movement around the construction sites, especially neighbouring buildings and surface transport network like roads and railways. To monitor the movements, an automatic monitoring system composed of a network of robotic total stations (RTS), control points and monitoring targets attached to neighbouring structures is designed and set up. The aim of this system is to provide the real-time coordinates and displacements of the targets in a three-dimensional system. Although the system provides the most reliable, height frequency and real-time measurements, which is required in this field, it presents some practical difficulties especially on construction sites located in a dense urban area like Paris. Inter-visibility limitations and lack of stable control points are the most encountered cases. This work reports in the context of the Grand Paris Express project the challenges of displacements monitoring and describes the RTS monitoring system installed by Cementys. The ground-motion monitoring is also investigated using the radar interferometry (InSAR) considered as a complementary survey technique. This study is using PSInSAR (Permanent Scatterer InSAR). Even if X-band data are currently available in this area, this first experiment focuses on the use of C-band Sentinel-1 images. The results show the limits and the advantages of such images in this context.

***Keywords:*** *Grand Paris Express; Tunnel; Ground deformation; Sentinel-1; PsInsar; RTS*



# APPLICATION OF A BAYESIAN-BASED NEURAL NETWORK ON SHM OF LONG-SPAN BRIDGES

**Dinh Tung Nguyen[1], Xiaolin Meng[1], John S Owen[1], Yilin Xie[1], Panagiotis Psimoulis[1], George Ye[2]**
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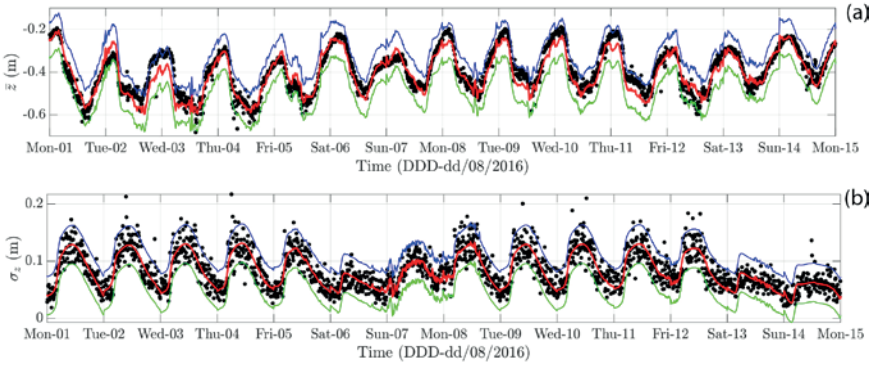
Thanks to the evolution of sensing and communication technologies, Structural Health Monitoring (SHM) of long-span bridges have developed significantly and give bridge operators an opportunity to monitor different parameters. These helps achieve better insights into bridge behavior, and ensure their safety and serviceability. However, the very characteristics of long-span bridges pose many challenges to the successfully delivery of a SHM framework in this context. Long-span bridges are non-linear and large-scale structures, and their responses are highly influenced by operational and environmental conditions. Together with a lack of a comprehensive definition of damage, they can cause substantial challenges concerning data analysis to establish normal behavior of these structures and hence to detect potential damages and structural changes.

The two projects *"GeoSHM – GNSS and Earth Observation for Structural Health Monitoring of Long-span Bridges"* and *"iSHM – Cloud-based Intelligent Structural Health Monitoring Platform for Long-span Bridges"* (sponsored by European Space Agency and Innovate UK respectively) aim to apply machine learning techniques to address this challenge. Recent outcomes of these two projects on one of the test structures – the Forth Road Bridge (Scotland) – is discussed in this paper. Monitoring data in 2015 and 2016 were analysed to define the baseline performance of the FRB, which was then modelled by a Neural-Network-based regression model. This regression model estimates the relationship between the bridge response and environmental and operational conditions, and offers a mean to separate effects of wind, traffic and temperature. More importantly, this regression model was embedded into a Bayesian framework, creating a self-adaptive online-sequential predictive model. This predictive model can predict the bridge response at given operational and environmental conditions and quantifying uncertainties associated with the prediction. These uncertainties can be further interrogated to uncover whether the bridge is experiencing an extreme loading condition, or some structural change is occurring to the bridge.

***Keywords:*** *SHM; long-span bridges; regression model; Neural Network; Bayesian*



# STRATEGIES AND METHODS FOR MULTI-EPOCH DEFORMATION ANALYSIS WITH GEODETIC NETWORKS

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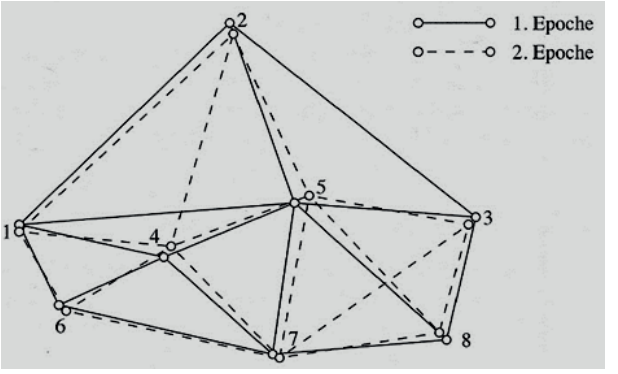
There is a long-lasting discussion within geodesy, which methods and strategies are adequate for a rigorous mathematical-statistical analysis of geodetic networks, when measuring results are available for several epochs. In this paper, first general pre-requisites and typical problems are outlined, which define the framework for the here presented new concepts. Then the basic ideas for data-driven and model-driven analyses techniques are described, leading to the conclusion that a data-driven technique normally is restricted to (multiple) congruency tests, whereas all further analysis-concepts have to be based on some prior-information or physical model describing the behaviour of objects. Different computational methods are discussed in some detail, like the consecutive two-epoch analysis, the multiple-epoch-congruency test and the - newly developed - constrained multi-epoch analysis. At the end a practical example for congruency analysis of multiple observed levelling networks is given.

***Keywords:*** *deformation analysis; multiple observed geodetic networks; congruency tests; multi-epoch analysis*



# A METHODOLOGY FOR CORRECTING REFRACTION IN VERTICAL ANGLESFOR PRECISE MONITORING IN TUNNELS

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The last three decades, the possibility of the high-precision instruments has been offered to the geodetic community by the technological development. Despite of this advantage some crucial parameters affect their performance. One of these parameters is the refraction.

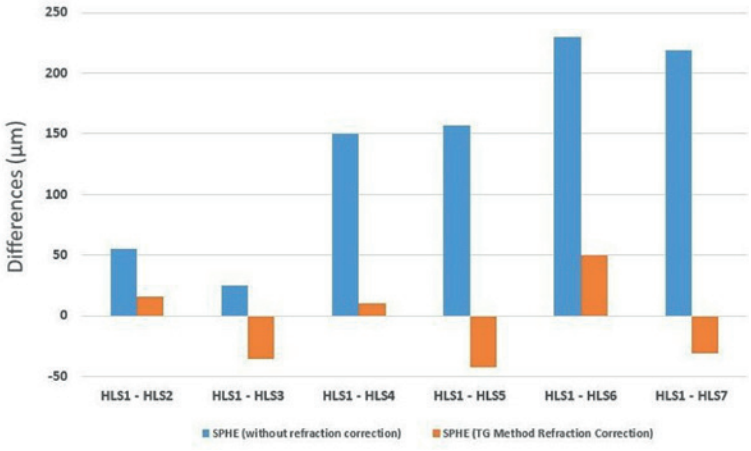
The geodetic refraction mainly affects the zenith angle measurements, especially in tunnels and underground facilities, where high accuracy is needed for the monitoring of the deformations. The term geodetic refraction, is found in the relevant surveying literature as a mean to describe the alteration in the direction of the light curve as it propagates through the different layers of the lower part of the Earth's atmosphere.

In this present work, a new methodology is analyzed in order to eliminate the influence of the refraction in the zenith angle measurements. The main idea is the accurate measurement of the air temperature in different heights in order to calculate the temperature gradient at each position, where measurements of angles took place.

The application of the method took place through the analysis of the adjustment results of 3D geodetic networks, which have been implemented in the TT1 tunnel at CERN. The choice of this test field is connected with the existence of seven Hydrostatic Levelling Systems. These systems can provide height differences which are unaffected by the refraction with accuracy of ±10μm. This choice permits the check of the results.

Finally, the new methodology is proved to be adequate for such accurate measurements since the standard deviation of the zenith angles residuals in 3D network adjustments is reduced approximately 70% after the refraction corrections and approaches the specifications of laser tracker (±1.5cc). Additionally, the maximum difference between the nominal height differences of HLSystems and the calculated height differences after the 3D network adjustments with the corrected zenith angles is very promising and approaches the value of 50μm.

***Keywords:*** *refraction; laser tracker; temperature gradient; Hydrostatic Levelling Systems; TT1 tunnel; CERN*



# A QUICK TOOL FOR THE PREDICTION OF TUNNEL CROWN DISPLACEMENT USING NEURAL NETWORKS

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The amount of information obtained from geological and geotechnical investigations at the initial stages of a tunnel project are not sufficient to give a clear image of the expected deformation behavior of the rock mass during excavation. The use of tunnel monitoring systems has extensively been applied in tunnel engineering as a means of obtaining more information on the behavior of the tunnel mass during construction and to reinforce the choice of excavation and support methods.

Artificial Neural Networks (ANN) and deep learning currently provide rigorous solutions to many problems in various fields like image and speech recognition, automation and classification whereas in geotechnical engineering it is growing rapidly mostly in deformation prediction and back analysis.

In this paper, deformation monitoring data from measured absolute displacements in a tunnel excavated at a complex geological system of the Pantokrator Limestone with fractured and loose cataclastic gouge using the New Austrian Tunneling Method has been used to train an Artificial Neural Network for prediction of the crown displacement along a tunnel. A Multi-layered Perceptron neural network has been developed and used as a quick tool for deformation behavior prediction (crown displacements) of the tunnel using the monitoring data measurements as target data and input training data from deformation parameters like the overload factor, the support class, the stress reduction factor, the rock mass category, the coefficient of lateral earth pressure and the overburden height. A detailed description of the developed ANN is given and results are shown which indicate the suitability of the proposed method.

***Key words:*** *Tunnel monitoring, monitoring data, neural networks, deformation prediction and deformation parameters.*

# BOOTSTRAP TESTS FOR MODEL SELECTION IN ROBUST VIBRATION ANALYSIS OF OSCILLATING STRUCTURES

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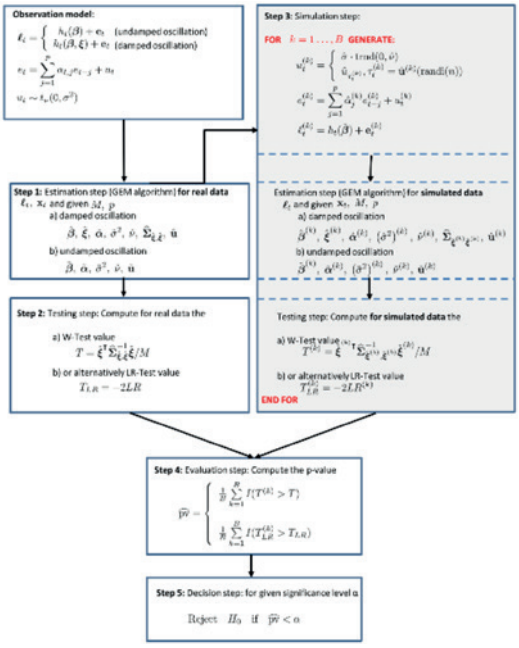
In this contribution, a procedure for deciding, whether the oscillation of a surveyed structure is damped or not, is proposed. For this purpose, two bootstrap tests under fairly general assumptions regarding auto-correlation and outlier-affliction of the random deviations ("measurement errors") are suggested. These tests are derived from an observation model consisting of (1) a parametric oscillation model based on trigonometric functions, (2) a parametric auto-correlation model in the form of an autoregressive process, and (3) a parametric stochastic model in terms of the heavy-tailed family of scaled t-distributions. These three levels, which generalize current observation models for oscillating structures, are jointly expressed as a likelihood function and jointly adjusted by means of a generalized expectation maximization algorithm. Closed-loop Monte Carlo simulations are performed to validate the bootstrap tests. Visual inspection of models fitted by standard least-squares techniques are shown to be insufficient to detect a small significant damped oscillation. Furthermore, the tests are applied to a controlled experiment in a laboratory environment. The oscillation was generated by means of a portable shaker vibration calibrator and measured by a reference accelerometer and a low-cost accelerometer.

***Keywords:*** *structural health monitoring; low-cost accelerometer; vibration analysis; damped harmonic oscillation; robust parameter estimation; model selection; bootstrap test*



# MACHINE LEARNING MEETS DEFORMATION MONITORING

**Tomasz Owerko**[1], **Szymon Walasik**[1], **Wojciech Karaś**[1]
[1] *AGH University of Science and Technology, (owerko@agh.edu.pl)*

The issue of deformation monitoring is a frequent topic discussed at scientific conferences and in specialized literature. The subject concerns not only construction objects, such as buildings or bridge structures, but also individual structural elements, which include beams. It is also important for natural hazards risk estimation. The research aims to create a model that determines the speed and direction in which the elements are moving, as well as carry out a classification that allows to determine the parameters of the phenomenon. This work focuses on the implementation of algorithms and was made with five modules: classical observation equalization module or free alignment, exploration transformation module for data presented on the plane and in space, flat and spatial coordinate transformation module , deformation test module (with determination of extreme values), and data classification module based on neural networks. The paper describes the both algorithms used and the methods of implementation. Examples of program's source code is provided. A comparative analysis of the application of classic and free equalization is presented, on the example of geodetic networks of different sizes and geometry of the network. Using data about the San Andreas Fault located near San Francisco, a model was created to classify the area with the distinction of points. Paper gives several important conclusions:

- Neural networks can be successfully used to classify objects deformations and determine the ranges of geodynamic phenomena,
- To build a correct classification model, the neural network needs a corresponding number of evenly spaced measuring points,
- Free estimation method provides a better distribution of errors, so it is worth using, regardless of the size of the network,
- Using free-form estimation, measurement errors will be scattered on all points, which will increase the reliability of the calculated displacements.

***Keywords:*** *Machine learning; Deformation monitoring; Classification model*

# SPATIO-TEMPORAL MONITORING OF A BRIDGE BASED ON 3D POINT CLOUDS - A COMPARISON AMONG SEVERAL DEFORMATION MEASUREMENT APPROACHES

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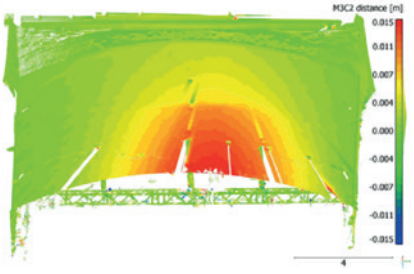
This contribution deals with the detection of load-induced arch displacements on a bridge by means of 3D point clouds acquired by terrestrial laser scanning (TLS). TLS has proved to be a suitable technique for geodetic monitoring of structures such as bridges as it allows determining object changes with high precision in the low millimeter level at high spatio-temporal resolutions. In an interdisciplinary project, which is being conducted with partners from industry and academia, a historic masonry arch bridge over the river Aller near Verden (Lower Saxony, Germany) has been investigated. Data acquisition was carried out using TLS sensors of kind Zoller+Fröhlich (Z+F) Imager 5006/h in periods of a constant load on the bridge. 3D point clouds for different load scenarios ranging from 1 MN up to 6 MN were captured and finally processed.

This study compares three different approaches for deformation measurements based on the captured 3D point clouds. The first approach under investigation is the Multiscale Model to Model Cloud Comparison (M3C2) algorithm. This algorithm establishes point-to-point correspondences between two datasets and computes stochastical measures based on the surrounding environment. The second approach is termed Araneo. It establishes correspondences between points and planes in line-of-sight. An extended uncertainty budget considers influences provoked by the applied sensor in form of an intensity-based stochastic model, the effect of spatial sampling as well as the datum-dependent impact of registration. Furthermore, a parametric procedure by means of B-spline approximation to estimate the deformation is deployed. This study reveals notable differences in terms of uncertainty budgets, magnitudes of deformation vectors and detected areal amount of deformation.

***Keywords:*** *laser scanning; uncertainty; stochastic modelling; monitoring; deformation; 3D point clouds; structures*



# DEFORMATION DETECTION THROUGH THE REALIZATION OF REFERENCE FRAMES

**Nestoras Papadopoulos[1], Melissinos Paraskevas[1], Katsafados Ioannis[1], Nikolaidis Georgios[1], Anagnwstou Eyaggelos[2]**

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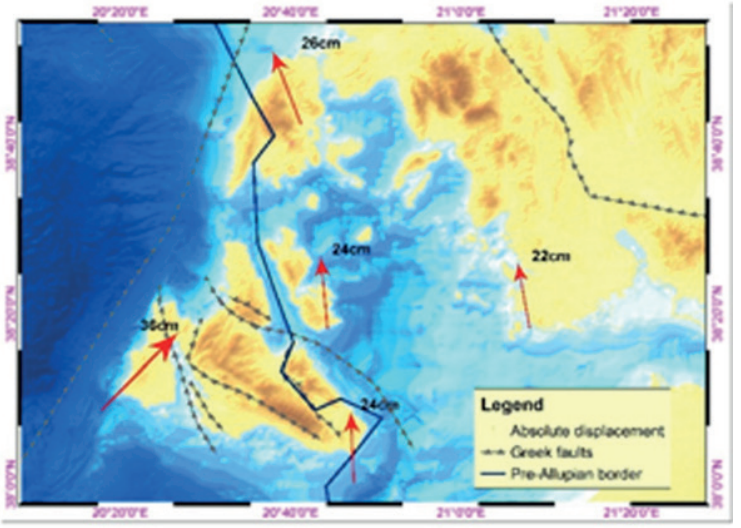
Hellenic Military Geographical Service (HMGS) has established and measured various networks in Greece which constitute the geodetic infrastructure of the country. One of them is the trigonometrical network consisting of about 26.000 pillars all over Greece. Angle and distance measurements held by HMGS through the years have been used after adjustment for the state reference frame which materializes the current Greek Geodetic Reference System of 1987 (GGRS87). The aforementioned System is a static one and is in use since 1989 after the decision of the State Geodetic and Geophysical Committee. Through the years especially in the era of satellite systems many GNSS networks have been established. The latest such network materialized by HMGS is ongoing and covers until now more than the 2/3 of the country. It is referenced by IGS permanent stations and consists a local realization of ITRF2008. Firstly, this gives the opportunity to calculate a transformation between the two systems and a statistical analysis of the residuals leads to intermediate conclusions. After that and in conjunction with existing past transformations tectonic deformations and their directions are concluded. Moreover past GPS observations on the same pillars in compare to the newer ones give also a sense of tectonic changes. Greece is one of the most tectonic active countries in Europe and the adoption of contemporary dynamic or semi-dynamic coordinate system is a necessity as it should incorporates a deformation model like 3d velocities on the realization frame. The detection of geodynamic changes is a continuous need and should be taken into consideration per each epoch.

***Keywords:*** *deformation; reference system; GGRS87; ITRF2008; HMGS; GPS; GNSS*



# CALCULATING A GEOID MODEL FOR GREECE USING GRAVITY AND GPS OBSERVATIONS

**Nestoras Papadopoulos**[1], **Melissinos Paraskevas**[1], **Ioannis Katsafados**[1], **Georgios Nikolaidis**[1]
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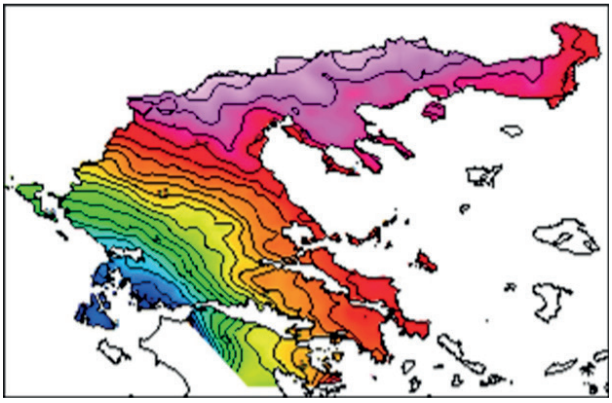
The main goal of the study is the calculation of a high resolution dataset that models the geoid for Greece using several kind of data collected by the Hellenic Military Geographical Service (HMGS). In situ gravity measurements and GPS/levelling on triangulation points plays a central role in the formation of covariance and cross-covariance functions used for the calculation of high frequency residuals. Also global models such as EGM2008 and EIGEN-6C4 contribute in the analysis of collected data and in the removal of low frequencies. A database of older gravity measurements completes and guarantees the data coverage of the whole region leading to a high resolution exported product. The whole project is based on the Remove – Compute – Restore (RCR) technique and the Least Squares Collocation (LSC) method is used at its core during the computation of the residual geoid height. In order to fulfill the RCR technique topographic corrections have been calculated on each measured point and the indirect effect has been computed for the total region. Rasters of the above have been extracted for visualization and analysis. The final product has been transformed through a parametric model for orthometric height adaption. Several scripts have been developed in Matlab and Python for the reckonings as no commercial or scientific software was used. Data combination and visualization in raster format has been made using the ESRI ArcGIS software. The study concludes to three different beta geoid height models depending on the RCR usage for further discussion and which will be evaluated in the light of new data collection.

***Keywords:*** *geoid; collocation; indirect effect; covariance function; gravity; GPS*



# ANALYSIS OF TWO DECADES OF SAR DATA FOR MEASURING GROUND DEFORMATION IN WIDER ATHENS, GREECE

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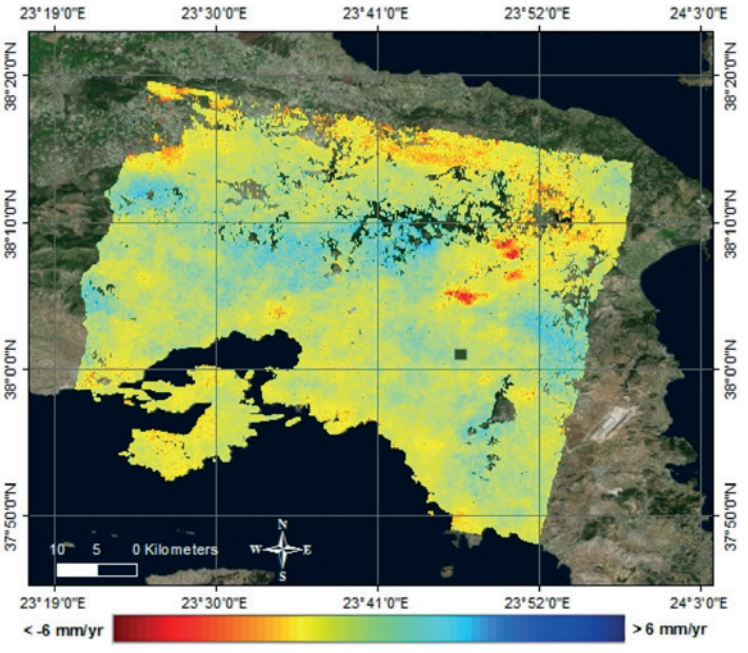
This work focuses on estimating ground velocities for the wider Athens area in a period spanning two decades, with an extended spatial coverage, increased spatial sampling of the measurements and at high precision. The aim is to deliver to the community a reference geodetic database containing consistent and robust velocity estimates to support further studies for modeling and multi-hazard assessment. The analysis employs advanced persistent scatterer interferometry (PSI) and Small Baseline Subset (SBAS) methods, covering Athens with both ascending and descending ERS-1, ERS-2 and Envisat Synthetic Aperture Radar data, forming six independent interferometric stacks. A methodology is developed and applied to exploit track diversity for decomposing the surface velocity field to its vertical and horizontal components. Results of the time series analysis reveal that a large area containing the Kifisia municipality experienced non-linear motion; while it had been subsiding in the period 1992–1995, the same area has been uplifting since 2005. This behavior is speculated to have its origin on the regional water extraction activities. In addition, a zoom in the area inflicted by the 1999 earthquake shows that there were zones of counter-force horizontal movement prior to the event. Further analysis is suggested to investigate the source and tectonic implications of this observation.

***Keywords:*** *PSI; track diversity; urban geodetic monitoring; subsidence rebound; Athens earthquake*



# GEODETIC AND GEOPHYSICAL APPROACH OF THE GRAVITATIONAL FIELD IN SANTORINI VOLCANIC GROUP

**Melissinos Paraskevas[1], Dimitrios Paradissis[1], Konstantinos Raptakis[1], Paraskevi Nomikou[2], Emilie Hooft[3], Dimitrios Papanikolaou[2]**

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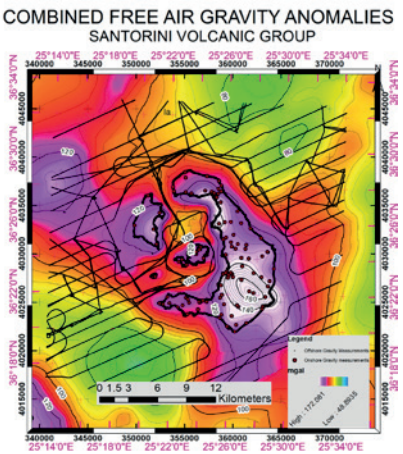
Santorini is located in the central part of the Hellenic Volcanic Arc (South Aegean Sea) and is well known for the Late-Bronze-Age "Minoan" eruption that might had been responsible for the decline of the great Minoan civilization on Crete island. Dionysos Satellite Observatory (DSO) of the National Technical University of Athens (NTUA) carried out terrestrial gravity measurements in December 2012 and in September 2014 at selected locations on Thira, Nea Kameni, Palea Kameni, Thirasia, Aspronisi and Christiana islands. Absolute gravity values were calculated using raw gravity data at every station to a combined dataset (2012-2014) and, consequently, complete Bouguer gravity anomaly maps were produced following the appropriate data corrections and reductions. The results were compared with gravity measurements that took place in July 1976 by DSO/NTUA and gravity variations at selected common locations were revealed. Marine gravity data that were collected during the PROTEUS project in November and December 2015 have been graded from University of Oregon and they fill the gravity dataset. An appropriate Digital Elevation Model (DEM) with topographic and bathymetric data was produced for the calculation of new, local scale, quasi-geoid and geoid model in Santorini Volcanic Group using the residual terrain approach and the GRAVSOFT package (Forsberg, 1994; Tscherning et al., 1992). Reliability of the model was carried out with geoid heights from independent measurements such as GPS-leveling in known triangulation points.

***Keywords:*** *Santorini; gravity; Bouger; geoid; Anomaly*



# FAST-MOVING LANDSLIDES MAPPING CONTRIBUTION USING SENTINEL-2 SATELLITE IMAGES

**Issaak Parcharidis[1], Constantinos Loupasakis[2], Ioannis Gougoustamos[1]**

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According to the World Atlas of Natural Hazards (McGuire, 2004), landslides are the most frequent and widespread natural hazard on Earth. They can occur on any terrain, particularly hilly and mountainous areas and mostly given the suitable conditions of soil or bedrock, groundwater, and the angle of slope (Varnes, 1978). Landslides can be characterized by low probability of evolution into a catastrophic event but can have very large direct and indirect impacts on man-made structures (Canuti et al., 2004, Klose et al., 2014). Mapping of existing landslides in areas of known slope instability produces maps that can potentially deliver knowledge for landslide risk management strategies. Monitoring is essential to predicting the behavior of landslides and forecasting. "Traditional" ground motion monitoring methods are based on field surveys. These methods include mainly geodetic/levelling measurements and Global Positioning System (GPS) networks, extensometers etc. Since 90's differential repeat-pass interferometry radar (DInSAR) based on SAR images processing has proven an interesting tool for the measurement and observation of ground deformation. In recent years using large stacks of SAR images acquired over the same area, long deformation time series can be analysed using multitemporal differential SAR interferometry techniques which overcome several limitations of repeat-pass interferometry. The technique has been widely applied for monitoring of slope instability with millimetric precision. Nevertheless, significant difficulties are found when using this technique. These difficulties are related to the large variability of slope (steep and rough topography typical of landslide-prone areas) instabilities in terms of mechanisms of movement, failure geometries, size of unstable areas and deformation rates causing phase ambiguity problems and signal decorrelation. Monitoring and measurement of landslide activity using optical satellite sensors is also an efficient method which has been used since the end of 70's (Sauchyn and Trench 1978) mainly based on visual interpretation. The current research work aims to examine further contribution of medium resolution of free optical satellite images and specifically Sentinel 2 in the mapping of landslide of moderate and/or rapid velocity of travel regardless of the cause induced them in two different areas specifically in USA (Yakima County, WA), Italy (Ponzano, Central Italy). Also validate the results based on knowledge derived from other sources of knowledge. For the purpose of this study the normalized cross-correlation (NCC) method of image matching was used (Debella-Gilo and Kääb 2010, Heid and Kääb, 2012). The results of the study, aimed at mapping the high velocity movement of landslide phenomena with the use of optical satellite images, were entirely consistent with the results obtained from other sources-methods.

***Keywords:*** *Surface deformation; Landslides; optical satellite images; Sentinel-2; Normalized Cross Correlation*

# DETECTION OF STRUCTURAL VIBRATION WITH HIGH-RATE GNSS PRECISE POINT POSITIONING – METHODOLOGY AND CASE STUDY RESULTS

**Jacek Paziewski[1], Pawel Wielgosz[1], Rafal Sieradzki[1], Radoslaw Baryla[1]**
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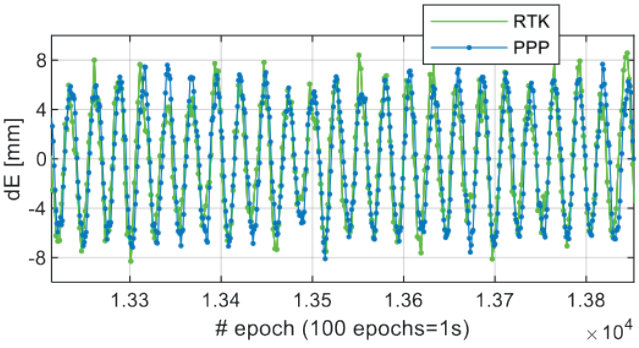
The core of this contribution is to develop and assess the methodology for application of Precise Point Positioning (PPP) for high-rate GNSS data processing in order to meet the requirements of structural vibration detection. Such applications ought to satisfy the highest demands in terms of reliability, precision and high temporal resolution of GNSS-derived position. Among other commonly applied GNSS positioning techniques, which can meet these specific demands such as RTK, we can also recognize PPP which is currently under extensive development. Recent contributions have confirmed the usability of PPP based on the processing of undifferenced observations for coordinates determination. Moreover, we can expect clear benefits in accuracy and reliability of Precise Point Positioning from application of multi-frequency and multi-constellation observations. On the other hand currently regular PPP may not meet the high-precision requirements of coordinate estimates; hence a novel processing strategy has been developed and applied. Such approach offers millimeter-level precision of displacement determination based on absolute GNSS positioning. According to these conditions and demands the main objective of the contribution is the development of the dedicated processing algorithms of high-rate un-differenced multi-GNSS data processing for structural deformation monitoring. The algorithms were implemented in the in-house developed software allowing for high-rate precise positioning and were used to assess the case study results. In the field experiment we have used a special device which artificially triggered dynamic horizontal displacements. The device had been designed and constructed to ensure a periodic motion of GNSS antenna with fixed amplitude and frequency of GNSS antenna motion. The results have confirmed the applicability of PPP for providing reliable and consistent results with the precision of the determined dynamic displacements at the millimeter level.

***Keywords:*** *Precise Point Positioning; PPP; GNSS; GPS; structural vibration*



# MODELLING ANTENNA VIBRATIONS USING THE SIGNAL-TO-NOISE RATIO (SNR) OF GNSS SIGNALS

**Ioulia Peppa**[1], **Panos Psimoulis**[1], **Xiaolin Meng**[1]
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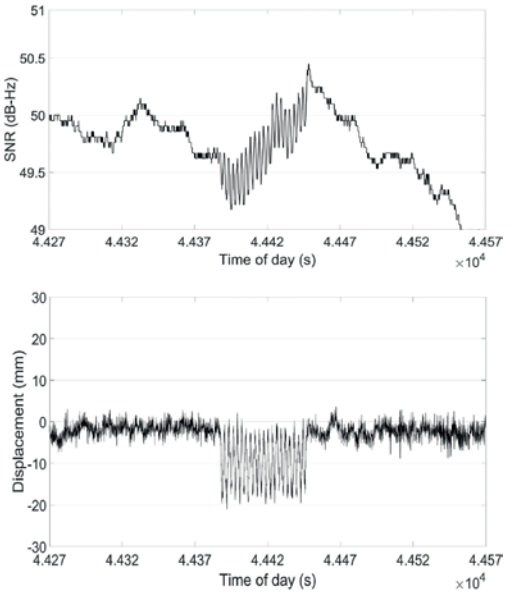
The multipath effect in GNSS measurements remains one of the dominant error sources in GNSS monitoring applications. The site-dependent, fast-changing characteristics of multipath render it difficult to model or predict, introducing errors in the GNSS measurements. Current techniques to mitigate the impact of multipath effect focus mainly on repeating GNSS measurements to detect multipath-induced patterns or integrating GNSS with other sensors. However, the multipath effect is used to identify potential changes in the environment in geoscience applications, such as detecting vegetation growth, snow and tidal changes. These applications are based on the concept that for static GNSS antenna, variations in the Signal-to-Noise Ratio (SNR) measurements, induced by the multipath effect during the satellite orbit, express changes in the multipath geometry attributed to different factors (vegetation, tides, snow). In the current paper, we develop the same concept for an oscillating GNSS antenna focusing on the changes in the multipath geometry caused by the antenna rather than the satellite motion. In this study, we investigate the potential of modelling the SNR data of satellite signals and estimating reflection parameters (reflection intensity, antenna-reflector distance, reflector's tilt) and the motion characteristics (amplitude, frequency and phase of motion). The theoretical SNR model is developed and applied on simulated GNSS records for antenna oscillations in the vertical direction and horizontal reflection surface in different cases of multipath intensity and antenna motion. The validity of the model is examined using vertical controlled oscillations of GNSS antenna, executed on the roof of Nottingham Geospatial Institute, in the UK.

***Keywords:*** *SNR; multipath; monitoring; GNSS-R; antenna vibration*



# TERRESTRIAL LASER SCANNING TIME SERIES FOR LANDSLIDE ADVANCED ANALYSIS

**Julien Point[1], jean-Philippe Malet[1], Mathilde Desrues[1], Ryan Kromer[2], Gilbert Ferhat[1,3]**

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We present a complete Terrestrial Laser Scanning (TLS) analysis system applied to the Pas de l'Ours-Aiguilles landslide. The unstable area has a width of 1 km and a length of 600m, associated with rockfalls, mudflows and large deformation of the road located at the base of the slope. The site has been instrumented with a permanent Optech ILRIS Lidar for 6 months allowing for acquisition of almost 200 scans. Considering the amount of data, an automated procedure had to be developed to inspect landslide activity. We developed a three-stepped data processing workflow from the acquisition to the estimation of the landslide volume.

Point cloud processing scripts were developed in C++ and are mainly based on PCL (RUSU & COUSINS, 2011), PDAL and GDAL libraries. A registration pipeline (KROMER et al, 2017) was first implemented to check point cloud consistency, reject unusable files, filter noise and unwanted areas, to finally align all point clouds to obtain a consistent dataset over the period of acquisition. The registration step is insensitive to vegetation which avoids time consuming vegetation filtering. Nevertheless, an optional pipeline can be activated to clean point clouds and compile Digital Surface Models (DSMs). The pipelines were parallelized with OpenMP in order to speed up the entire dataset computation. A second module handles the registered scans and outputs the 3D displacement fields, for each component. The TLS-derived displacement fields are compared to surface displacements measured by a permanent total station. Finally, the third module takes the displacement field as input data for the inversion of landslide thickness using the strategy initially proposed by BOOTH et al. (2013) and adapted to long time series. The tool allows estimating the landslide geometry and volume according to the depth inversion. The workflow provides an efficient way to value TLS point cloud datasets for the analysis of mass movements. It can be set up either for near-real-time monitoring situations or for post-acquisition processing.

***Keywords:*** *Landslide; Terrestrial Laser Scanning; Monitoring; Automated registration; Displacement analysis Thickness inversion*

# GROUND DEFORMATION MONITORING TECHNIQUES AT CONTINUOUS SURFACE LIGNITE MINES

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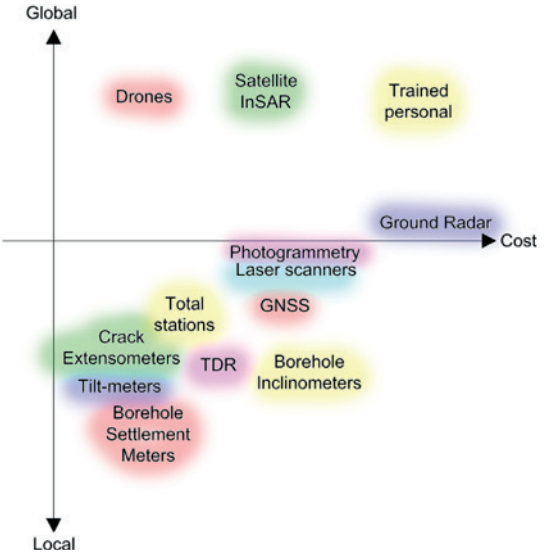
Several methods for monitoring ground deformation at surface lignite mines have been developed. The Public Power Cooperation (PPC) lignite mines in Western Macedonia and Megalopolis are being constantly monitored by an array of these methods. This paper presents the methods that are currently implemented and the reasoning behind their selection. Mine planning, mine size, time constraints, expected magnitude of movement, terrain morphology and geology dictate the monitoring scheme.

The vast majority of the measuring techniques can be classified as local and they tend to be much cheaper and easier to implement. These methods include GNSS, high accuracy Total Stations, borehole inclinometers, structure tilt-meters and borehole settlement meters. Satellite InSAR, aerial photography and most importantly continuous experienced eye observation can be categorised as global techniques that give a general overview and can be used to notify about slope deformation that requires closer, ground – based measurements. Some of these data collection techniques can be automated, or do not require highly skilled personal. This paper separates monitoring techniques into local and global and the main pros and cons of each technique will be presented.

Due however to the fact that the measurements are far from homogenous, the paper concludes with the presentation of a cloud based real time slope movement monitoring system (GIS). This built to order system has been developed for the evaluation of the observations, by automatic generation of tangible reports.

***Keywords:*** *ignite Surface Mine; Slope Monitoring; Ground Deformation*



# STATIC AND DYNAMIC INTERACTION OF SOIL AND STRUCTURES DURING THE DESIGN, CONSTRUCTION AND OPERATION OF VARIOUS ENGINEERING PROJECTS

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Since the size and the complexity of an engineering project increases, its design and construction may be very demanding tasks, especially when the new structure interacts with the soil and the pre-existing adjacent structures. Depending on the circumstances (i.e. the soil conditions and the sensitivity of the pre-existing structures), any mistake during the design phase or the construction phase may lead to serious damages or even collapse. It is evident that in the case of additional dynamic loading (due to earthquakes, explosions, or vibrations) the interaction between (a) the new engineering project, (b) the soil, and (c) the pre-existing structures may be more challenging during the operation phase as well, especially when the engineering project is permanent.

The current study is trying to shed some light to these important issues of geotechnical engineering under static and seismic conditions. Through records and numerical results (from various case studies the author has been involved in the past) it is shown that, apart from realistic numerical simulations, real-time monitoring during the construction and the operation may be a very useful tool for improving the safety of the new and the pre-existing adjacent structures.

***Keywords:*** *real-time monitoring; numerical simulations; soil-structure interaction (SSI)*

(a)

(b)

# NON-SIGNALIZED STRUCTURAL MONITORING USING SCANNING TOTAL STATIONS

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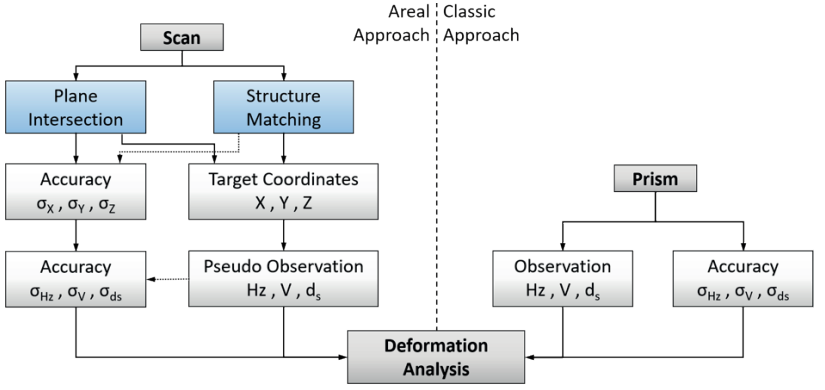
A new method for structural monitoring using scanning total stations is presented, enabling to forego the cumbersome signaling of target points but still detect significant movements in the millimeter range. In contrast to the existing scanning-based strategies of deformation analysis, this approach is based on creating reproducible discrete object points, so that a rigorous deformation analysis including statistical significance tests can be performed.

In structural monitoring, usually a number of prisms is permanently mounted on the facade. Particularly in places difficult to access, the installation requires great effort, causes considerable costs and leads to damages to the facade. In this approach the automated total station scans predefined geometric structures from which homologous points can be extracted over all epochs. These discrete points can be created by modeling and intersecting three planes, e.g. at window openings. Alternatively, points can also be generated on irregular structures using the ICP algorithm. From the residuals an accuracy statement for the modeled target point results and the extracted points can be converted into a tacheometric pseudo-observation with associated variance-covariance matrix. These observations are subsequently combined with other tacheometric measurements and – if a monitoring network exists – processed in a classical rigorous deformation analysis with significance tests.

Several experiments to validate this innovative monitoring concept are presented, whereby significant deformations could be detected already from displacements of one millimeter on. This corresponds to the level of accuracy that can be achieved with permanently installed prisms. The omission of most signalized target points makes the setup of a monitoring system much easier and faster. Additional non-signaled object points can easily be included into an existing prism-based monitoring network.

***Keywords:*** *structural monitoring; laser scan; scanning total station; deformation analysis; point identities; statistical significance*



# POLYPHYTON DAM: MONITORING OF THE RIGHT ABUTMENT SLIDE

**Spyridon Raftopoulos**[1]
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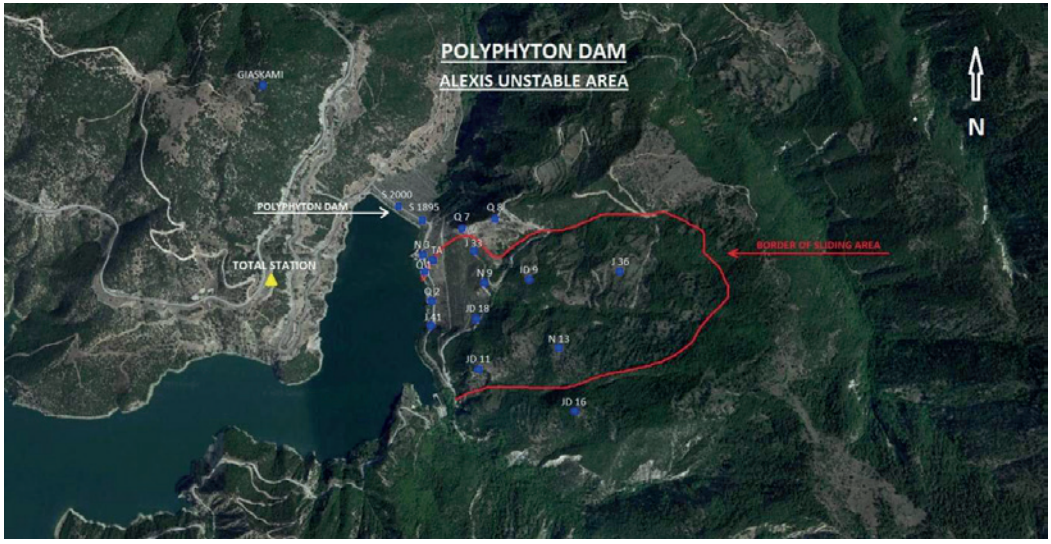
Polyphyton Hydroelectric Dam is a rockfill Dam with central inclined core, 105 m. tall, with a crest length of 297 m., located 26 km south of the town of Kozani, in the Region of Western Macedonia, Greece. Construction completed in 1974.

An unstable area located in the right abutment, upstream of and in the vicinity of the Dam is critical for the Dam safety. This particular area could potentially affect all supplementary parts of the project, such as the Inlet of the Power Intake and Spillway, as well as the upstream shell of the Dam. It covers an area of 0,66 $km^2$, with a volume of approximately $30x10^6$ $m^3$ and came up during the process of excavations within the borrow area on the right abutment, which provided rock materials for the Dam construction.

This paper discusses the monitoring of the slide on the right abutment of the Dam through geodetic methods, supported by a Total Station, located on the opposite side on the left abutment. Additionally, monitoring includes; a crack meter system founded on the bottom of an adit on the right abutment at a certain position, where a serious volume of deformations is expected, which gives depth information regarding the moving area.

Nevertheless, although the above mentioned system has changed the previous routine of topographic measurements in the area, some of them still proceed in being carried out. Therefore, a correlation between former and current status of measurements is attempted, so that their improvement, as well as the information of the ongoing stability of the specific area emerge.

***Keywords:*** *crack meter; total station; slide; unstable area; monuments*



# DEFLECTION MONITORING AND FREQUENCY RESPONSE OF A SHIP USING GPS AND FIBRE OPTIC BASED SENSORS

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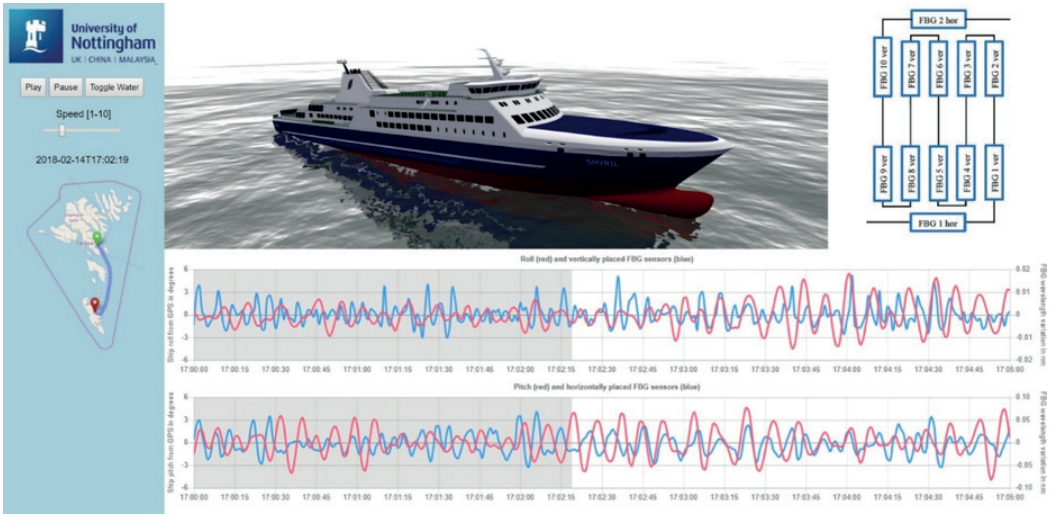
Kinematic GPS and GNSS has been used as a tool to monitor the deflections and natural frequencies of large structures, and hence Structural Health Monitoring. In addition, fibre optic based measuring systems have been used to measure the long term deformations of natural and engineered structures. In this paper, we discuss the use of both GPS and fibre optic based measuring systems to measure the deflections and natural frequencies of specific locations on a ship.

Field tests were conducted on the 138m long Smyril ship on the Faroe Islands. The one way journey time between Tórshavn and Suðuroy is 2 hours, with a distance of approximately 68km.

Surveys were carried out on the 1 August 2017 and on the 12, 13 and 14 February 2018. Fibre optic sensors of three different configurations were placed within the ship, one at the bow and two in the engine room, gathering data at 1kHz. Two GPS antennas were placed on either ends of the roof of the ship's bridge, and a third at the stern of the ship, all gathering data at 1Hz.

This paper presents details of the configuration of the surveys, and shows results from both the GPS and fibre optic units. A fundamental frequency of around 0.11Hz was extracted from the GPS data, illustrating this as being the frequency of the motion of the ship at sea. Quicker frequencies due to the vibration of the ship mainly due to the engine were too small for the GPS to pick up. The fibre optic units, however, were much more sensitive and could pick up a variety of frequencies, and changes in frequencies due to the ship and engine.

***Keywords:*** *Deflection monitoring, GNSS, fibre optic sensors*



# INPUT FOR INTRA-FRAME VELOCITY MODELS FOR THE U.S. N.S.R.S. IN 2022

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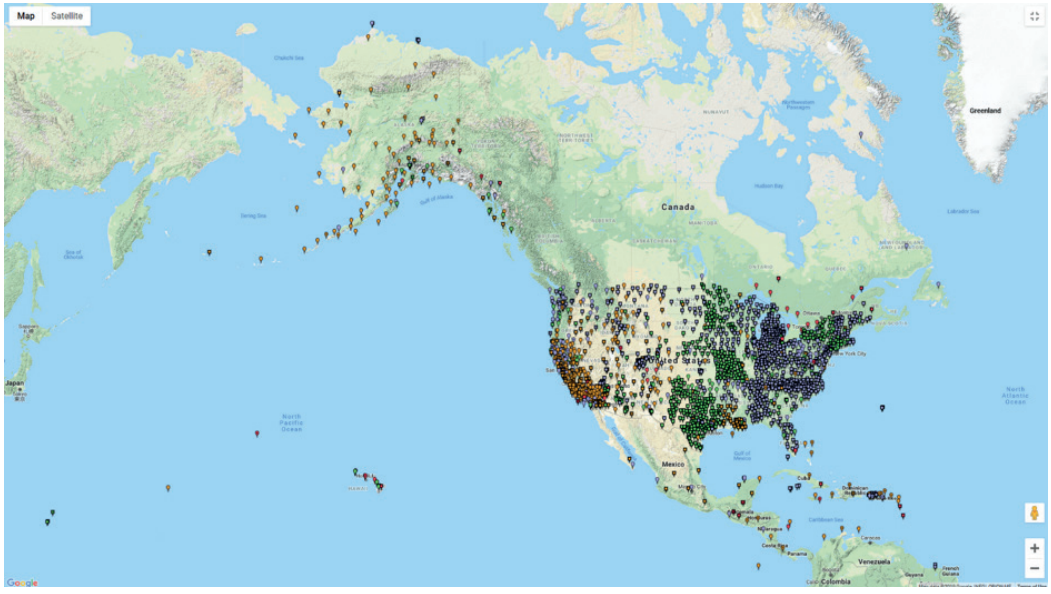
The United States will update its National Spatial Reference System in 2022. There will be four separate terrestrial reference frames (TRF's) tied to the International Terrestrial Reference Frame (ITRF). All will be identical to the ITRF at epoch 2020.0, but they will rotate according to Euler Pole Parameters (EPP) determined for each plate: North America, the Caribbean, the Pacific and the Mariana. While these EPP will describe most motion in these plates, significant horizontal and all vertical motions must be captured by deformation models or Intra-Frame Velocity Models (IFVM). A single densified ITRF velocity model will provide the basis for the four TRF's. The EPP-implied motion is removed and the remaining signal is the IFVM for the plate. The simplest solution is simply to grid velocities at the nearly 2000 CORS (see Figure). The recently completed reprocessing CORS has determined velocities for over 20 years. This velocity information works well in densely packed regions of CORS but performs below desired tolerance in sparsely covered regions. A denser set of control is available if other cGNSS networks are incorporated. This works better but uncertainty in the quality of some sites may affect the velocities. More complicated still would be incorporating geophysical models to better interpolate between control CORS. Finally, the use of satellite based InSAR would provide a basis for persistent updates. While InSAR may help in remote regions such as the Mariana Islands, it can be problematic in other areas. The optimal solution will likely be a combination of all.

***Keywords:*** *Terrestrial Reference Frames (TRF); regional deformation; Intra-Frame Velocity Model (IFVM); National Spatial Reference System (NSRS)*



# MULTI-STATION GROUND-BASED REAL-APERTURE RADAR FOR QUASI-STATIC DEFORMATION MEASUREMENT

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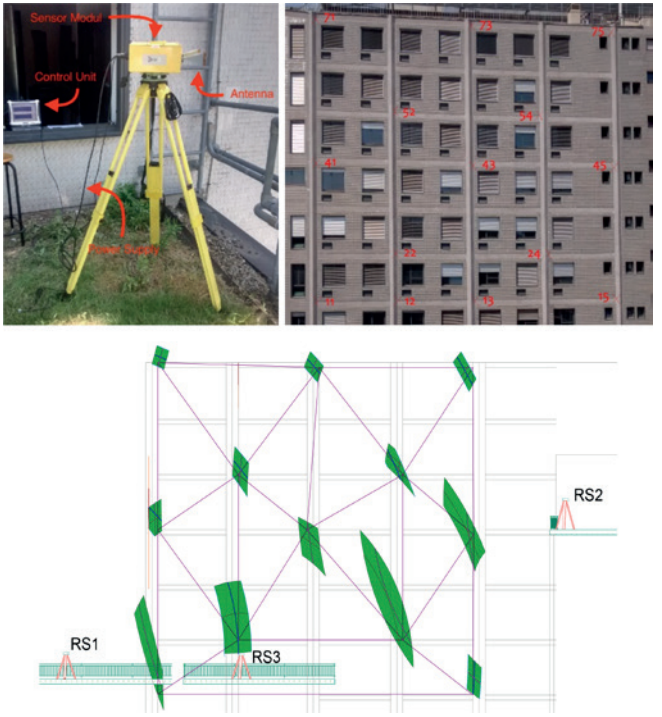
2 Politecnico di Bari, DICATECh, University Campus "Quagliariello," via Edoardo Orabona 4, 70125 Bari, Italy Ground-based Real-aperture Radar (GBRAR) has been applied in recent years for the dynamic analysis of civil constructions. The same technology could be also exploited for the high-precision quasi-static deformation measurement. Unfortunately, in this modality GBRAR still suffers from important drawbacks (accurate repositioning for long-term monitoring, target ambiguity, mitigation of atmospheric effects) which make its application less competitive with respect to other techniques. After reviewing a set of experiments to evaluate the instrumental performances of IBIS-S sensor by former IDS Sistemi Italian company, a solution based on the use of multiple stations ('stereo-radar') is discussed. This approach may help discriminate target ambiguity and improve the geometric definition of spatial displacements. 'Stereo-radar' is based on the use of at least two GBRAR sensors to work concurrently to monitor quasi-static observations. Here a preliminary test to demonstrate the feasibility of this technique is reported.

***Key words:*** *Deformation Measurement; Ground-based Real-aperture Radar; Interferometry; Monitoring*



# TOWARDS A MORE RIGOROUS ERROR PROPAGATION WITHIN THE ERRORS-IN-VARIABLES MODEL FOR APPLICATIONS IN GEODETIC NETWORKS

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The use of the Errors-In-Variables (EIV) model for geodetic applications, along with the corresponding Total Least-Squares (TLS) adjustment, has been around for over a decade; see Schaffrin and Wieser (2008) who pioneered this method in geodetic science along with Schaffrin and Felus (2005). But, beyond the successful derivation of nonlinear formulas for TLS estimates of both the parameters and the variance component, a similarly elegant formula for the variance-covariance matrix of the estimated parameters is still missing. Moreover, a first attempt for an approximate representation by Amiri-Simkooei and Jazaeri (2012) had to be dismissed by Schaffrin and Snow (2014) shortly thereafter as being non-satisfactory due to the neglection of various sources of random errors in the nonlinear relationship between the data and the parameter estimates.

Here, we shall try to compensate for some of these neglections, while still relying on a linearized approach, as our attempts for fully nonlinear error propagation were unsuccessful so far. An example from geodetic network analysis will illustrate the new, more rigorous formulas.

***Key words:*** *Errors-In-Variables model; Total Least-Squares adjustments; error propagation; geodetic network analysis*

# SINGLE POINT ADJUSTMENT WITHIN EXISTING NETWORKS BY MEANS OF THE repro-BLE

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It is well known that, within a Gauss-Markov Model (GMM), the Best Linear Estimate (BLE) shows smaller Mean Squared Errors (MSE) for the estimated parameters if compared with the more traditional BLUUE (Best Linear Uniformly Unbiased Estimate). This result, however, is only of theoretical value as the BLE itself cannot be numerically evaluated without further assumptions. One common approach is based on the use of the BLUUE whenever an approximation of the BLE is required which leads to the so-called ``empirical BLE.''

In contrast, Schaffrin (2000) had argued that, at least in the univariate case of ``direct/replicated'' observations of one parameter, the so-called ``reproducing BLE'' should be superior to the empirical BLE whenever it exists. Both are, of course, nonlinear estimates in the end, and the formulae for their MSE can only be approximations.

Here, we shall consider the 2-D case where we put the necessary generalizations of the repro-BLE to work as presented by Schaffrin and Xu (2017). Concretely, a single point will be adjusted within an (existing) planar geodetic network for which we compare the BLUUE, the empirical BLE, and the repro-BLE (after checking the existence condition) of the point's coordinates.

***Key words:*** *Gauss-Markov model; Best Linear Estimate (BLE); Empirical BLE; repro-BLE*

# DEFORMATION MONITORING OF NOISE BARRIERS WITH PROFILE LASER SCANNING

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Noise barriers along railway tracks are exposed to frequent load changes, as a result of the strongly varying pressure field, induced by passing trains. Especially at high speed tracks the dynamic load effects can lead to heavy mechanical stress on the structure, due to the high and low pressure sections following each other directly.

The deformation monitoring of noise barriers is usually realised with conventional sensors for the monitoring of supporting structures (accelerometers or inductive displacement sensors), which require a lot of installation effort. Furthermore, they are yielding only information at discrete measurement points.

With the usage of a profile scanner, the installation effort can be reduced to a minimum, and it is possible to generate added value in information about the structure, due to its high profile wise spatial resolution. Compared to conventional sensors the profile scanner can generate qualitatively comparable results with less effort and therefore opens up new possibilities for the efficient monitoring of noise barriers.

***Keywords:*** *deformation monitoring; noise barrier; railway; profile scanner; spatial clustering; B-splines*

# GEODETIC SURFACE BASED METHODS FOR STRUCTURAL ANALYSIS DURING CONSTRUCTION PHASE

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Surface-based metrology, like terrestrial laser scanner, needs new surface-based analysis and evaluation methods. These approximation methods are one of the main challenges making the information of 3D point clouds suitable and taking benefits from the redundancy. Freeform curves and surfaces are promising approximation methods to create parameterized curves and surfaces. Their properties enhance further evaluation steps, like providing continuous geometry for structural analysis or deviation ratings for quality assurance aspects of built objects. Both applications are shown in here.

At the Institute of Structural Engineering at the TU Wien an cost and resource efficient concrete dome construction was invented by using a shell structure. Therefore, a flat fully hardened concrete plat is transformed with a simple air cushion and prestressing strands into a double curved shell. Basically the stability of a concrete shell is sensitive against geometric imperfections. As part of the quality assurance, the engineering geodesy audits the geometry during the construction process with point and surface-based metrology. The measurement system consists of two classic and one scanning total station positioned inside the dome. The station-points of the three measurement devices are part of a geodetic network in- and outside the dome to provide a controlled and stable reference frame. The analyse concept includes the geometric modelling and the identification of geometric deviations. In the modelling part, the point cloud is continuously approximated by estimating the control points of the B-Spline function in a least squares adjustment. It additionally includes the iterative optimization of the parameters belonging to the observations (xyz-coordinates). The approximated geometry is used to assess the stability of the shell by means of a static finite element model.

The identification of geometric deviations is subdivided into the analysis of the B-Spline parameters, the control points, and of the displacement within the point cloud itself. The surface-based deviations (using the point cloud) and the point-based deviations (using the control points of B-Spline function) are obtained from the comparison between the nominal CAD model and the actual measurements. The displacements are analysed with respect to three different frames derived from the requirements of the civil engineers, e.g. to assign geometry impacts to different construction steps. Necessary preparation steps of the approximated geometry as main part of the structural analysis, computed with a finite element model, are shown in the workflow from the point cloud to the static behavior of the dome. The results of the structural analysis shows no significant changes due to the geometric deviations in the static load behavior compared to nominal finite element model.

https://www.youtube.com/watch?v=LE-6Nrm-6zs&feature=youtu.be

***Keywords:*** *Modelling point cloud; freeform approximation; structural analysis; finite element model; shell structure*

# ECOAQUA MODELING AND MONITORING OF AN EXPLOITED AQUIFER SYSTEM IN NORTHERN BAJA CALIFORNIA, MEXICO

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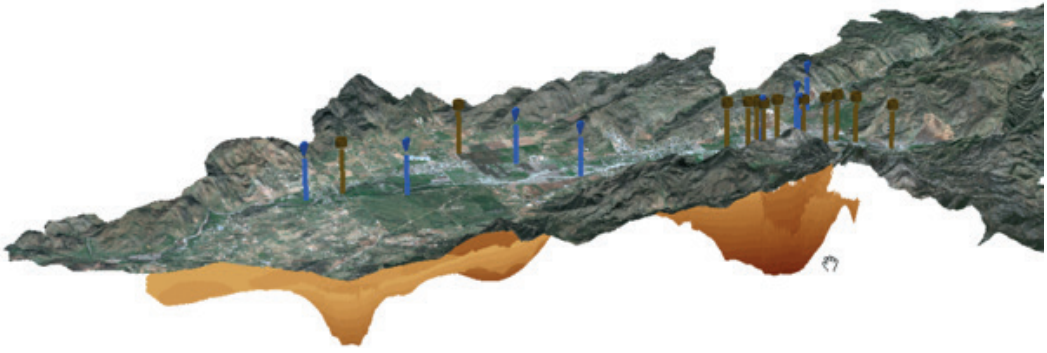
The progressive urbanization, industrialization and cultivation of the Ensenada city region located at the west coast of Mexico causes high pressure on the local marine and coastal ecosystems. High demand on the freshwater resources in combination with the semi-arid climatic conditions has led to overuse of local aquifers in recent decades. Resulting scarcity and salinization problems, land subsidence accompanying infrastructure damage, degradation of soil quality and hydrological droughts present significant challenges to both civil society and local utilities, businesses and science.

Developing a methodology to determine the temporal and spatial performance of acting factors on the affected aquifer system and promoting regional actors to assess and modify its state is the main objective of the bi-national research project ECOAQUA. This is achieved by, among other things, conceptualizing and modeling a local socio-hydrological system and its interactions, as well as capturing and weighting influencing and risk factors.

The contribution of the TU Braunschweig working group to the analysis of the dynamics and complexity of a socio-hydrological consists in applying and extending remote sensing techniques (satellite-based InSAR), cause-specific modeling of surface deformation and data-based descriptive and qualitative hydrological modeling using Support Vector Machine (SVM) algorithms. The latter is facilitated by the high density of relevant field data and remote sensing data. This enables the generation of reliable temporal and spatial information about the state and the transformation processes of the local aquifers, taking into account different data levels.

Here we will present preliminary results of this approach.

***Keywords:*** *Socio-hydrologic model; Support Vector Machines; InSAR*



# NUMERICAL STRUCTURAL IDENTIFICATION USING 3D LASER SCANNING – A SIMULATION-BASED CASE STUDY

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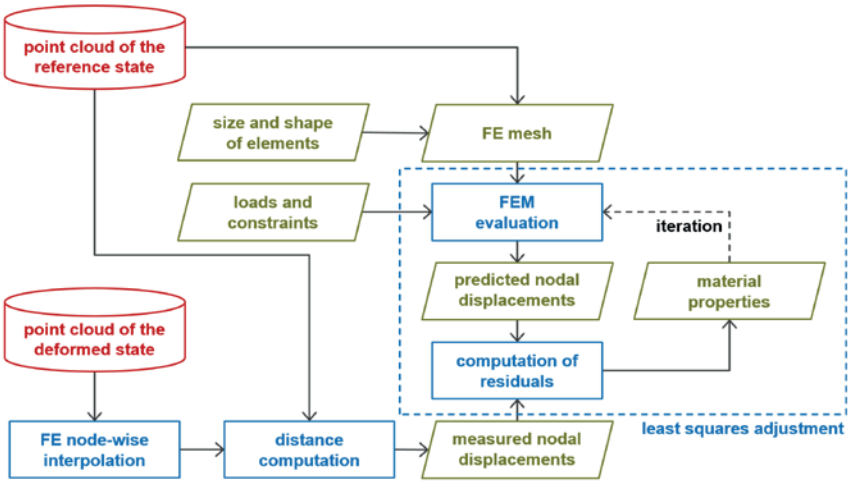
The integration of areal monitoring techniques such as terrestrial laser scanning (TLS) and the numerical simulation of complex structures is a challenge in the context of Structural Health Monitoring (SHM). Key aspects to facilitate this integration are the thorough handling and modelling of the uncertainties of both measurement and numeric model, and the quantification of the attainable accuracy of the investigated structural parameters depending on the setup configuration.

We give a detailed explanation of an algorithm that integrates the contactless areal monitoring of the surface of a structure and the numerical determination of its material parameters with a finite element (FE) model. The FE mesh is generated automatically from a point cloud acquired using TLS, while the best linear unbiased estimates of unknown material parameters are calculated by matching the displacements predicted with the FE model to the ones derived from laser scans taken at different epochs.

In this contribution, we refine a previously introduced algorithm by (i) explicitly linking the scanned points to the FE mesh, and (ii) taking into account a spatial distribution of uncertainties of the point clouds. Furthermore, we use a closed-loop simulation to study the performance of the algorithm for the case of a simply supported horizontal beam loaded at midspan and the sensitivity of the results with respect to the scanner location.

***Keywords:*** *structural health monitoring (SHM); terrestrial laser scanning (TLS); structural identification; finite element method (FEM); integrated monitoring*



# DEVELOPMENT AND RESEARCH OF THE METHODS FOR ANALYSIS OF GEODETIC MONITORING RESULTS FOR THE SUBWAY TUNNELS

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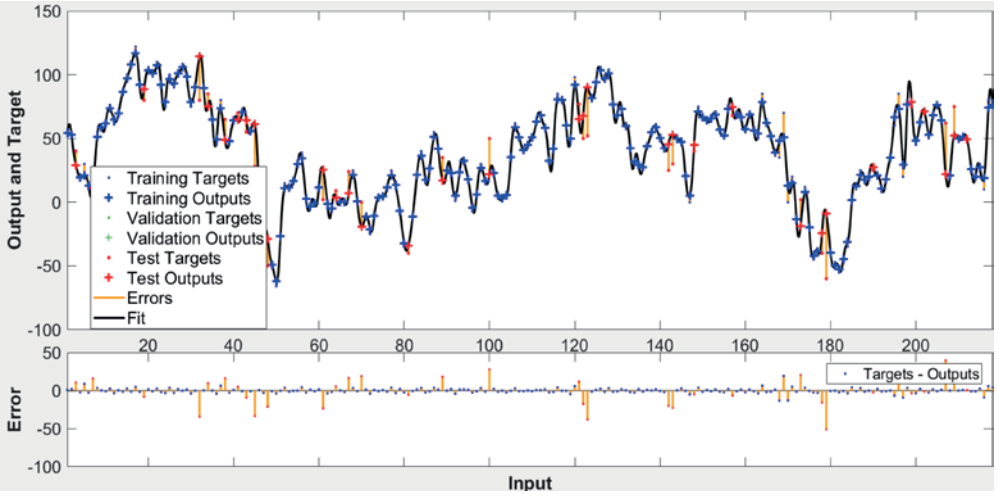
In the presented paper, the different methods for analysis of the geodetic monitoring results for the subway tunnels were discussed. Using the results of the geodetic monitoring for the displacements of seven new subway tunnels in Kiev the traditional and new methods for measurements analysis were researched. The sections of these tunnels have a form of a circle with 5.5 meters diameter. For analysis of the whole tunnel structure, the vertical displacements by the results of precise levelling were used. Two types of displacements were considered: vertical displacements of the tunnel surface and vertical displacements of the whole tunnel structure. For these displacements were carried out different types of analysis. Before data analysis, correlation relationships between displacements of the tunnel surface and the whole structure displacements were considered. These correlations were assessed using statistical criteria. It turned out that there is a high correlation between tunnel surface vertical displacements and structure vertical displacements in all. In order to smooth away possible geodetic measurements errors and approximate results of displacements measurements, Fourier analysis method was used. As an alternative approach for such an analysis neural networks method was considered. For quality assessment of the carried out analysis for both types of displacements the simplest deformation model which obeys to stress-strain condition was developed. This model is grounded on structural mechanics principles and allows to calculate tunnel surface displacements under specific construction conditions. The vertical displacements of the whole structure were analyzed both by Fourier analysis and neural networks methods.

***Keywords:*** *displacements; approximation; prediction models; Fourier analysis; neural network*



# SENSOR NOISE CHARACTERISTICS AND ERROR PROPAGATION: AN EDUCATIONAL APPROACH BASED ON COLLOCATED MEMS ACCELEROMETERS

**Stathis Stiros**[1], **Georgia Fotopoulou**[1], **Christodoulos Glaros**[1]
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With the advent of modern electronic instruments and of modern computational techniques permitting collection and analysis of masses of data, various aspects of the theory of measurements and errors have been ignored, and measurements and measurement-derived data are usually assumed to be characterized by white noise only, while apparently divergent sensors and data are usually selectively discarded.

A method to highlight the non-random character of errors and of their propagation is based on MEMS accelerometers, which are currently accessible in smartphones as hardware, in many cases of good quality, while data collection and analysis with output in CSV files is easily made through freely available APPs.

Accelerometers record acceleration, and double numerical integration of the time series of their recordings is expected to permit to record 1-d to 3-d displacement. Still, theoretical analysis based on the law of error propagation indicates non-linearly increasing uncertainty in displacements as a function of time (and of measurements). This can be derived from simple controlled experiments with one of more accelerometers fixed in certain common facilities and instruments and forced to controlled movements; for example, to follow the same pre-determined path and return to the starting point; this permits an easy control of misfits, differences of computed displacement from the "true" null (cumulative) displacement and differences between collocated identical sensors. Comparison of such misfits indicates a gradually increasing error in the cumulative displacement derived from accelerometers, as predicted by the theory of error propagation, as well as differences in the final output even of identical sensors, a kind of self-noise, characterizing most sensors.

The overall approach is easy, with no cost and it can be easily implemented in teaching, either in projects or even in visualized examples in classroom.

***Keywords:*** *sensor; noise; error propagation; education*

# RTS MEASUREMENT OF AEROELASTIC EFFECTS ON A 30M-HIGH HISTORICAL INDUSTRIAL CHIMNEY

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We used a robotic total station (RTS, or robotic theodolite) with a frequency of 1-2Hz to measure the instantaneous deflections at the top of one of the three 30m-high historical brick chimneys in the Gazi area (historical center of Athens) because of wind excitation.

Measurements were made sighting on reflectors operational at the time of observations (May 2005), already established on the top and the middle of these chimneys in the framework of a project to monitor their subsidence and tilting during the excavation of a line of the Athens Metro.

Geodetic measurements were made under favorable meteorological conditions during several intervals, each a few hours long, during which the wind velocity was fluctuating between 3 and 12m/sec but with a nearly stable direction, as recordings with a frequency of 1min from the nearby Theseion NOA station indicate.

The output of this study is that during this rather common wind event deflections measured at the top of the chimney along the direction of the wind were within the noise interval (±1.5-2mm), while in a direction across the wind they were statistically significant, up to the order of 10mm. This indicates that the Gazi chimneys, 30m high and 3x3m wide at their base, are subject to aeroelastic effects, as is expected for tall and slender structures, although such deflections in other cases have wrongly been assigned to observation errors.

However, the correlation between dynamic deflections and variations of the amplitude/direction of the wind is not clear, probably indicating deflections due to gusts, not described by the available wind data, as well as excitation of the chimneys above a threshold of wind velocity.

***Keywords:*** *Robotic total station; Dynamic deflections; Structural Health Monitoring; Aeroelastic effects*

# DEFORMATION PREDICTION VIA THE NON-EQUIDISTANT GM (1,1) MODEL BASED ON TOTAL LEAST SQUARES ALGORITHM

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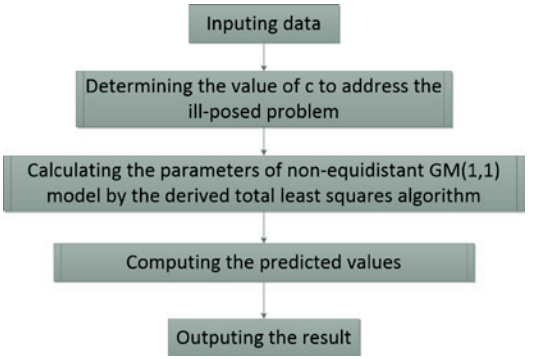
The GM(1,1) is a powerful technology for predicting the deformation of a construction and has been widely applied, because the clutter data can manifest regularity after being processed by the GM(1,1). In order to guarantee people's life and property security, it is important to monitor and predict the deformation of a construction. Therefore, many scholars dedicate to improve the prediction accuracy of the GM(1,1). The GM(1,1) is suitable for the data (called original sequence in the GM(1,1)) that are collected in equal time interval. However, it is hard to make sure that the original sequence is collected in equal time interval in practical application. Therefore, the non-equidistant GM(1,1) is proposed. Previously, the errors of the coefficient matrix were usually neglected, and a least squares algorithm was applied to estimate the parameters of the non-equidistant GM(1,1) model. In this paper, both the errors of the coefficient matrix and errors of the observation vector are taken into consideration, and total least squares adjustment is introduced to estimate the parameters of the non-equidistant GM(1,1). In addition, the random elements of the coefficient matrix and observation vector are from the original sequence, i.e., there are the same elements at different positions in the coefficient matrix and observation vector. In theory, these same elements with different positions should have the same error corrections. Moreover, the error corrections of the constant terms of the coefficient matrix should be zero. Motivated by these considerations, a total least squares algorithm is derived, which is suitable for the non-equidistant GM(1,1). The ill-posed problem is also discussed in this paper, which is negatively affect the parameter estimates, and a simple method is proposed to address the ill-posed problem. An engineering application is carry out to validate our method, and the results well demonstrate that our method is efficient and feasible. By our method, the ill-posed problem can be addressed and using the derived total least squares algorithm can obtain the better prediction accuracy.

***Keywords:*** *GM (1,1) model; total least squares; ill-posed problem; deformation monitoring*



# A MODEL OF VERTICAL LAND MOVEMENTS ALONG THE GERMAN COAST BASED ON A COMBINED SOLUTION OF GNSS AND InSAR DATA

**Dieter Tengen[1], Anika Riedel[1], Björn Riedel[1], Wolfgang Niemeier[1], Markus Gerke[1]**

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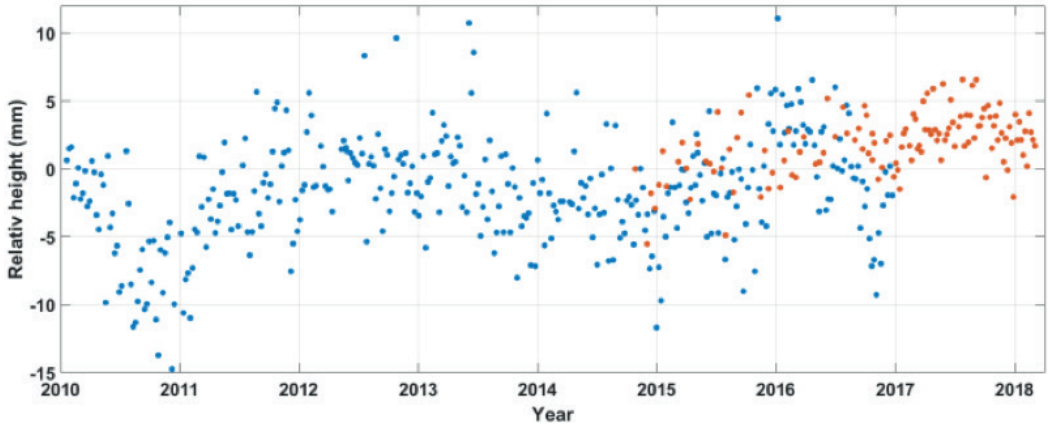
The development of a model for the description of vertical land movements in North Germany is an essential part within the project of „Investigations on the absolute sea-level rise on the German North Sea and Baltic Sea coasts" funded by Federal Ministry of Education and Research (BMBF). A major problem for the detection of absolute sea level changes is the relative character of tidal records. These water level data describe the changes of the mean sea level (MSL), but they also include the influence of vertical movements of the gauging stations and of ups and downs of the hinterland.

To take these two effects into account for MSL estimation we developed a model to describe subsidence and uplift effects in Northern Germany. On the one hand we processed a network of 180 GNSS stations including IGS, EUREF, GREF, SAPOS and gauge stations with GNSS from January 2010 until end of 2016. On the other hand we used radar data from October 2014 until October 2018 of the European satellites Sentinel-1a and -1b for Persistent Scatterer (PS) processing along a 50km wide corridor along the coast of North sea and Baltic sea.

In this presentation we will show the results from the GNSS data processing with the analysis of stable reference points, time series of different sites, as well as a complete velocity field from PS interferometry processing. The mathematical approach of the presented model is mainly based on a combination of different radial basis functions and includes pointwise GNSS and much denser PS information for an areal solution for vertical land movements in Northern Germany. This main result of the working group of Technische Universität Braunschweig will be used by the project partner of the Universität Siegen to improve tidal records of gauge stations.

***Keywords:*** *Modelling; Radial basisfunction; GNSS time series; PS Interferomtetry*



# THE CONTRIBUTION OF SENTINEL-1 DINSAR TO THE DETERMINATION OF VERTICAL DEFORMATION AND HEIGHT SYSTEM MONITORING

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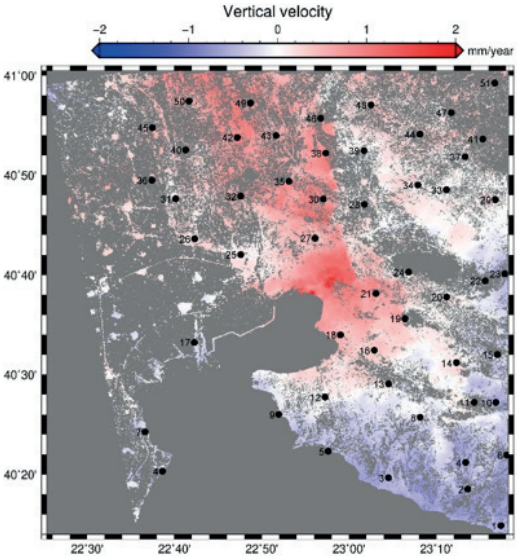
The city of Thessaloniki in Northern Greece has become a highly populated and heavily industrialized region. Due to its geographic location and geophysical seating, the city is dominated by almost continuous, but low in magnitude, tectonic activity, suggesting that the area must be subject to small but important displacements. The main objective of this study is to exploit the DInSAR technique for the detection and monitoring of those deformation phenomena, focusing on the vertical component, using data acquired by the Sentinel-1 constellation of satellites. A large set of ascending C-band Sentinel1-SAR images, covering the period between 2016 and 2018, was used for this purpose. To investigate the improvement of the interferometric deformation measurements, the SBAS (Small Baseline Subsets) algorithm was used, employing an advanced multi-pass DInSAR technique that combines unwrapped interferograms with small spatial and temporal baselines to minimize the topographic and atmospheric artifacts. The aim of this work is to use the such-derived vertical deformations as an apriori measure of corresponding potential deformations, the latter being the fundamental quantity needed for the definition and realization of a vertical datum. As a final step, prior measurements acquired by CORS GNSS stations located are compared with the DInSAR estimates to assess a more precise and validated vertical ground deformation model of the area.

***Keywords:*** *SAR; Sentinel-1; vertical datum; benchmark potential values; time evolution*



# IDENTIFYING BRIDGE DEFORMATION USING LASER SCANNING DATA

**Linh Truong-Hong**[1], **Roderik Lindenbergh**[1]
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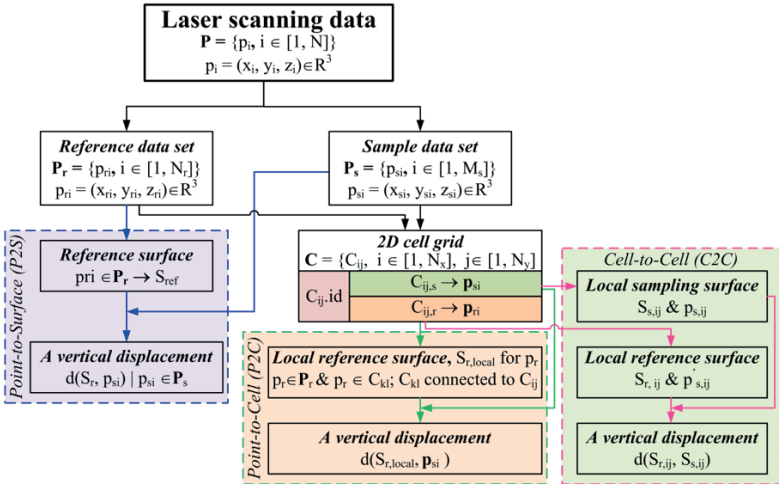
Increasing traffic weights and aggressive environmental conditions may result in unexpected deterioration of a bridge's components. Particularly, most bridges in Europe and US over half life span are affected by such impact. Structural deficiencies may cause partial or full collapse of bridges resulting in problems for human life, economy, society and environment. As such, deformation monitoring of the bridge's components has high priority in bridge inspection and assessment. Laser scanning has been used to capture the three-dimensional (3D) topographic surface of structures accurately and efficiently, which can be subsequently used to measure change of the structures. This paper introduces three approaches called point-to-surface (P2S), point-to-cell (P2C) and cell-to-cell (C2C) to measure the deformation of a structure using laser scanning data. This study also investigates the impact of the quality of a point cloud and selected surface or cell size to the achieved accuracy of deformation detection, which will be demonstrated through an implementation to measure the bridge's vertical clearance, which is the maximum vertical drop distance from the bottom of the bridge deck to the ground or water level.

***Keywords:*** *Bridge deformation; vertical clearance; laser scanning; point cloud; cell grid*



# MULTITEMPORAL SURFACE DEFORMATION ANALYSIS OF AMYNTAIO SLIDE (GREECE) USING REMOTELY PILOTED AIRBORNE SYSTEM AND STRUCTURE-FROM-MOTION PHOTOGRAMMETRY

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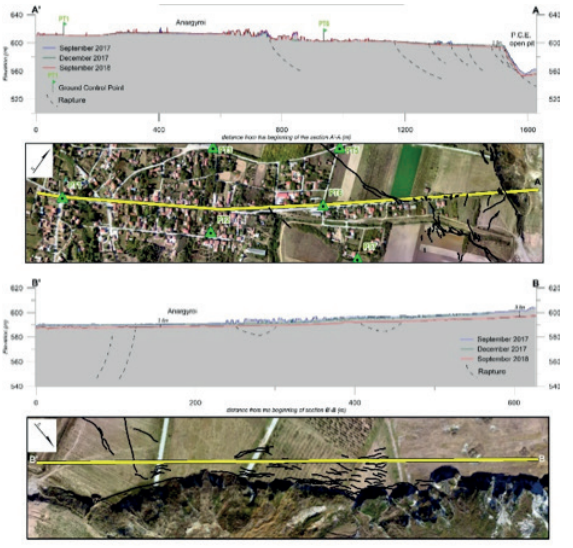
The results of Structure-from-Motion photogrammetry for the quantification of the ground surface deformation due to the massive landslide that occurred at the lignite open pit in Amyntaio, Greece on 10th June 2017, is presented in this paper. This unexpected slide damaged the entire westernmost marginal area of the pit, significant number of buildings and infrastructures (incl. road network, powerlines, biological treatment etc.) of the nearby village of Anargiri, as well as agricultural land at the head of the landslide. We generated a very high-resolution surface topography and corresponding co-registered ortho-rectified images covering a total area of 2 km2 by analyzing images acquired from Remotely Piloted Airborne Systems (RPASs). A high resolution (0.13 m) Digital Surface Model (DSM) was produced after photogrammetric processing, serving as a reference dataset for comparison with other surveys realized on December 2017 and September 2018. We compared the high-resolution DSMs acquired during the post landslide periods, quantified the overall ground deformation and finally delineated regions of potential risk.

***Keywords:*** *Amyntaio landslide; ground deformation; Remotely Piloted Airborne System; photogrammetry*



# DIAGNOSTIC SURVEYS OF DISPLACEMENTS OF A ROTATING PEDESTRIAN BRIDGE DURING ITS MOVEMENT

**Ireneusz Wyczałek[1], Michał Wyczałek[1], Elżbieta Wyczałek[1]**

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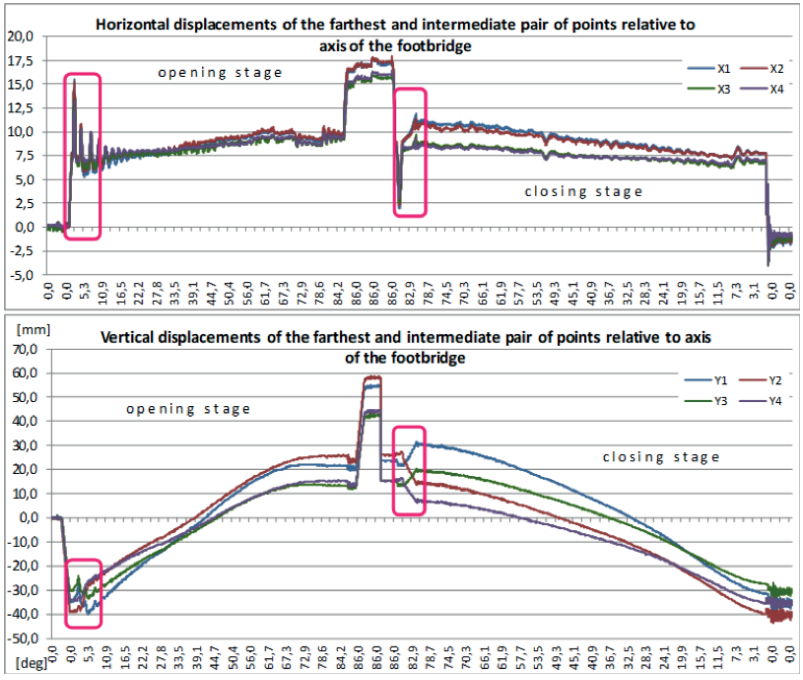
Innovative engineering structures are exposed to disturbances in their operation, especially under the influence of unexpected external factors. Sometimes this can lead to damage or cause threats to users. An example of such a construction is a rotating footbridge at the mouth of the Słupia River to the Baltic Sea, which under conditions of significant swelter began to fall into undesirable vibrations and crackles during rotation. The footbridge is suspended with steel cables to the swivel located on top of the supporting structure. In order to assess the phenomenon, a series of control measurements of selected elements of the footbridge were made during its opening and closing procedure. Among them, the most relevant information was obtained from TS measurement, inclinometry and photogrammetric image analysis. The use of biaxial inclinometers directly on the footbridge allowed identifying its lateral tilts during rotation. The size and the nature of the footbridge vibration were determined by photographic recording of displacements of two pairs of LED lights using a fast digital camera located on the platform in its axis of rotation. The article presents technical problem and related aspects, discusses the course of research, presents the results obtained and formulate main conclusions. Resolving all these aspects illustrate how a surveyor choosing different available measurement techniques can carry out measurements in order to detect an incomprehensible phenomenon.

***Keywords:*** *footbridge tests; total station; inclinometers; image analyses; engineering inference*



# MONITORING OF THE STATIC AND DYNAMIC DISPLACEMENTS OF RAILWAY BRIDGES WITH THE USE OF THE TOTAL STATION AND SET OF THE ELECTRONIC INCLINOMETERS

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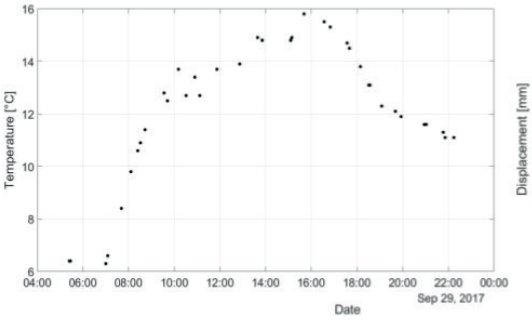
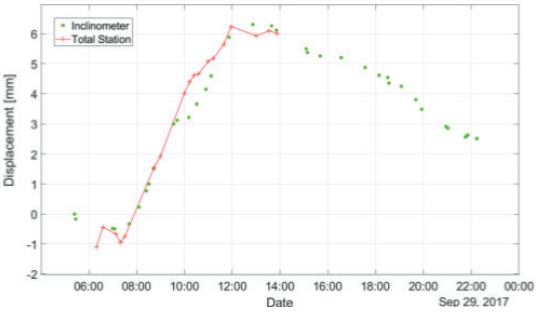
In the case of monitoring of bridges, the determination of vertical displacements is one of the most important issues. New measuring system was developed and implemented to assess the technical condition of railway bridges and viaducts based on measurements of the construction response to passing trains. The system uses inertial sensors: inclinometers and accelerometers, which do not need any referential points. During the passage of a train all the signals from the sensors are registered by a central unit and then sent to a server via Internet. Measured values of displacements and accelerations are compared with the results of the model analysis, which allows the assessment of the current condition of the bridge. Static displacements referenced to the external coordinate system are measured independently at a certain time interval using Total Station. An automatic mode of measurement to the group of prisms installed on the bridge was used in presented project. Three fixed points has been marked as a reference – one of them serves as a directional and refractive point. Based on observations to this distant point, a temporary refraction was taken into account in calculations of displacements. The tests were carried out on a viaduct along high-speed railway line. Results of tachymetric surveys were compared to readings of static component from inclinometers measured before entering the train. Analyzes were conducted on the possibility of the use of inclinometers to static displacement measurements.

***Keywords:*** *bridge monitoring; dynamic displacements; total station; MEMS*



# ACCURACY OF $M_{SPLIT}$ ESTIMATES IN THE CONTEXT OF VERTICAL DISPLACEMENT ANALYSIS

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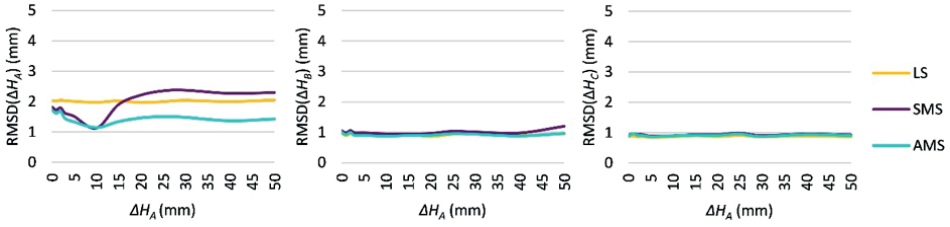
$M_{split}$ estimation is a development of M-estimation which can also be applied in deformation analysis. This paper concerns two types of such an estimation: squared $M_{split}$ estimation (SMS), which is based on the assumption of normality of the observation errors and absolute $M_{split}$ estimation (AMS), which is based on $L_1$ norm criterion. The main objective of the paper is to assess the accuracy of such estimators in the cases of analysis of vertical displacements of network points (or object points). The estimators in question are not linear, and the theory of estimating their accuracy has not been accomplished yet, hence we apply the Monte Carlo simulations to achieve the main objective of the paper. Another interesting issue is to compare the accuracy of SMS estimation with the accuracy of AMS estimation but also with the accuracy of the traditional least squares estimation (LS). Generally, AMS estimates have a better accuracy than SMS estimates. In many cases the accuracy of both $M_{split}$ estimates is similar to the accuracy of LS estimates. However, if there are some nonrandom errors in the observation sets then there are some cases when the accuracy of AMS estimates is better than the accuracy of the rest of the estimates considered here. It stems from the fact that AMS estimates are robust against disturbances which have a small magnitude. It is also worth noting than the accuracy of both $M_{split}$ estimates might also depend on the values of the point displacements; however, such an influence might be varied for different network points or network shapes themselves. The paper presents some empirical analysis in such a context.

***Keywords:*** *Vertical displacement; $M_{split}$ estimation; accuracy; deformation analysis; Monte Carlo simulations*



# PERFORMANCE ANALYSIS OF BRIDGE MONITORING WITH THE INTEGRATED GPS, BDS AND GLONASS

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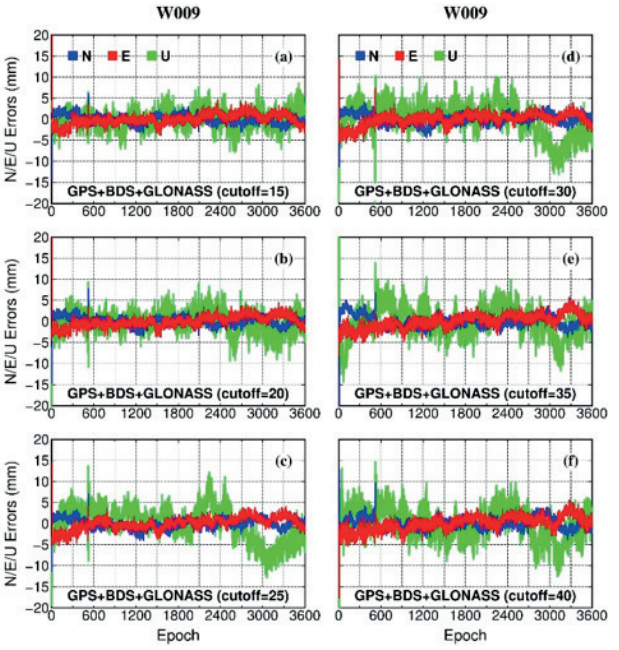
In present, Global Navigation Satellite System (GNSS) technology has been widely applied as an essential part of a SHM system. With the BeiDou Navigation Satellite System (BDS) becoming available in Asian-Pacific region and the full operation of the GLONASS system, multi-constellation GNSS tend to be the best choice in the SHM systems. The paper presents an SHM experiment on the Baishazhou Yangtze River Bridge in Wuhan, China with the integrated GPS, BDS and GLONASS observations to analyze its performance. Firstly, the precision metrics that a single GNSS system, the integration of two systems and the combined GPS/BDS/GLONASS could be achieved are compared with the bridge monitoring data. It shows that, with more satellites available and the strongest satellite geometry, the combined GPS/BDS/GLONASS gives the highest precision, with 1-2 mm horizontal and 2-5 mm vertical precision. Then, with the integration of GPS/BDS/GLONASS, different elevation cutoffs are set to figure out the best elevation cutoff in the data processing in the bridge monitoring application. The results demonstrate that the precision in horizontal component can always achieve to 1-2 mm level with the rising cutoff elevation angles, and when the cutoff angle of 40° is selected, the precision in horizontal component can still achieve to 1-2 mm level. A vibration test was carried out in the experiment. It shows that the noise level of the solutions from the integrated GPS/BDS/GLONASS is the lowest, which can greatly benefit the modal parameter estimation.

***Keywords:*** *Integration of GPS; BDS and GLONASS; Bridge deformation monitoring; Monitoring precision; Elevation cutoff; Vibration testing*



# INVESTIGATING THE ABILITY OF HIGH-RATE GNSS-PPP FOR DETERMINING THE VIBRATION MODES OF ENGINEERING STRUCTURES: SMALL SCALE MODEL EXPERIMENT

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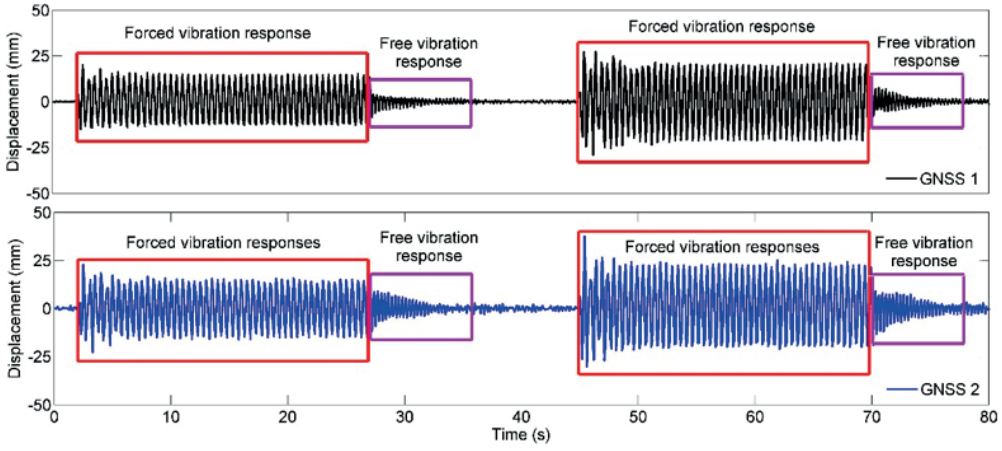
This study evaluates the performance of the Precise Point Positioning method using Global Navigation Satellite System measurements (GNSS-PPP) for monitoring vibration modes of shear type buildings excited by harmonic ground motions and hammer tests. For experimental testing, the shear type lumped-mass building system is represented by a specially designed metal frame model, resembling a three story building, which was excited on a small scale shaking table. The excitation protocols applied were harmonic motions with different frequencies and amplitudes. The metal model has special deformation plates at the column tips to prevent the nonlinear rotations and out-of-plane motions for the entire system. The fundamental vibration periods of the model structure were computed by a Finite Element Mathematical (FEM) model, which were compared with the position variations determined by GNSS-PPP. Two GNSS receivers were mounted on top of the model structure on the line perpendicular to the motion axis to measure the prevented rotation motion. The GNSS data comprised dual-frequency observations with a 10 Hz sampling rate. GNSS-derived positioning was obtained by processing the data using a post-mission kinematic PPP method with fixed phase ambiguities. Analysis of the characteristics of the vibration frequencies showed that the high-rate GNSS PPP method can capture the frequencies of first motion mode of shear type structural response when compared with the FEM output. Results demonstrate the efficiency of the high-rate GNSS PPP method in monitoring first motion mode of a natural frequency.

***Keywords:*** *Kinematic PPP; GNSS; Structural Health Monitoring; FEM*



# THE USE OF GEODETIC TECHNIQUES IN STABILITY MONITORING OF FLOATING STRUCTURES

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The stability of a ship is one of the most important concepts about the vessel's performance, seaworthiness and safety. Any vessel must fulfil the intact stability criteria set by international maritime codes and regulations.

Stability is the way the vessel floats after loading and some of the stability criteria refer to the metacentric height (GM) and the area under the righting lever curve. The stability characteristics of a specific vessel are usually determined by carrying out the inclining experiment with a main purpose being to measure the lightship weight of the ship. This is implemented having the vessel inclined in the transverse direction using known loads.

This paper describes the use of geodetic measurements in monitoring the inclination of a vessel during the inclining experiment. This is performed in a model vessel with dimensions of overall length overall 3.19m, breadth 41.50cm and moulded depth 24.50cm. The model vessel was floating in calm water and zero heel angle in a water tank of length 11m, width 1.35m and height 0.80m.

Initially, the geometric documentation of the vessel was performed using terrestrial laser scanning measurements and an accurate 3D digital model was created. At the second stage, the inclining experiment was performed, by placing a number of different loads in the vessel in order to estimate the heel angle. The pendulum method was used to measure the inclined angles.

During the inclining experiment special targets were placed on critical points of the vessel and continuous measurements were obtained at different conditions of loading. Two robotic total stations were performing in real-time the monitoring of the targets. The measurements provided from the pendulum method and the geodetic measurements were compared in terms of accuracy and time.

***Keywords:*** *laser scanner, robotic total station, moving platform, inclining experiment*

# THE SIGNIFICANCE OF 3D NETWORK ADJUSTMENT BY USING DIFFERENT LEAST SQUARES METHODS FOR THE CONSTRUCTIONS' MONITORING APPLICATION ON THE MONITORING NETWORK OF THE HOLY AEDICULE IN JERUSALEM

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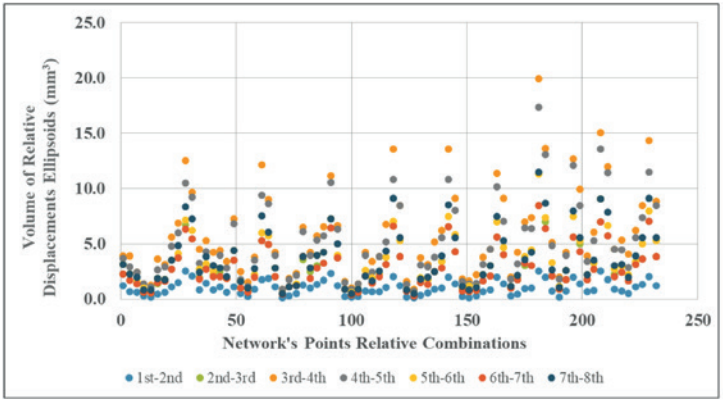
This paper deals with the comparison of the minimum constraints of the least squares methods that are used for the adjustment of a 3D monitoring network. The comparison is applied for the 3D geodetic network that was established in the site of the Holy Aedicule of the Holy Sepulchre in Jerusalem during the rehabilitation works (2016 - 2017). The permanent 3D monitoring geodetic network was implemented with special benchmarks. This network was measured at 8 different times from July 2016 to January 2017, in order to allow the displacements' control of the network.

Two methods of minimum constraints adjustment are studied, minimum external and inner constraints. The main difference between these methods is the way each of them overcomes the datum deficiency. External constraints require a minimum of known point coordinates and line direction, while inner constraints overcome control problem by using a set of constraints equations.

The network of the Aedicule is being adjusted for every phase, using both methods of minimum constraints. Adjusting the Holy Aedicule network with the external constraints, the accuracy of the determination is better than ±1mm for 95% confidence level, while the absolute and relative displacements are calculated using triaxial ellipsoids. Absolute displacements are equal to 4.1mm. Using inner constraints, the accuracy of determination is better than ±0.5mm for the same confidence level and the absolute displacements equals to 3.8mm.

Through error ellipsoids is proven that inner constraints lead to absolute error ellipsoids 60% smaller than using external constraints, while the displacement vectors do not differ notably, concluding that the sensitivity (i.e. possibility to detect displacements) of the network increases. The results are visually presented with diagrams.

***Keywords:*** *Jerusalem; Holy Aedicule; monitoring; minimum constraints; adjustment; ellipsoid; sensitivity; accuracy*



# INVESTIGATION OF THE RELATIONSHIP BETWEEN RAINFALL AND LONG-TERM SETTLEMENTS OF AN EARTHFILL DAM BASED ON GEODETIC MEASUREMENTS

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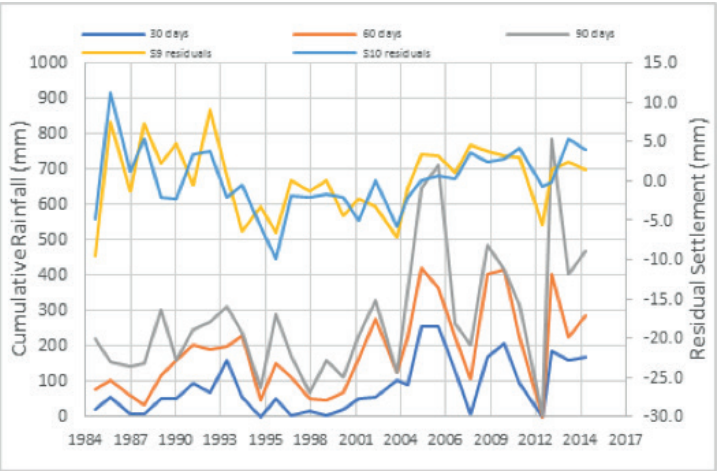
Ageing earthfill dams become vulnerable to weather phenomena such as rainfall and flooding, with severe consequences, economic and life threatening, to the communities living downstream. A better understanding of their long-term behaviour and the factors affecting it, is crucial.

A unique data set was used, consisting of the crest settlements of an earthfill, central clay core dam, the Pournari I dam in Greece, and the rainfall height values at the dam site between 1981 and 2015. The dam is 107 m high and its construction was completed in 1981. In previous studies the settlements of this dam, including rates, were found to be within limits and compliant with empirical relationships derived for dams of this type.

In this work we remove the effect of primary consolidation and creep from the settlements and attempt to study the relationship between the residuals and rainfall. We find that consolidation was completed within 4 years since the end of construction (by 1985) and residuals of all points on the crest appear to follow the same evolution pattern. While no direct relationship could be established between the actual settlement observations and the rainfall, residuals seem to have maximum correlation with the cumulative rainfall height over a period of two months before the settlement measurement epoch. Our findings most likely represent a threshold value of rainfall above which the dam seems to be responding rather than a time duration over which rainfall plays an important role to the settlements of the dam.

***Keywords:*** *earthfill dam, rainfall, crest settlements, long-term geodetic monitoring*



# REDUCING MULTIPATH EFFECT OF LOW-COST GNSS RECEIVERS FOR MONITORING BY CONSIDERING TEMPORAL CORRELATIONS

**Li Zhang**[1], **Volker Schwieger**[1]

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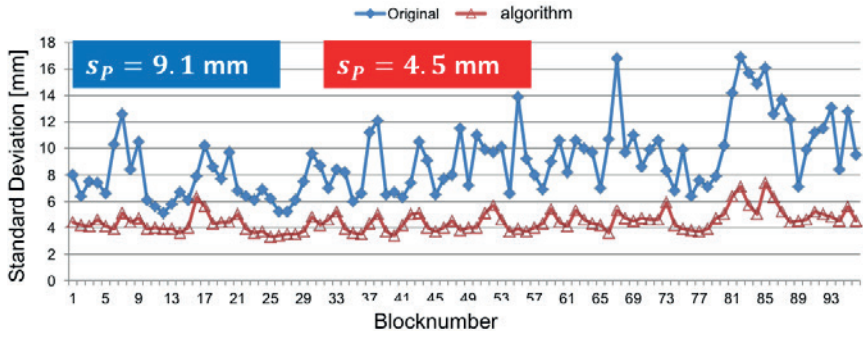
The investigations on low-cost single frequency GNSS receivers at the Institute of Engineering Geodesy (IIGS) show that u-blox GNSS receivers combined with low-cost antennas and self-constructed L1-optimized choke rings can reach an accuracy which almost meets the requirements of geodetic applications (see Zhang and Schwieger, 2017). However, the quality (accuracy and reliability) of low-cost GPS receiver data should still be improved, particularly in environments with obstructions. The multipath effects are a major error source for the short baselines. The ground plate or the choke ring ground plane can reduce the multipath signals from the horizontal reflector (e.g. ground). However, the shielding cannot reduce the multipath signals from the vertical reflectors (e.g. walls).

Because multipath effects are spatially and temporally correlated, an algorithm is developed for reducing the multipath effect by considering the spatial corrections of the adjoined stations (see Zhang and Schwieger, 2016). In this paper, an algorithm based on the temporal correlation will be introduced. The developed algorithm is based on the coordinates not on carrier phase raw data, which is easy to use. Because, for the users, coordinates are more accessible than the raw data. So that the algorithm is un The multipath effect can cause periodic oscillations but the periods change over time. Besides this, the multipath effect's influence on the coordinates is a mixture of different multipath signals from different satellites and different reflectors. These two properties will be used to reduce the multipath effect. The algorithm runs in two steps and iteratively. Test measurements were carried out in a multipath intensive environment; the accuracies of the measurements are improved by about 50% and the results can be delivered in near-real-time (in ca. 30 minutes), therefore the algorithm is suitable for structural health monitoring applications.

***Keywords:*** *Low-cost GNSS; multipath-effect; temporal correlations analysis; monitoring*




# Poster presentations
## abstracts

# 2014 Mw 6.5 GÖKÇEADA EARTHQUAKE DEFORMATION ANALYSIS WITH GEODETIC AND GEOPHYSICAL METHODS

**Duygu Akyürek**[1], **Serdar Erol**[1], **Murat Merdivan**[1], **Bihter Erol**[1]

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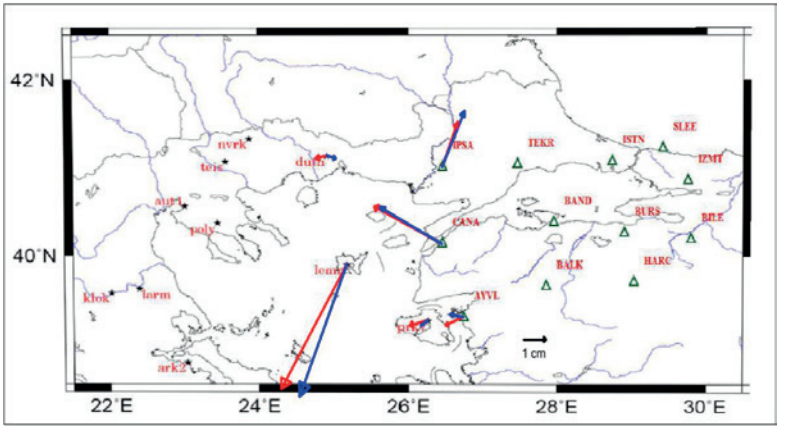
On 24 May, 2014 12:25 (09:25 UTC) in local time of Turkey, the Mw.6.5 Gökçeada earthquake occurred in Aegean Sea (offshore of Gökçeada) and also epicenter coordinates of earthquake were 40.2108 N, 25.3073 E. Gökçeada earthquake was felt in both Aegean and Marmara regions and it lasted 42 seconds. Additionally, 405 aftershocks occurred within the first 48 hours after the earthquake.

In order to determine the deformation in affected areas after earthquake, displacements of 6 permanent Global Navigation Satellite System (GNSS) stations were investigated by using GNSS data. The data obtained from the affected GNSS stations in the study area were evaluated by considering the earthquake region. GNSS data obtained from GNSS networks which are National Observatory of Athens GNSS Network (NOANET), European Reference Frame (EUREF) and CORS-TR (TUSAGA AKTIF) were solved by internet based GNSS evaluation services in Online Positioning User Service (OPUS) and Canadian Spatial Reference System-Precise Point Positioning (CSRS-PPP) services with static and kinematic methods. One-week GNSS dataset which contained pre-seismic, co-seismic and post-seismic effects of earthquake were solved by using one-week daily dataset for static processing solution and 6-hour and 3-hour time series for kinematic processing solution. Furthermore, the seismic sensor data of Gökçeada earthquake were obtained from database of The National Strong Motion Network of Turkey (TR-NSMN). The maximum acceleration values recorded during the earthquake were converted to the velocity values by Mercalli intensity. As a result of the study, the maximum deformations were determined at CANA, LEMN and IPSA stations, which are close to the epicenter of the earthquake. The coordinates obtained from the OPUS and the CSRS-PPP services were similar to each other, with no difference more than the millimeter level.

***Keywords:*** *Gökçeada Earthquake; Crustal Deformation; Permanent GNSS Networks; Web-based GNSS Services; Precise Point Positioning*



# ACCURACY ASSESSMENT OF MULTI-GNSS PRECISE POINT POSITIONING

**Duygu Akyürek[1], Serdar Erol[1], Asude Meryem Karaç[1] , Bihter Erol[1]**

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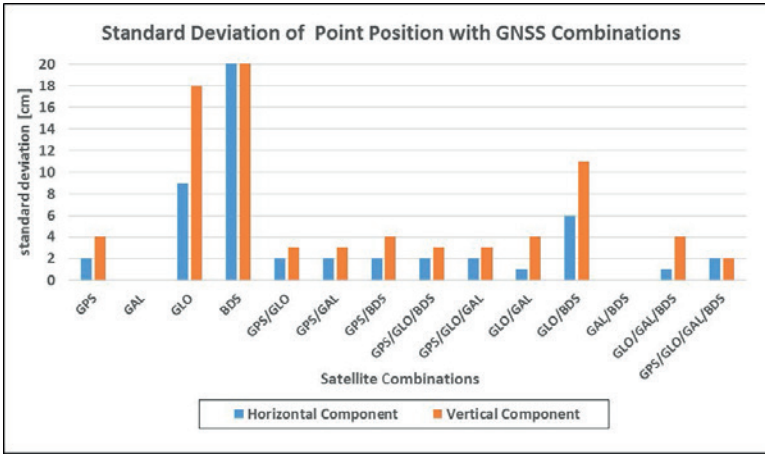
The necessity and demand of more accurate position information has been increased along with evolving technology and increasing needs. Precise Point Positioning (PPP) method provides more accurate Global Navigation Satellite System (GNSS) solution by using precise orbital and time information with a single GNSS receiver. Several web based and desktop software services are available to provide PPP solutions at centimeter to decimeter level. Furthermore, these services are classified as commercial, open source or academic purposes. Some of web based PPP evaluation services are Canadian Spatial Reference System-Precise Point Positioning (CSRS-PPP), Automatic Precise Positioning Service (APPS), GNSS Analysis and Positioning Software (GAPS), MagicGNSS, Trimble RTX and the desktop based PPP software is GNSS Analysis software for Multiconstellation and multi-frequency Precise Positioning (GAMP).

In this study, considering these developments, the positioning performance of the PPP method was investigated with using GPS, GLONASS, GALILEO and BeiDou (BDS) systems in combination and separately. For this purpose, the date of August 2, 2017 (day 214 of 2017), two observation data of RTXS and ISTA International GNSS Service (IGS) stations which are in Turkey were used. RTXS station GNSS data in 1 second interval for approximately 80 minutes and ISTA station GNSS data in 30 seconds interval for 24 hours were used. Additionally, precise orbit and clock information from Multi-GNSS Experiment (MGEX) were used in GNSS solution. The GAMP software was used to examine the effect of Multi-GNSS on PPP performance. This software was developed to implement the Multi-GNSS PPP solution, which includes GPS, GLONASS, GALILEO and BDS. In addition, the effect of Multi-GNSS solutions on the position components obtained from the PPP technique was examined by means of accuracy and convergence time. The results show that Multi GNSS PPP solutions improve position accuracy and convergence time than single GNSS-PPP solutions.

***Keywords:*** *Multi-GNSS*



# INVESTIGATION OF THE OPTIMUM MINIMUM INPUT DATA FOR THE FORECASTING OF 3D POINT POSITION CHANGING, USING NON-LINEAR AUTOREGRESSIVE NEURAL NETWORKS

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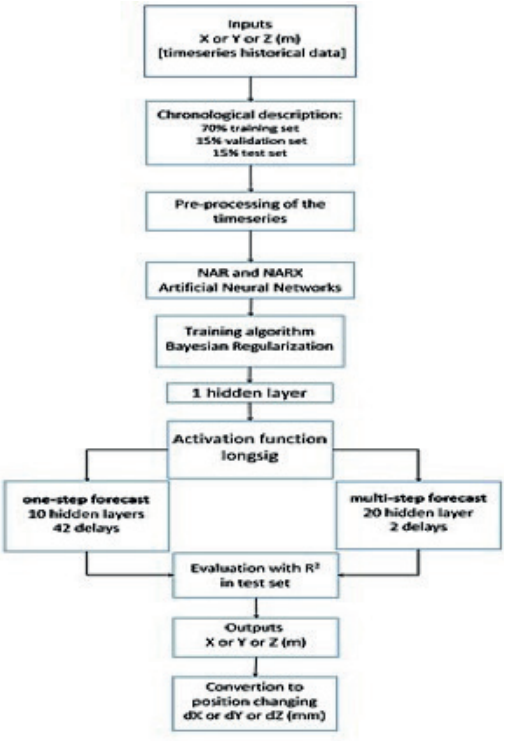
One of the most attractive and popular intelligent techniques in the scientific community, lately, is the Artificial Neural Networks (ANNs). They have been globally used in most disciplines (e.g., Economics, Medicine, Engineering) in order to solve difficult and complex problems neither as a new method nor as a complementary, more effective one. As it was expected, ANNs have been also introduced in numerous geodetic fields such as regional mapping of the Geoid, sea level forecasting, coordinate transformation, deformation monitoring etc. As far as the deformation monitoring is concerned ANNs have recently been used in the position changing forecast problem. In particular, a methodology, based on Non-Linear Autoregressive (NAR) and non-linear autoregressive with eXogenous inputs (NARX) Neural Networks, has been developed in order to provide forecasts for point position changing. A question that emerged applying this methodology was the investigation of the optimum minimum number of available input data. The research reported in this paper aims to investigate this number, so that the produced short-term and long-term forecasts would have acceptable Mean Absolute Error (MAE), depending on the order of the individual position changing. The idea behind this research is mainly based on the probability of lack of access to big data. Experiments with different number of daily continuous data from GNSS permanent stations, starting from 3190 daily records, were carried out. Results reveal that the number of inputs plays an important but not crucial role during implementation of the methodology. It was concluded that reliable forecasts could indeed be produced using smaller number of input data

***Keywords:*** *Artificial Neural Networks (ANNs); Geodesy; position changing; forecasting; non-linear autoregressive recurrent network (NAR); non-linear autoregressive with eXogenous inputs (NARX)*



# A NEW GPS-DERIVED DATABASE FOR CO-SEISMIC DISPLACEMENTS IN THE AEGEAN AREA AND ITS GEODYNAMIC SIGNIFICANCE

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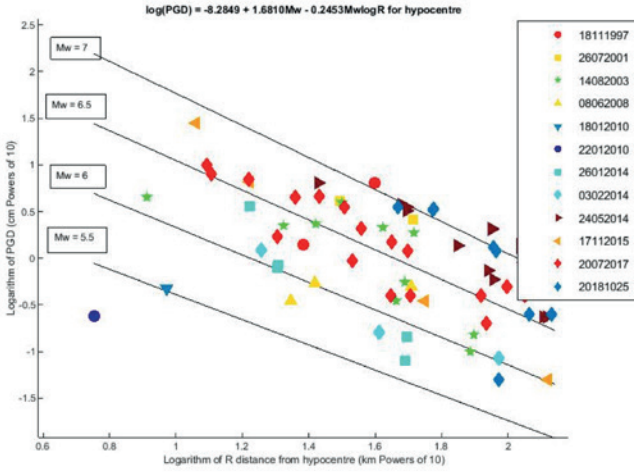
GNSS (GPS) technology is new method to measure surface deformation resulting from earthquakes. In this contribution we describe a dataset of co-seismic displacements for significant earthquakes in Greece during the period 1997-2017, measured with GPS dual-frequency receivers and discuss its geodynamic significance. We include recordings from GNSS networks (such as NOANET operated by the National Observatory of Athens - NOA) at near-source to regional distances (up to 140 km) for eleven (11) earthquakes between moment magnitudes (from the global CMT catalogue of $M_w$) 5.5 and 6.9. All earthquakes were shallow and created geo-environmental effects including surface deformations. The GPS displacement data range from several mm up to tens of cm in size and were obtained by rigorous processing of raw observations using double-difference or precise-point-positioning techniques. The results were published by various authors in peer-reviewed journals and earthquake reports. This dataset can be used by geologists, engineers and seismologists towards a better understanding of the mechanics of ground deformation, the shallow faulting process, the earthquake rupture mechanics, and in engineering applications. We also investigate the geodynamic implications of this data by modelling the scaling properties of peak ground horizontal displacements (PGD). We are interested in the relation in log-log space between PGD (for these strong events) with corresponding earthquake magnitude and distance from hypocentre. We model the scaling relations using L1-norm minimisation regression (see Fig.1 below). Our data indicate a linear attenuation of seismic strain with distance for this range of earthquake magnitudes.

***Keywords:*** *GNSS; deformation; Greece; earthquake; scaling*



# A METHODOLOGY INVESTIGATION FOR A SEMI-KINEMATIC DATUM REALIZATION IN GREECE COMBINING GEODETIC AND GEOLOGICAL DATA

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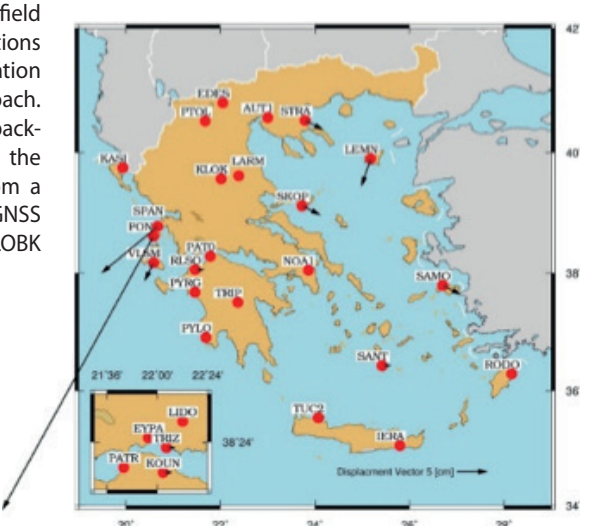
Greece is one of the most active geodynamic areas in the world with variety of type faults and geomorphological features, (e.g. North Anatolian Trough, Cephalonia Transform Fault etc.) which effects to Terrestrial Reference Frame (TRF) realization. Last years, the need of a new modern geodetic reference frame become more and more obvious, in order to replace the Greek Geodetic Reference System 1987 (GGRS'87) which is the official national geodetic datum. The GGRS'87 is a static TRF and have been implemented with classical geodetic techniques in trigonometric benchmarks (BMs). In addition, the measurements have been executed in a long period of about five decades ago. The main scope of the present study is on one side to show up the influence of the earthquake events in a modern TRFs such as, the International Terrestrial Reference Frame 2014 (ITRF2014) and on the other side to provide a methodology which treats this issue in a semi-kinematic datum, exploit the GNSS permanent networks. We proposed a modern approach that combining geodetic and geological techniques in order to improve the estimation of deformation field after strong earthquake events using observations as obtained from GNSS stations and dislocation modeling following the theoretical Okada approach. An essential parameter, in order to do the back-wise analysis in a semi-kinematic datum, is the geodetic velocity estimation which derived from a daily GPS/GNSS time series analysis. The GPS/GNSS data processing was carried out with GAMIT/GLOBK software package following all the recommendations of IGS. For coordinate time-series analysis (covering a time span of more than 16 years) we use firstly, a simply linear trend with the assumption that all error sources characterized as a white noise. Secondly, we apply an automatic robust estimator Median Interannual Difference Adjusted for Skewness (MIDAS) which is resistant to common problems (e.g. discontinuities, outliers, seasonality). Analyzing the post-seismic displacements for three greater seismic events in the Greek area (Samothrace, Lefkada and Cephalonia) of the period of 2012 – 2016 in a network of 47 cGPS sites, we found that have an impact of 33.5 cm on 3D position estimation for the Lefkada seismic event. According to the proposed methodology, which considers the EQ offsets in GNSS position time series, the improvement in 3D position is treated on sub-centimeter level.

***Keywords:*** *Crustal deformation; GNSS time-series; Geodetic datum; Geodetic velocities; GNSS Permanent network*



# METHOD FOR CONFIRMING MONITORING SYSTEM ACCURACY

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Often tender specifications include requirements for monitoring system accuracy. Usually these specifications do not include a clear description or method statement of how these accuracies should be tested. In addition, some uncertainty remains about what the specifications imply, and the terms 'accuracy', 'stability' and 'sensitivity' are used interchangeably.

Using a pre-analysis application of the least-squares adjustment method, it is possible to estimate expected accuracy, based on instruments specifications and network geometry. This allows for pre-installation planning of instrument numbers and locations, while allowing for site specific constraints like line-of-sight, and physical access to ideal locations. After installation it may be required to show that the specifications are met. For this purpose, system accuracy is separated into stability accuracy and sensitivity accuracy. If both these parts can be proven to comply to the general accuracy specifications, the conditions are met.

In a static case the determination of the stability accuracy is trivial. A number of samples are taken, and statistical analysis easily shows estimators for accuracy. However, in a dynamic structure this test is somewhat more complex. Sensor positions change over time, and statistical analysis must be remodeled to eliminate the apparent noise induced by seasonal dynamics.

In order to test the sensitivity accuracy, a method was developed employing a measuring slide, with X-Y movement, and micrometer scales for precise displacements. This allows for artificially inducing small displacements, and measuring the system response. The method considers the internal seasonal dynamics of the object, and applies sample size calculations to determine the minimum time required to arrive at a reliable quantity. In addition to the displacement values, analysis of the unaffected points was performed to establish independence of sensors. Finally, analysis of the ability of the system to return to the undisturbed state after the test period was completed to ensure resilience.

***Keywords:*** *Specifications; Accuracy; Sensitivity; Testing Method; Displacements*

# PRELIMINARY RESULTS ON POTENTIAL DEFORMATIONS OCCURRING ON SLOPES OF MAJOR HIGHWAYS BY ANALYZING SENTINEL 1 IMAGES

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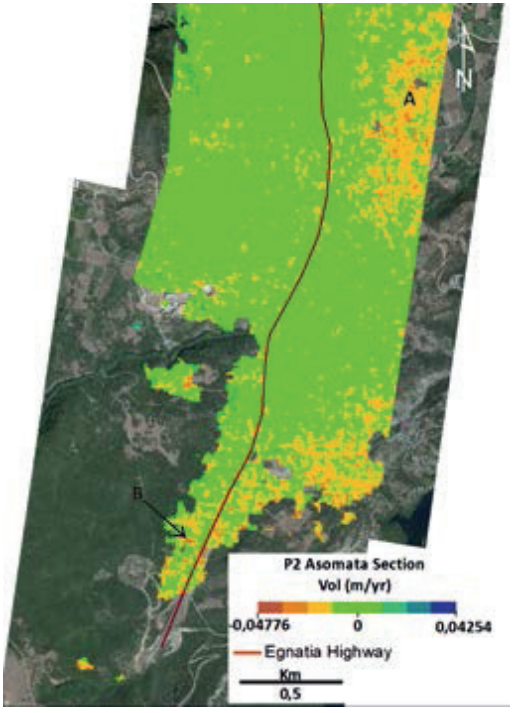
Last decades, there is a growing evolution in using satellite images and remote sensing methods for monitoring and studying instability phenomena, the occurrence of which have large social and economic cost, especially when affecting inhabited and under exploitation areas or roadways. In this paper, preliminary results of applying a Multitemporal SAR Interferometry methodology, using Copernicus Sentinel 1 scenes, in order to study Asomata and Lefkopetra sections of Highway in Greece, are presented. The methodology applied is a hybrid SBAS type that uses SVD algorithm. It was chosen because areas under investigation are mountainous and covered by trees, thus with lack of scatterers. For scene processing and methodology application, Gamma Remote Sensing Software was used. Two time periods, January 2016 to August 2017 (P1) and January to April 2018 (P2) are examined. For period P1, 22 ascending and 23 descending S1A scenes and for P2, 20 ascending and 20 descending S1A and S1B scenes have been processed, with time interval of 30 and 6 days respectively. The results obtained are deformation measurements projected along LOS direction and were analyzed for calculating the total velocity components. Evaluating the results, proved that time interval between successive scenes plays significant role in terms of results quality and coverage, especially in mountainous areas. Deformation phenomena in progress related to landslides, affecting the Highway, were not detected. Of course, in situ investigation is needed. Indicatively, results for Asomata section of P2 period are presented in the figure. Deformation phenomena appearing South of Asomata village (A), related to a land subsidence zone, does not affect the Highway.




***Keywords:*** *Deformations; Highways; Slopes; Sentinel 1; Multitemporal SAR Interferometry*

# LINEAR AND NON-LINEAR DEFORMATION EFFECTS IN THE PERMANENT GNSS NETWORK OF CYPRUS

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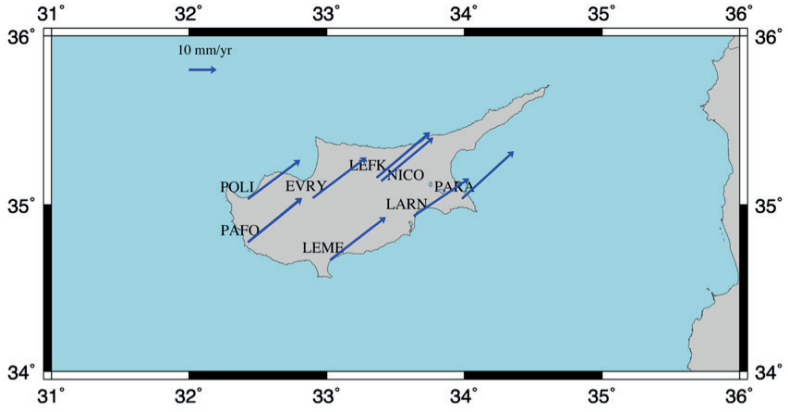
Since 2008 a geodetic network of seven permanent GNSS reference stations is operating in the island of Cyprus under the auspices of the Department of Lands and Surveys. The network covers the entire country with inter-station distances of about 60 km, and it supports the needs for various surveying engineering applications. The continuous character of positioning data that are systematically collected over this network offer rich information to investigate the behaviour of the crustal deformation field in Cyprus, yet no relevant geodetic studies on this topic have been performed up to now. This paper presents, for the first time, the scientific results by a multi-year analysis (2011-2018) of daily GNSS data in the aforementioned network, leading to precise estimates of linear and nonlinear deforming effects caused by geophysical phenomena of different nature. In particular, 3D station velocities and seasonal periodic displacements are jointly estimated via a time-series stacking approach with respect to the ITRF2008 reference frame. Furthermore, the derived station velocities are used to determine the main characteristics of the strain-rate field within the GNSS permanent network, and to assess its spatially varying structure in relation to known geological information. The implications of the findings of our work for: (a) current geodetic and surveying applications in Cyprus, and (b) the establishment of a new national long-term geodetic reference system in support of high accuracy (mm-level) applications, are finally discussed.

***Keywords:*** *GNSS; Geodesy; Crustal Deformation; Strain; Cyprus*



# APPLICATION OF MERGING MODEL BASED ON MEA+BP IN DAM DEFORMATION ANALYSIS

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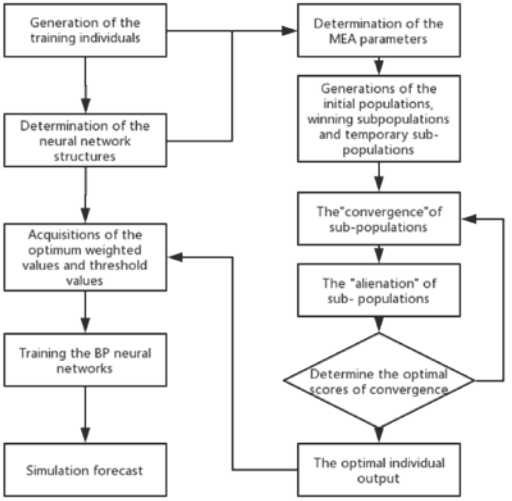
Dam deformation monitoring is a key component of dam safety monitoring system. Establishing an effective and reliable dam deformation prediction model is very important for timely understanding of dam deformation state and ensuring its safe operation. Traditional statistical models are often used for dam deformation analysis and prediction. In order to improve the prediction accuracy and test the generalization of the dam deformation analysis model, the back-propagation(BP) neural network optimized by mind evolutionary algorithm(MEA) is studied. Considering the error compensation technique, the merging model is built based on the neural network BP algorithm optimized by MEA. The three models mentioned above are calculated and analyzed according to the long-term deformation observation data in Chencun Dam. The results show that the average prediction accuracies of the statistical model and the BP neural network model are ±0.5220 mm and ±0.4289 mm, while the merging model based on the error compensation technique is the smallest, with an average of ±0.3753 mm, which is improved by 12% and 28% compared to the other two models. The merging model has a better generalization ability and broad applicability.

***Keywords:*** *dam deformation analysis; statistical model; BP neural network; mind evolutionary algorithm; merging model*




| Key points | Statistical model | | MEA+BP model | | Merging model | |
|---|---|---|---|---|---|---|
| | MAD | RMSE | MAD | RMSE | MAD | RMSE |
| 5#104 | 0.2677 | 0.3199 | 0.1958 | 0.2496 | 0.1498 | 0.1938 |
| 11#110 | 0.3544 | 0.4402 | 0.3049 | 0.3809 | 0.2887 | 0.3561 |
| 12#112 | 0.5102 | 0.6134 | 0.3582 | 0.4430 | 0.3407 | 0.4227 |
| 14#114 | 0.5202 | 0.6435 | 0.3785 | 0.4979 | 0.3589 | 0.4594 |
| 16#116 | 0.4481 | 0.5490 | 0.3539 | 0.4398 | 0.3377 | 0.4211 |
| 18#118 | 0.4557 | 0.5660 | 0.3867 | 0.5022 | 0.3457 | 0.3989 |
| AVG | 0.4261 | 0.5220 | 0.3297 | 0.4289 | 0.3036 | 0.3753 |

# EMPIRICAL INFLUENCE FUNCTIONS OF DIFFERENT ROBUST ESTIMATION METHODS APPLIED IN DISPLACEMENT ANALYSIS

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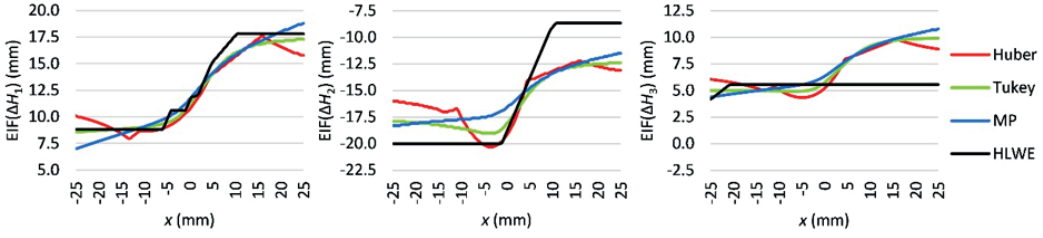
Robust methods of estimation might have different foundations, necessary assumptions and hence also different general properties. Some robust estimators might also be applied in deformation analysis. Here, we consider three kinds of the robust estimates: basic M-estimators (the Huber or Tukey methods), $M_P$ estimator (M-estimator based on the Pearson distribution family) and finally R-estimator (weighted Hodges-Lehmann estimator). Note, that the first two estimators belong to the same family of M-estimation; however, their theoretical assumptions differ much from each other. The last estimator considered here has completely different foundations (it is based on the rank tests), and hence it has different properties. To describe the properties of the estimators one can apply different ways or measures. The influence function is one of the most important and popular way to describe such estimators and it is also very useful while designing new variants of the estimators in question. Such a function provides the general information about the estimator's properties. From the practical point of view, it is also important to know how the estimates behave in the case of a particular observation structure (geodetic network or observation set). Hence it is also very advisable to analyze the empirical influence functions (EIFs) which might describe the behavior of estimates from many points of view and for various disturbances within the observation set. The paper presents EIFs obtained for different variants of disturbing errors which might occur in deformation analysis. They show that it is difficult to flag the best, "most universal" estimation method, and the choice of the most convenient method is sometime just impossible.

***Keywords:*** *M-estimation; robust estimation; EIF; vertical displacement*



# PROCESSING STRATEGY OF CONTINUOUS GPS (CGPS) OBSERVATIONS FOR THE FRENCH LANDSLIDE OBSERVATORY OMIV

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The French Landslide Observatory (OMIV - Observatoire Multi-disciplinaire des Instabilités de Versants) is a national research structure clustering six research institutes in earth sciences under the auspices of INSU (Institut National des Sciences de l'Univers). Six continuously active landslides in France are monitored by the OMIV research group; they have been chosen according to their past history of monitoring, to the hazard/risk they may create and to the scientific challenges they raise up. The six studied landslides are: (1) the Avignonet landslide (30 km South of Grenoble), (2) the Super-Sauze landslide (5 km South to Barcelonnette), (2) the La Clapière (100 km North of Nice), (4) the Séchilienne landslide (25 km East of Grenoble), (5) the Pégairolles landslide (40 km North of Montpellier), and (6) the Villerville landslide (10 km South of Le Havre).

These landslides show various displacement rates (ranging from a few centimetres to several meters per year) and kinematic regimes. The objective of this work is to evaluate the performance of PPP (Precise Point Positioning) and DD (Double Difference) processing techniques on GPS observations acquired at the landslides. The PPP approach is a positioning method used to calculate precise positions using a single receiver from un-differenced phase measurements, precise clocks and precise satellite orbits. The PPP method is different from the DD positioning method which eliminates most errors using one or more reference stations with known positions. Position time series of several GPS located on landslides are computed with the NRCan (Natural Resource Canada) PPP software, the GINS (*Géodésie par Intégrations Numériques Simultanées*) PPP software and the GAMIT/GLOBK DD software. Evaluation of the results will be discussed. Time series of positions are available at: http://www.ano-omiv.cnrs.fr/

***Keywords:*** *GPS/GNSS; Continuous observations; Automated processing; Landslide*

# INVESTIGATION OF THE DEPENDENCE BETWEEN DIGITAL HEIGHT READINGS AND THE METEOROLOGICAL PARAMETERS BY USING A STAND-ALONE SET UP AND REPEATABLE SHORT TERM MEASUREMENTS

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The need of high accuracy geodetic measurements, especially in the vertical displacements control networks, is nowadays extended and thus the thorough investigation of all possible error sources is necessary. Despite the fact of technological improvement the accuracy of geodetic measurements is still limited mainly due to the unpredictable propagation of a sighting line. These error sources are concentrated on the variations of the refractive index; witch either bends or retards the electromagnetic wave path and is caused of air density inhomogeneity, which is in terms influenced by the fluctuations of the atmospheric parameters.

The present paper aims to the determination of the dependence between digital height readings and the air temperature as well as the atmospheric pressure by performing repeatable short term measurements. Thus, a stand-alone set up of a high accuracy digital level was developed and both indoors and outdoors experiments were carried out for a time period of several days with a time interval of five minutes. At the same time there was an air temperature sensor functioning, which was mounted on the staff, and a meteorological station.

Hence the additional time series were generated and correlation coefficients were computed in order to investigate as much as the linear relationships as well as the monotonic relationships among the measured parameters. Also the repeatability of the digital level's height readings was calculated. The basic term is that the meteorological conditions are stable, which means that heat flux effects are not applied (ventilation or convection). Thus the influence of the meteorological parameters regarding the level's repeatability was detected while moderate and poor correlations were computed between the acquired data.

***Keywords:*** *geodetic leveling; digital level; air temperature; atmospheric pressure*

# THE AITOLO-AKARNANIA (WESTERN GREECE) GNSS NETWORK PPGNet – FIRST RESULTS

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At the Aitolo-Akarnania prefecture, western Greece, strong earthquakes have occurred, and large active faults have been mapped. The most significant faults include the Katouna sinistral strike slip fault and the Trichonis Lake normal fault system. Proximity of these faults to large cities, as well as lack of information related to their seismogenic potential calls for detailed monitoring. Since 2013 crustal deformation in the area, is monitored by a dense GPS network. The GNSS Network PPGNet consists of five stations in Aitolo-Akarnania, equipped with Leica and Septentrio receivers. Data are recorded using two sampling frequencies, 1 Hz and 10Hz and hourly and daily files are produced. Daily data are processed using the Bernese GNSS Processing Software using final orbits of the International GNSS Service. The double-difference solution is computed using data from the PPGNet network data complemented by four stations from the GNSS network of National Observatory of Athens and six stations from METRICA network.

The first results show a NNE movement of PVOG station at 12mm per year and a similar movement of RETS station at about 9 mm per year. This means that the Trichonis Lake normal fault system, that is located between these two stations, depicts a slip rate of 3mm/y. The KTCH and RGNI stations move eastwards at a velocity of about 5 mm per year.

It is expected that data from PPGNet will provide valuable information on the Aitolo-Akarnania area internal deformation and eventually will help us understand how this deformation is linked to the major active structures in the broader area.

***Keywords:*** *GNSS network; Aitolo-Akarnania; Trichonis Lake; slip rate; velocity field*

# NOISE ANALYSIS OF BDS COORDINATE TIME SERIES BASED ON DYNAMIC POSITIONING

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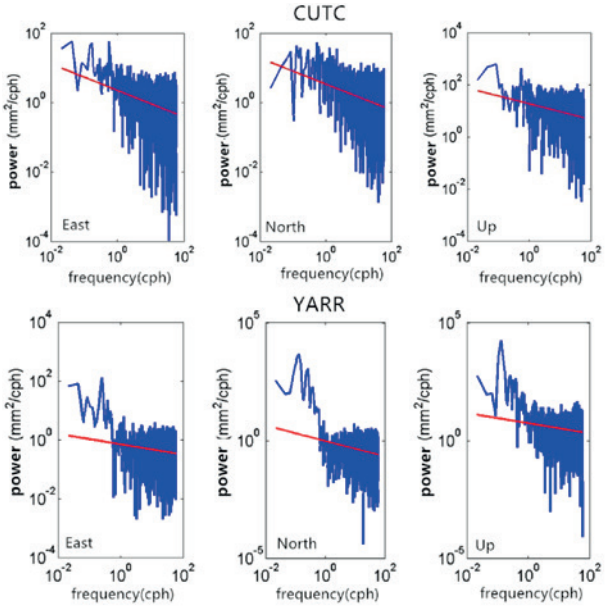
At present, most of the deformation monitoring research based on BDS (BeiDou Navigation Satellite System) ignores the influence of colored noise in the coordinate time series of station, which is not conducive to obtaining accurate deformation speed, and may lead to an erroneous analysis of deformation results. In the real-time deformation monitoring using BDS dynamic positioning technology, in order to analyze the colored noise in the BDS coordinate time series and its influence in this mode, This study selects 2 days of observations from two pairs of short baseline stations located in various locations in Australia. The noise amplitudes and accuracy of deformation velocity in BDS, Global Positioning System (GPS), and GPS/BDS coordinate time series are analyzed on the basis of white noise (WN) + power law (PL) noise combination model. Results show that the BDS coordinate time series in the dynamic positioning mode contains colored noise (including spurious periodic signals), and ignoring its influence will lead to an overly optimistic evaluation of the deformation monitoring results. Moreover, using GPS/BDS technology for deformation monitoring will weaken the false periodic signal caused by error, thereby reducing the influence of colored noise and improving the accuracy of deformation velocity estimations.

***Keywords:*** *colored noise; BDS; coordinate time series; dynamic positioning; periodic signals*



# UNDISPUTABLE, OBJECTIVE AND RELIABLE GEODETIC DAM MONITORING WITH FRM STANDARDIZATION

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Deformation monitoring of the "VALSAMIOTIS" dam in Chania, Crete, Greece is carried out by GNSS geodetic surveying in combination with total geodetic station monitoring. A central monitoring site, near the dam, has been established with absolute and permanent GNSS site coordinates, as well as with a number of selected reference geodetic control points around the dam. Geodetic coordinates for these reference markers have been determined in an absolute way, with respect to the center of mass of the earth and thus not influenced by local effects.

To establish a continuous, homogeneous and reliable system for this dam deformation monitoring and to ensure dam stability and safety, uncertainties arising from each geodetic constituent in observations, instruments and processing have to be identified and carefully dissected. The main steps involved in this standardization process are presented along with the overall uncertainty of the monitoring system. This work will provide a roadmap following internationally agreed standards to (1) support accuracy in scientific and monitoring data we produce and evaluate, (2) to provide accurate information presented to the public when critical values have been reached, and finally (3) to help make the right decisions, and put into action the right policies for large project deformation monitoring. Ways to express uncertainty will be given to meet the guidelines of the Bureau International des Poids et Measures.

***Keywords:*** *standardization; dam monitoring; Fiducial Reference Measurements; Uncertainties*


# MONITORING APPLICATIONS BY USING THE REMOTE SURVEY METHOD

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In 2014 a methodology of Remote Survey was introduced. This methodology is a combination of instrumentation, software and means of communication, which allows surveyor to sight and measure, without having to be at the designated site. This successful experiment took place in the laboratories of the NTUA, where the surveyor managed to operate an Image Assisted Total Station (IATS), using two intermediate devices (PCs) and an internet connection, with acceptable results, according to the ISO17123-3 procedure. The goal of this paper is the presentation of implementing the methodology of Remote Survey for constructions monitoring. For this purpose an IATS will be placed on the appropriate monitoring position at the construction by using internet connection via WiFi network. Also, it will be essential to synchronize the internal clock of the IATS with the global time servers and to report automatically the real time of the observation, which by default is different than the one when the surveyor gives the command via the PC in office. The most important advantage of this methodology is the fact that free software mid cost instrumentation combined with common wireless connection and low cost PCs can provide to the engineers the potential to obtain the remote control and handling of a total station without any additional costs. The pros and cons of this attempt are presented and further discussion is presented in how this methodology can be implemented

***Keywords:*** *Geodesy; Remote Survey method; deformation; constructions monitoring*

# HIGH RATE GPS AND SEISMOLOGICAL DATA TO MONITOR COSEISMIC DEFORMATION OF THE PENINSULA OF BAJA CALIFORNIA, MEXICO

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The evolution of the Global Positioning System (GPS) allows to be used in monitoring long periods of the plate geotectonic. The continuous observations of GPS (cGPS) are similar to the seismogram in a range of frequency, providing differences, like the reference frame, likewise, the type of specific measure of each instrument. This differences present advantages which allow us to complement the GPS and seismological measurements. One of the problems of the seismograms is the sign saturation, it does not present equal in the GPS observations. With the definition presented previously, the use of GPS of high rate as a seismological instrument result fundamentally efficient to the study of earthquakes. In the present project, it is processed and analyzed time series generated with GPS data, for earthquakes occurred in the region of the Gulf of California, over the period of 2008-2010. In this way it is obtained the coseismic movement associated to displacements of these events. It performed an analysis of the quality of the observations and a filtering which, be necessary, remove the effect caused by the movement in the reference station upon to the cinematic stations. The analysis of the cGPS time series and the integrated acelerometers, shows that, to lower frequencies 0.1.Hz, due to similar response. Otherwise, the domain of the accelerometer in the high rate and GPS in the low rate make them to be complementary instruments capable to yield relevant information in the analysis of seismic events.

***Key words:*** *CGPS; accelerometer; track; seismology; tectonic*

# COMPARISON OF SEVERAL GEOMATIC TECHNIQUES FOR ROCKFALL MONITORING

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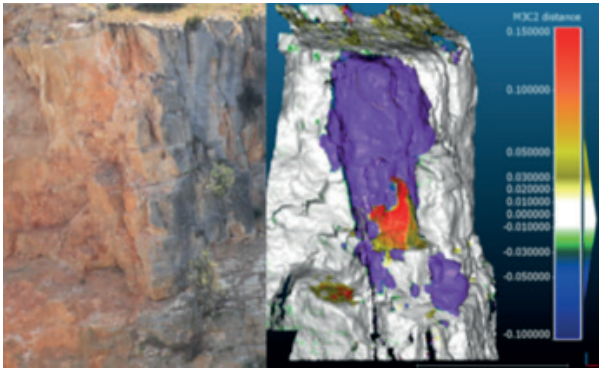
Rockfalls are slope instabilities very frequent and harmful in mountainous areas. They can be the cause of damage in infrastructures (roads and railways), buildings... We have had the opportunity to improve the knowledge of this kind of events in the frame of a Spanish R+D project named ROCKMODELS. The field activities comprised real scale tests and the characterization of natural events in the N-E of Spain, mainly in the Pyrenees range. Moreover, in order to understand the behavior of the real scale tests were carried out. We dropped a total of 124 rock blocs (0.2 to 4.3 m3) under controlled conditions. Prior to the block release and during their propagation downslope, several geomatic techniques have been used to monitor the volumes, shapes and trajectories of the original blocks and their possible fragments (due to breakage); it is worth to highlight the videogrammetry to determinate the trajectories. In order to survey the natural rock walls origin of the rockfalls, the so-called massive data capture by photogrammetry (both terrestrial and UAV-drone with image and video) has been used, also the Terrestrial Laser Scanning, in this way the different techniques can be compared. Finally, for the monitoring of some rock cliffs, with recurrent falls of blocks, the TLS was used, trying to catch some precursory displacements that may help in the risk management of the areas at the bottom. In our intended contribution, several geomatic techniques (Videogrammetry, photogrammetry – terrestrial or aerial --, and the TLS) are combined and compared, highlighting the pros and cons of the different methods and their applications according to work conditions.

***Keywords:*** *Rockfall; field test; geomatic methods for measuring 3D scenes and displacements; Terrestrial Laser Scanning, Terrestrial and UAV photogrammetry, combination and comparison; TLS for slope monitoring*



# LONG-TERM GEODETIC MONITORING OF SEASONAL DEFORMATIONS OF EARTH DAMS AND RELEVANT FINITE ELEMENT VERIFICATION

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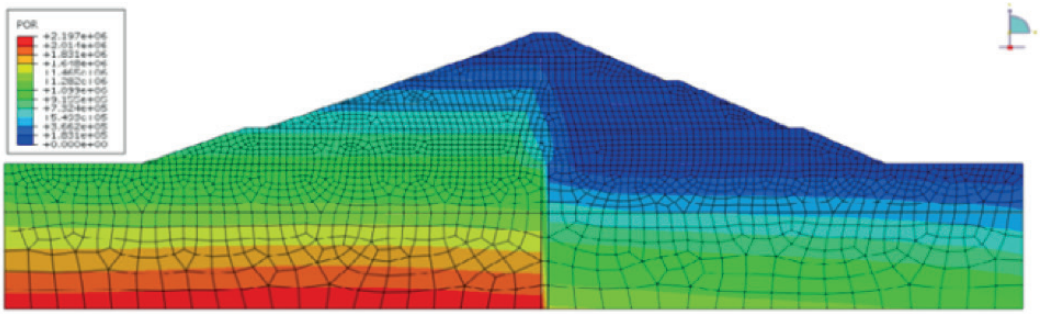
Earth dams are massive structures retaining large volumes of reservoir-water. They constitute an important part of modern civil infrastructure contributing to water supply, irrigation and power generation. Their structural stability/safety is crucial, as a possible failure of a large dam will lead to a sudden release of huge amounts of water which may potentially lead to damage and casualties in in the downstream. It is therefore important to monitor their deformations and the structural health to avoid any such unfortunate events.

This paper presents a comprehensive study on the long-term monitoring of earth dams. A well-documented case, the Kouris dam, which is the largest dam in Cyprus, is examined in detail. The paper consists of three main parts. The first part presents the different types of instrumentation installed and how data processing of the monitoring data is performed. The second part presents the analysis and interpretation of the monitoring data, both in the time- and frequency-domain. The third part presents relevant complementary finite-element analyses of the dam and its calculated long-term response subject to embankment construction, reservoir impoundment, operation and reservoir level fluctuations.

The collected monitoring data exhibit a consistent pattern of long-term crest settlements and downstream deformations. The magnitude of these is compared well to previous monitored dam cases and was therefore expected. It is also shown that frequency analysis reveals a strong correlation between crest settlements and reservoir level fluctuations, suggesting a seasonal variation of dam deformations. Additionally, the finite-element analysis shows that soil consolidation is the dominant mechanism of dam settlements in the short-term, whereas reservoir level fluctuations dominate in the long-term. Finally, the main message of this investigation is that robust and reliable measurements are important and high-quality and accurate monitoring data are substantial for evaluating the long-term structural health monitoring of large earth dams.

***Keywords:*** *long-term monitoring; deformations; geodetic measurements; earth dams; finite element analysis; structural health monitoring*



# DEFORMATION MONITORING USING LiDAR DATA SETS

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Sustainability and durability are strictly related with the *monitoring* of structures and the ability of the observer to deliver complete and efficient data for the object's behavior within time.

*Laser Scanner* is a tool to determine *displacements* or *deformations* of a surface. Within minutes, it collects a dense *point cloud* getting a full detailed description of the monitored object.

Despite the fact that this method is fast, *contactless* and *complete*, scanning was not extensively used due to 3 reasons: cost of purchasing a laser scanner, instrument's specified *accuracy* and handling of such large amount of data.

The last couple of years laser scanners are accurate and affordable. The 3d obstacle is now overpassed by *OPSIS*, a smart software just developed.

*Deformation Monitoring Analysis* is entering a new *era*.

The philosophy behind OPSIS design, is that forces applied to a surface are causing displacements, mainly perpendicular to the open side of the surface, the side we can scan.

The measured point cloud is projected on a mathematically defined 3D surface that can be deployed to a 2D shape. This surface, called Template, is defined as best fit adjustment to the specific cloud.

Template is tessellated using a squared grid of adjustable size and the points contained in each cell are subject to statistical analysis. Each cell gets one value representing all inscribed points, if the criteria of the standard deviation value of the distances point cloud – template, is fulfilled. A 2D projection map is created.

Monitoring using OPSIS comes down to processing the subsequent point clouds obtained in different epochs using the same template and grid. Significant changes will occur variations of the projection cells and make them easily detectable.

Animation of the projection's ongoing monitoring and deformation vs time graphs are also presented.

***Keywords:*** *Monitoring; Laser Scanner; displacements; deformations; point cloud; contactless; complete; accuracy; Deformation Monitoring Analysis*

# DETERMINATION OF LOCAL ACTIVE TECTONICS REGIME IN CENTRAL AND NORTHERN GREECE, USING PRIMARY GEODETIC DATA

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Numerous active fault zones are observed throughout the central and northern part of Greece, while in some cases they are related to destructive earthquakes. The geometric characteristics of these fault zones vary, revealing both extensional and compressional tectonics of these structures. The use of geodetic data, received by permanently installed GPS stations, is a precise way of analyzing the tectonic regime. In particular, 58 permanent GPS stations are included in the study area, having collected primary data for a 7-year period. The calculated East and North velocity components and their errors, respectively, derived from each GPS station, were processed applying a triangulation methodology, based on the triangle construction, combining three different GPS stations each time. The use of dense GPS stations distribution resulted in the extraction of 1,092 different triangles and then, the centroid of each triangle was determined. For each centroid the following parameters were estimated: 1) maximum horizontal extension, 2) total velocity, 3) maximum shear strain, 4) area strain and 5) rotation. The extracted values were interpolated into a grid pattern, showing low to medium values, especially north of the inferred extension of the North Aegean Fault System, the same parameter values are high for the southern part of Greece, confirming the geological and seismological data suggesting that Central – Northern Greece is generally less active than Southern Greece. However, it is noted that the length of the neotectonic faults in the area are capable of producing significant earthquakes, albeit in longer recurrence intervals.

***Keywords:*** *active tectonics; geodynamics; triangulation methodology; geodetic data; GPS stations; Central – Northern Greece*

# UNMANNED AERIAL VEHICLE (UAV) BASED MAPPING IN ENGINEERING SURVEYS: TECHNICAL CONSIDERATIONS FOR OPTIMUM RESULTS

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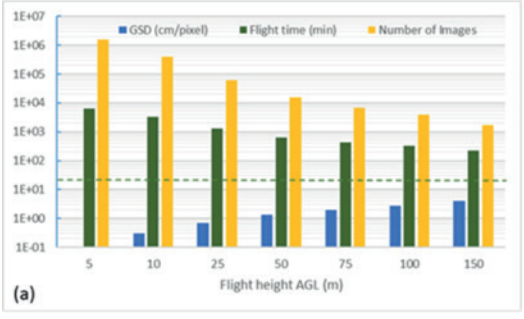
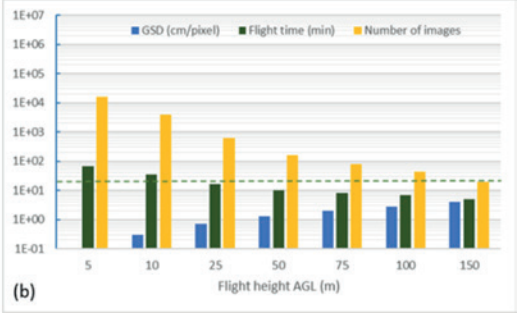
Due to the wide availability of UAVs and their ease of use, the number of operators with limited surveying and photogrammetric knowledge is constantly increasing. At the same time, there are no easily accessible guidelines available regarding the choice of some of the parameters that greatly affect the quality of photos and consequently the orthomosaic obtained from a UAV e.g. overlap between photos, flight height, light conditions, specifications of the lens and camera, and weather conditions. As a result, if the user is not experienced or does not have a basic knowledge on surveying and photogrammetry (quite common considering the wide range of UAV user backgrounds), a poor quality orthomosaic is produced. This frequently leads to the misconception that a poor outcome is always due to limitations of the UAV technology. In this study, we discuss some of the main technical parameters, such as the effect of topography and UAV orientation on the overlap value, the camera calibration, number of control points and lighting conditions that need to be taken into account in order to utilize UAVs to their maximum potential.

***Keywords:*** *UAV; Fixed wing; VTOL; Mapping; Image resolution; Engineering geological survey*



# SEISMIC INSTRUMENTATION AND MONITORING SYSTEMS IN LARGE HYDROELECTRIC INFRASTRUCTURE IN GREECE

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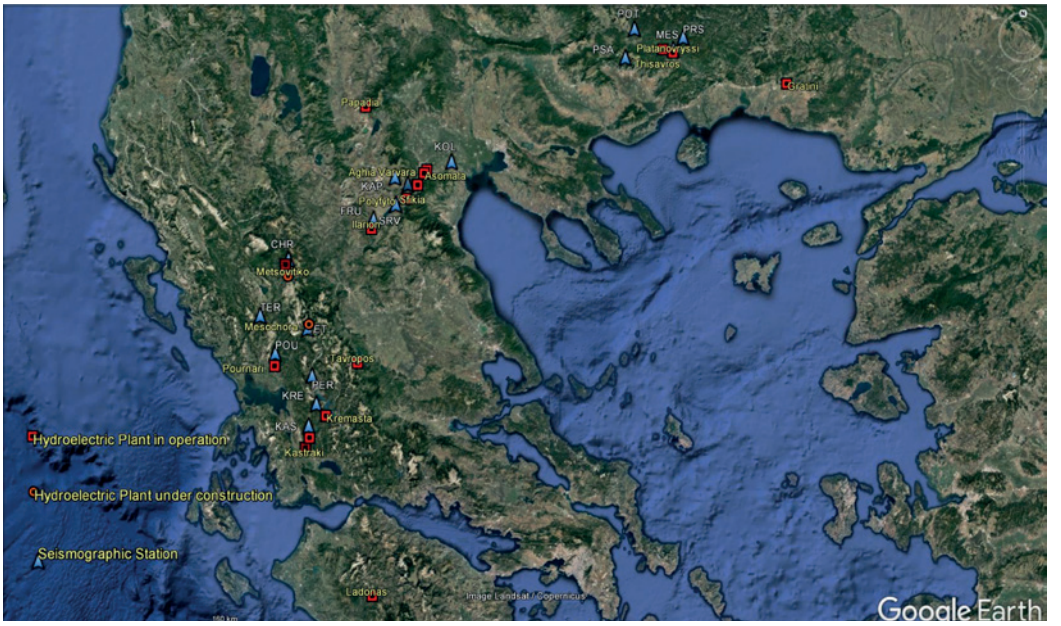
Large dams are particularly sensitive to earthquakes due to several reasons: dams are in some cases built in active earthquake areas, reservoirs can trigger earthquakes under certain circumstances, earthquake shaking affects the dam body, its appartenant structures and the embankments at the same time. Shaking an unstable slope, that has been weakened after saturation due to rising of ground water levels, may produce a landslide into the reservoir. The monitoring of seismicity level is achieved by operating an extended seismographic network established around the hydroelectric power reservoirs. Deploying strong motion accelerometers and associated data acquisition / analysis systems in a dam, in order to detect exceedance of allowed performance criteria as well as identify and verify structural behavior, is very important. Utilising seismic instrumentation and monitoring systems, timely notifications about any potential problems can be generated and behaviour of the dam can be monitored and correlated with the dynamic analysis of the dam. The factors that eventually lead to failures and damages, as well as their severity and effect on the structure can be measured and monitored with Seismic Instrumentation and Monitoring systems. Presented in this paper is the plan by which P.P.C. has organized its seismographic network in hydroelectric project areas and the system of accelerographs that has been established on hydroelectric dams. Some analyzed data and the resulting conclusions are presented as well.

***Keywords:*** *dam safety; seismic instrumentation; monitoring; accelerographs; seismographs*



# DETERMINATION OF THE TECTONIC PLATE MOTION PARAMETERS FOR THE EURASIAN PLATE BASED ON THE VLBI STATION POSITIONS

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This is the next paper from a series of our articles on the subject of the estimation tectonic plate motion parameters. The study is based on the velocities of the VLBI station positions in the ITRF2008 system. We estimated parameters Φ, Λ, ω which define the tectonic plate motion. The analysis was carried out for the Eurasian plate. The influence of the number and localization of stations on the plate surface on the estimation accuracy of the tectonic plate motion parameters were discussed. The results were compared with our earlier estimation for the DORIS and SLR technique and the APKIM 2005 model. Good agreement between our earlier solutions (for DORIS and SLR techniques), APKIM 2005 model and the present solution for VLBI technique was found.

***Keywords:*** *tectonic plate motion parameters; VLBI; Eurasian plate*

# STUDY THE DEFORMATION OF ELEVATED WATER STORAGE TANK

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Deformation of any engineering structure may cause damages and failure to structures itself and sometimes loss of life and injury to people. Structure deformation may occurred due to several reasons, such as the incomplete investigation of foundation soil properties, improper construction of the foundation system, insufficient knowledge of the operating conditions, earthquakes etc. So, continuous monitoring for deformation of the structure is important and vital because observations and recordings of deformation don't present only scientific interest for the civil engineers, but they are also indications of the long-term behavior of the structure Water storage tanks are widely used in both residential and commercial areas. Based on the location of the tank, the tanks can be classified as elevated, on ground or underground. Water storage devices made from different materials. Water storage tanks are widely used in both residential and commercial areas. Based on the location of the tank, the tanks can be classified as elevated, on ground or underground. Water storage devices made from different materials.

This paper investigates the deformation observations techniques and results analysis of monitoring elevated water storage tank. Monitoring of the water tank settlement and deformation has gradually gained greater importance in tank maintenance programs.

As results of monitoring the water storage tank deformation, circular reinforced concrete beams and vertical inclination reinforced concrete columns at three monitoring epochs

***Keywords:*** *Reflector-less total station; Monitoring, Setting out; Accuracy; Structural Deformation*

# i²MON - INTEGRATED MONITORING FOR THE DETECTION OF GROUND AND SURFACE DISPLACEMENTS CAUSED BY COAL MINING

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i²MON joins highly recognized European institutions to develop an integrated monitoring service for identification and assessment of ground and slope movements related to coal mining. i²MON is an RFCS-funded research project with a duration of 4 years, which started in July 2018. The service comprises innovative monitoring tools including terrestrial laser and radar technology as well as space- and airborne remote sensing. To understand the physical movement processes and in order to minimize mining impact, extensive predictive modelling will be directly integrated with the monitoring information. Finally merged into an integrated web-based system the service will substantially improve monitoring quality and costs and deliver the mining industry a key evaluation and decision-making instrument. The task of DMT and Mainz University of Applied Sciences in this project is to extend existing point-related sensor information (e.g. low-cost GNSS) with areal sensors. The focus here is on the use of a long-range laser scanning. Besides the integration of the scanner in a sensor network (data acquisition, data transfer), the focus is on the appropriate processing of the data. This means that according to the theoretical principles of deformation analysis, the focus is on a proper georeferencing of all sensors as well as a sophisticated stochastic model, so that systematic error influences and false alarms are minimized by an application-related modeling.

***Keywords:*** *multi-temporal 3D point cloud analysis; online monitoring; terrestrial laser scanning; slope monitoring; mining*

# SPECIFIC PROCEDURES FOR MONITORING GEOTECTONIC RECENT MOVEMENTS IN THE KOŠICE BASIN, SLOVAKIA

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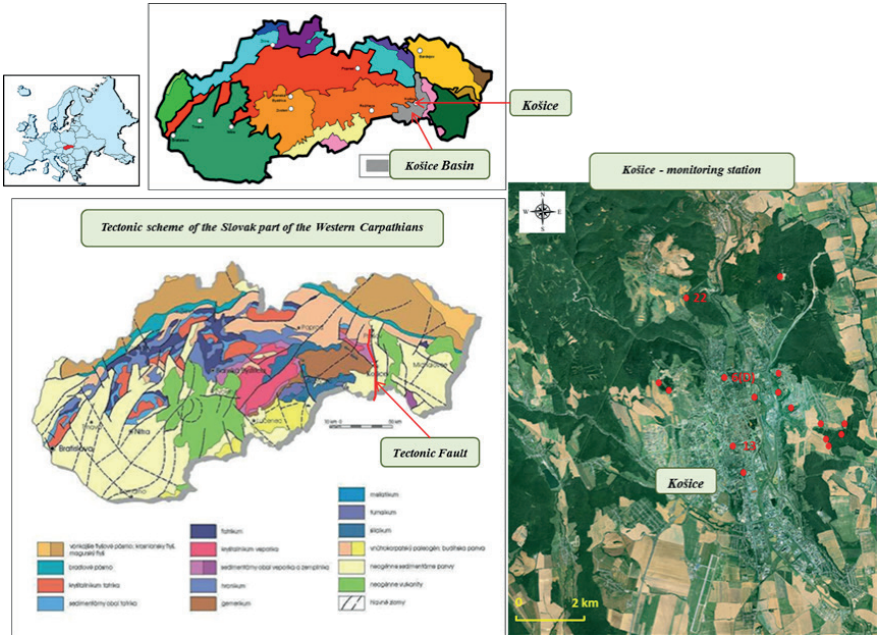
The presented study deals with the investigation of deformations due to geotectonic recent movements in the east of Slovakia. Geodetic measurements were carried out using GNSS (Global navigation satellite Systems) techniques. Satellite measurements were realized on points of the monitoring station in the Košice Basin (Figure). The adjustment with constraints and free adjustment were applied to adjustment processing of all points of the geodetic network in the monitoring station. Transformation of coordinates from WGS-84 into the national geodetic system of Slovakia was realized on the basis of the spatial Helmert transformation. The main objective of deformation measurements was to determine geotectonic recent movements in the city conurbation of the city of Košice. The deformation investigation was carried out in the Košice Basin for a long period (since 1997). Satellite measurements were periodically realized twice a year, i.e. in spring and autumn. 3D coordinate differences presented by the deformation vectors were subjected to the selected test statistics. The outputs from deformation investigations were provided to the municipalities of the city of Košice and Košice province. For the monitoring period of nineteen years the expected geotectonic recent movements in the monitored area of the Košice Basin exceed the safety limit values were not recorded. The research was granted from the projects KEGA No.: 007UPJŠ-4/2017, APVV/SK-CN-RD-18-0015 and VEGA1/0839/18, researched at the Institute of Geography of the Faculty of Science of the Pavol Jozef Šafárik University in Košice.

***Key words:*** *GNSS; geotectonics; deformation vector; Helmert transformation*



# THE METHOD OF DETECTING OUTLIERS, JUMPS AND BREAKS IN MEASUREMENT DATA FROM A STRUCTURAL MONITORING SYSTEM

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Geodetic monitoring systems used mainly for monitoring engineering and natural structures (which may threaten the safety of surroundings) also used in industry, construction, mining and many other branches, provide information on the status of examined objects. Observations, usually carried out over long periods of time, generate time series.

In this data - generally originating from geodetic or geotechnical sensors, due to their character (measured automatically without human intervention), outliers can be found. The authors have presented an original method for the detection of outliers, data jumps and trend changes in the time series of observations derived from the structural geodetic monitoring system.

The main purpose of the presented methods is the detection of outliers, which may disturb further analyzes and influence the assessment of the monitored object condition as well as data jumps. Most methods for detecting outlier observations are based on basic statistical parameters. The authors have put forward an original method that is based on detecting the trend in small time intervals and verifying observations in terms of detection (congruent to the model) in a given window. The method presented is dedicated to data from geodetic monitoring systems, in which it is very important to distinguish outliers and data jumps (which can be identified as significant displacements of observed points) or significant observations occurring after a break in observation. The authors use data from the geodetic monitoring system installed in a chosen building at the Wrocław University of Environmental and Life Sciences. Data was derived from continuous observations made over one year (2017). Data from eight Nivel 220 precision inclination meters and total station data from two instruments taking measurements both inside and outside the building were used for the analysis. The proposed solution may constitute a significant contribution to the development of automatic control and measurement systems.

***Keywords:*** *outlier detection method; jump detection; structural monitoring system*

# AN EXAMPLE OF USING THE OPTD METHOD TO OPTIMIZATION OF POINT CLOUDS IN THE BUILDINGS DIAGNOSTICS

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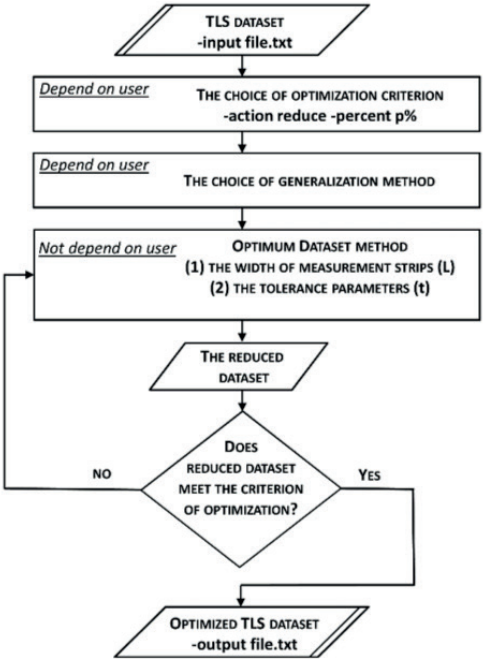
Terrestrial Laser Scanner (TLS) measurements can be used to assess the technical condition of buildings and structures: in particular, very high resolution TLS measurements should be taken in order to detect defects on building walls. This consequently results in the creation of a huge amount of data in a very short time. Despite high resolution measurements are typically needed in certain areas of interest, e.g. to detect cracks, reducing redundant information on regions of low interest is of fundamental importance in order to enable computationally efficient and effective analysis of the dataset. In this work, data reduction is made by using the Optimum Dataset (OptD) method, which allows to significantly reduce the amount of data while preserving the geometrical information of interest area. As a result, more points are kept on areas corresponding to cracks and cavities than on flat and homogeneous surfaces. This approach allows for a thorough analysis of the surface discontinuity in building walls. In this investigation, TLS dataset was acquired by means of the time-of-flight scanner Riegl VZ-400i. The results obtained by reducing the TLS dataset by means of OptD show that this method is a viable solution for data reduction in building and structure diagnostics.

***Keywords:*** *OptD method; TLS; optimization of the dataset; defect detection*

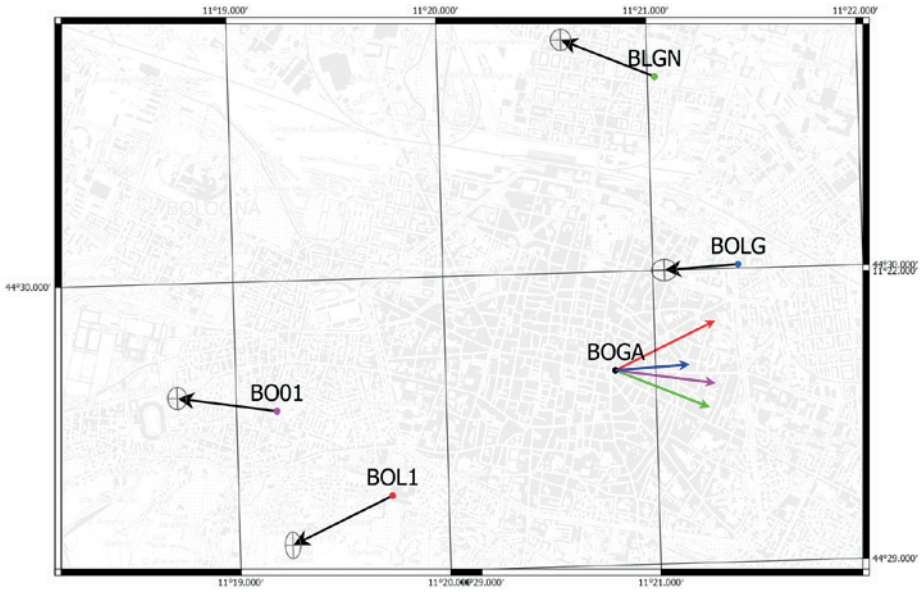


# A STRATEGY FOR THE MONITORING OF TALL STRUCTURES IN URBAN AREA USING GNSS TECHNOLOGY

**Luca Tavasci[1], Luca Poluzzi[1], Stefano Gandolfi[1]**
[1] *DICAM - University of Bologna, Viale Risorgimento 2, 40136 Bologna, Italy, (luca.tavasci2@unibo.it)*

GNSS technology has become widely used for monitoring purposes. The high precisions nowadays available have made the technique suitable also for the monitoring of structures that are usually affected by very small displacements. In this work we investigate the issue concerning the monitoring of a tall structure such as the Garisenda tower, which lay in the Bologna city centre, by using GNSS data gathered by a permanent station placed on its top. We consider the need to investigate the variations in the leaning of the structure, therefore also the position of the ground at the bottom of the structure should be known. Unfortunately it is not possible to place a GNSS receiver under a tall structure in urban context because of the too poor sky visibility. A solution would be to choose another permanent station located as close as possible assuming its behaviour coherent with the ground under the monitored structure. This hypothesis has proven not to be verified in the analysed case, where four permanent stations located within few kilometres far from the Garisenda tower were available. Therefore a strategy to combine data from the five permanent stations using a uniform strain model was developed in order to define a reference to which compare the positions given by the GNSS sensor placed on the top of the tower. The impact of such strategy will be shown and discussed in terms of mean variation of the leaning of the tower over a period of about four years. This variation estimated using the strain model is mostly similar to what found using the closest station (BOLG) as reference, with a difference in terms of magnitude of 0,3 mm/y (about 22%).

***Keywords:*** *GNSS monitoring; tall structures monitoring; deformation model; GNSS permanent stations; Garisenda tower*



# MONITORING GROUND DEFORMATION OF CULTURAL HERITAGE SITES USING SAR AND GEODETIC TECHNIQUES: THE CASE STUDY OF CHOIROKOITIA, CYPRUS

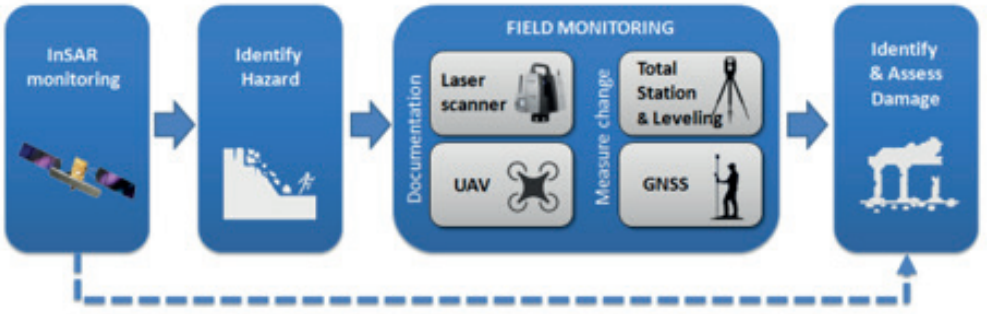
**Kyriacos Themistocleous[1], Chris Danezis[1], Evangelos Mendonidis[1], Vassilis Gikas[2]**

[1] *Cyprus University of Technology, Department of Civil Engineering & Geomatics, Eratosthenes Research Center P.O. BOX 50329, 3036, Limassol, Cyprus, (k.themistocleous@cut.ac.cy)*

[2] *National Technical University of Athens, School of Rural & Surveying Engineering, 9 Iroon Polythechniou Str, 15780, Zografos, Athens*

Currently, assessing geo-hazards, in cultural heritage sites takes place after the hazard has occurred. Monitoring the deformation of structures as a result of geo-hazards, including their surrounding areas facilitates the early recognition of potential risks and encourages effective conservation planning. This paper presents the integrated methods using SAR data, GPS/GNSS observations, and aerial images from UAVs to monitor ground deformation within the Choirokoitia UNESCO World Heritage Site in Cyprus. The Neolithic settlement of Choirokoitia is one of the most important prehistoric sites in the eastern Mediterranean. The field measurements collected at the Choirokoitia site were compared with SAR data to verify displacements in the area and to monitor potential geohazards over time. The Choirokoitia site is located on a steep hill, which makes it vulnerable to rock falls and landslides. The results indicated displacement rates at the order of 3cm per year and verified that long-term low-impact monitoring systems such as SAR images, UAVs and geodetic techniques can be used to monitor and assess potential geohazards on archaeological sites.

***Keywords:*** *Cultural heritage, natural hazards, remote sensing, geodetic techniques, SAR, UAV*



# INVESTIGATION FOR MINING-INDUCED DEFORMATION IN UPPER SILESIA COAL BASIN WITH MULTI-GNSS IN NEAR REAL-TIME

**Damian Tondaś**[1], **Kamila Pawłuszek**[1], **Maya Ilieva**[1], **Jan Kapłon**[1], **Witold Rohm**[1]
[1] *Wrocław University of Environmental and Life Sciences, (damian.tondas@upwr.edu.pl)*

The EPOS project is The European Plate Observing System which integrate the existing and newly created research infrastructures to facilitate use the multidisciplinary data and products in the field of Earth sciences in Europe. The assumptions of the project provide for the construction and integration of research infrastructure in the field of earth sciences at the local and national level, which in turn will lead to integration with European and global databases and services. One of the tasks in EPOS project is creation the service for continuous monitoring of GNSS stations position in Near Real- Time (NRT) processing on areas covered by mining exploration. The NRT processing is carried out with a 15-minutes GNSS parameter estimation interval.

The most exposed region in Poland on the effects of deformation is the area of Upper Silesia Coal Basin (USCB) in the south of the country. This is one of the largest coal deposits in Europe. The exploitation of deposits has been carried out there for the last 200 years. The mining works cause further subsidence of the most populated area in Poland.

In order to conduct deformation research in this area eight high-frequency GNSS receivers have been purchased in EPOS project. The NRT processing enables constant monitoring of the stations location. Depending on the duration of the seismic phenomenon (long-term - subsidence, short-term - Earthquakes), it is possible to observe the coordinates changes. The displacements may occur not only in the vertical but also in the horizontal plane.

The paper will depict the results obtained in the research of multi-GNSS deformations in the USCB areas. The determined time series of coordinates analysed for long-term and short-term effects of deformations. The long-term subsidence were compared with InSAR techniques. The research will be carried out for vertical and horizontal shifts.

***Keywords:*** *Near Real-Time; multi-GNSS; InSAR; subsidence; mine deformations*

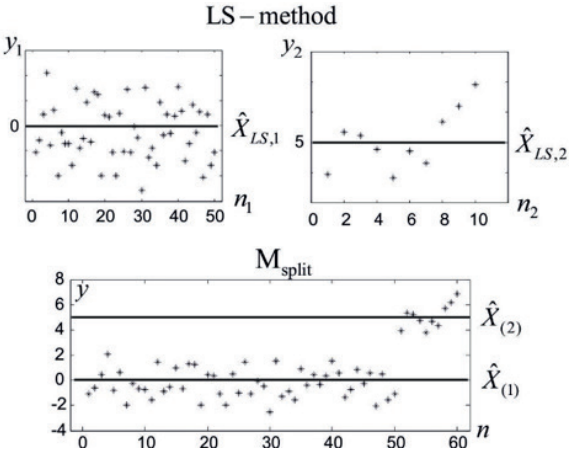
# EFFICACY OF $M_{split}$ ESTIMATION IN DISPLACEMENT ANALYSIS

**Zbigniew Wiśniewski[1], Andrzej Dumalski[1], Robert Duchnowski[1]**

[1] *Institute of Geodesy, University of Warmia and Mazury in Olsztyn, 1 Oczapowskiego St., 10-957 Olsztyn, Poland, (robert.duchnowski@uwm.edu.pl)*

Sets of geodetic observation often contain groups of observations which differ from each other in the functional model (or at least in the values of the parameters of such a model). Sets which include the observations from various measurement epochs might be a practical example in such a context. From the conventional point of view, for example in the case of the least squares estimation, subsets in question should be separated before the parameter estimation process, for example before deformation analysis. Another option would be an application of $M_{split}$ estimation. That method is based on a fundamental assumption that each observation is related to several competitive functional models (which usually differ from each other in the parameter values). The optimal automatic assignment of every observation to the respective functional model is one of the objective of the estimation process. $M_{split}$ estimates of the model parameters are obtained during the iterative process which is based on two (or more) weight functions (stemmed from the respective influence functions). The functions mention here also determinate the method properties. Considering deformation analysis, each observation is assigned to the set of the functional models, each of which is related to one measurement epoch. The paper focuses on the efficacy of the method in detecting point displacements. The research is based on example observation sets and with the application of Monte Carlo simulations. The results of $M_{split}$ estimation are also compared with the classical deformation analysis, which shows that $M_{split}$ estimation might be an interesting alternative for the conventional methods.

***Keywords:*** *$M_{split}$ estimation; efficacy; MC simulations; deformation analysis*



# DEFORMATION MONITORING AND ANALYSIS OF SUPER HIGH-RISE BUILDING BASED ON GB-RAR

**Lv Zhou[1,2], Xuelin Wen[1,2], Fei Yang[3], Jun Ma[4], Xianjian Lu[1]**

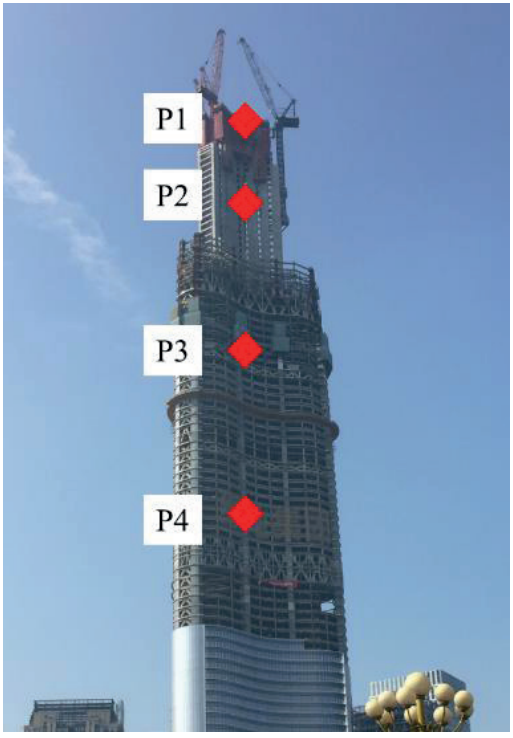
[1] *College of Geomatics and Geoinformation, Guilin University of Technology, Qixing District, Guilin, Guangxi, China, 541004, (wxlwzj6389@hotmail.com)*

[2] *Guangxi Key Laboratory for Spatial Information and Geomatics, Guilin University of Technology, Qixing District, Guilin, Guangxi, China, 541004*

[3] *School of Geodesy and Geomatics, Wuhan University, Hongshan District, Wuhan, Hubei, China, 430079*

[4] *China Railway Siyuan Survey and Design Group Co. LTD., Wuchang, Wuhan, Hubei, China, 430063*

Due to the characteristics of the height of the super high-rise building, the building body will produce yaw movement under the influence of sunlight, wind load, and other factors. When the deformation of a building exceeds a certain specification limit, the building structure will be destroyed. Therefore, monitoring and analyzing the deformation of buildings to master the deformation law, which is an important guarantee for building safety. Ground-based real aperture radar (GB-RAR) technique integrates SFCW and interferometry techniques, which can realize continuous deformation monitoring for monitoring targets. In this study, a GB-RAR was used to monitor the continuous deformation of a super high-rise building under construction in Wuhan, China. To investigate the deformation law of the building, we first extracted the deformation time series of the building during the monitoring period based on the time series InSAR technique. Furthermore, based on the wavelet analysis and time series analysis method, the accurate dynamic characteristics information of the building were extracted. Additionally, to further analyze the deformation change process of the building, four feature points in different heights were selected for deformation time series analysis. The results show that the deformation of the building body presented obvious nonlinear changes. The maximum deformation amplitude at the top of the building were 4.96 mm during the monitoring period, and the accuracy reached submillimeter level. Meanwhile, the natural frequency of the building was detected as 0.20 Hz. The GB-RAR technique can realize high accuracy continuous dynamic deformation monitoring and analysis of super high-rise buildings.




***Keywords:*** *GB-RAR; super high-rise building; deformation monitoring; time series analysis; interferometry*

# HELLASTRON

## Το μέλλον των ελληνικών αυτοκινητόδρομων στο σήμερα

Η **HELLASTRON** (**HELL**ENIC **AS**SOCIATION of **T**OLL **RO**AD **N**ETWORK), κατάφερε, μέσα σε μόλις μία 5ετία, να θεωρείται ένα από τα πιο δραστήρια μέλη της Ένωσης των Ευρωπαϊκών Αυτοκινητόδρομων (ASECAP). Το σύγχρονο δίκτυο των ελληνικών αυτοκινητόδρομων έχει να επιδείξει εντυπωσιακά στοιχεία σε ό,τι αφορά στην ασφάλεια και την εξυπηρέτηση των χρηστών.

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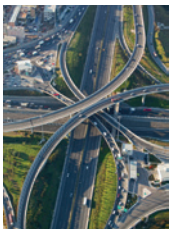
Το όραμα για τα μέλη της **HELLASTRON** παραμένει η διατήρηση ενός σύγχρονου και ασφαλούς δικτύου οδικών αξόνων, τμήμα των Πανευρωπαϊκών Δικτύων, όπου η μείωση των ατυχημάτων αποτελεί στρατηγικό στόχο.



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# USEFUL INFORMATION



## Symposium venue

The conference is held in the Eugenides Foundation: 387 Syngrou Avenue, 175 64, P. Faliro, Greece

## Accessibility

**Public Transportation – Urban Buses to Eugenides Foundation:**

**550** (P. Faliro – Kifisia): Station Euginides*
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**Coordinates in WGS84:**

N: 37° 56' 25.2744"
E: 23° 41' 46.0608"

## Registration desk & conference secretary opening hours

1st Day, Wednesday, 15th of May 08:30-18:30
2nd Day, Thursday, 16th of May 08:30-18:30
3rd Day, Friday, 17th of May 08:30-18:30

## Presentations

### Oral presentations

Prepare your oral presentation using the 4th JISDM oral resentation template. Each oral presentation will have 15 minutes including 3 minutes of questions. Each presentation room will equipped with a video projector with a VGA connector and a Windows laptop with PowerPoint and Adobe Acrobat. We recommend that you embed all fonts and visuals in your presentation files. You should bring your presentation and a short biography on a USB drive. Load your presentation and short bio into the conference PC and contact your Session Chair before your session starts. Please respect the time duration of your presentation.

### Poster presentations

Poster presentations split into three sessions, each one lasting one day. Authors of poster presentations should prepare their poster according to the 4th JISDM poster presentation template. The posters will be displayed along the corridor aside the symposium amphitheater. During the coffee breaks authors should be ready to present their posters and to answers the questions of the attendees.

### Lunches and Coffee Breaks

Lunches will be provided free of charge for registered attendees at the peristyle located opposite of the symposium amphitheater. Coffee and beverages will be served during the coffee breaks according to the symposium schedule. No food is allowed in the conference rooms except the peristyle during the lunch time and coffee breaks.

### Exhibition

The exhibition will open to the attendees of the symposium on Wednesday, 15th May at 09:00 the peristyle on the amphitheater level. It will be held simultaneously with the symposium until 17th May at 16:00.

### Internet access

Free internet access will be available during the symposium.
Network name: Eugenwifi
Username: efcc
Password: 9845

# SOCIAL EVENTS

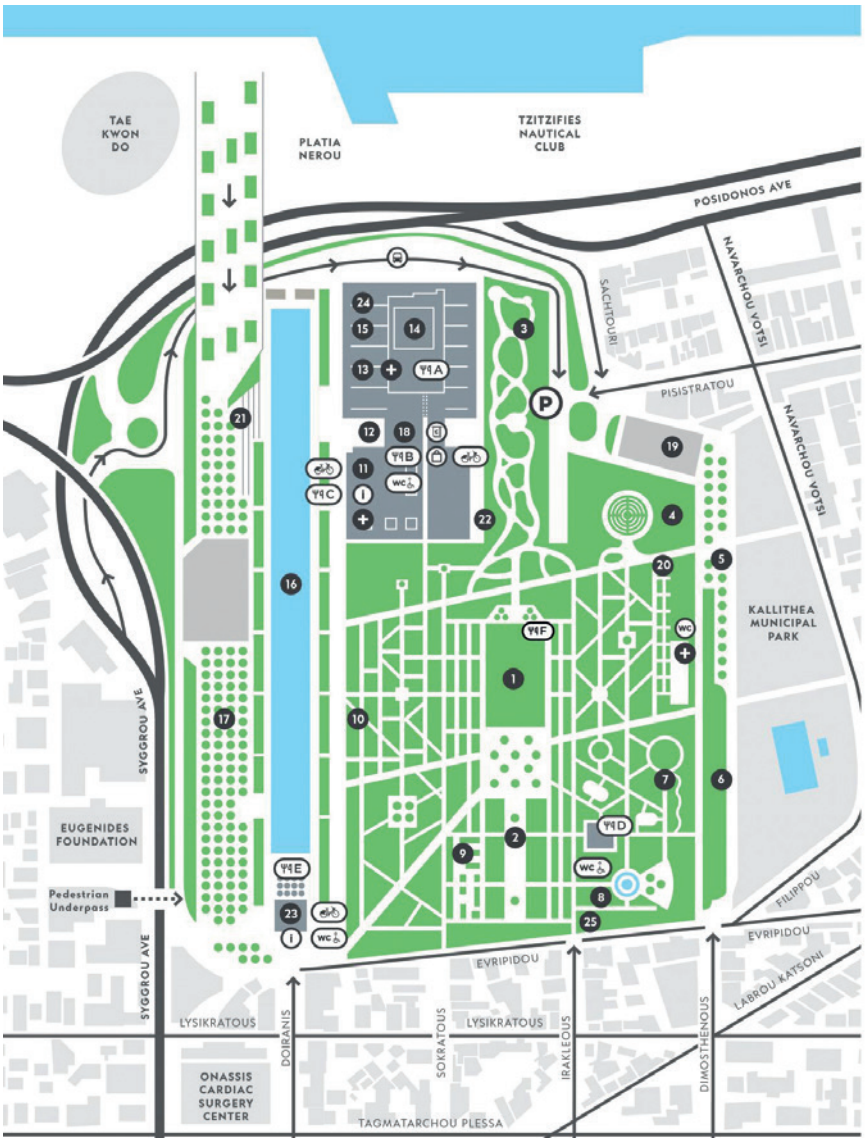
## Welcome reception

Welcome Reception (Ice Breaker) will be held at SNFCC Lighthouse which is located within a walking distance from the conference venue. Like every lighthouse, the SNFCC Lighthouse is encased in glass, offering panoramic views of Athens, Piraeus and the Saronic Gulf, as well as direct visual connection to the Acropolis hill. Surrounding this glass space, the Lighthouse offers an open-air space, sheltered by the canopy.

To reach SNFCC Lighthouse just get on the other side of the highway in front of the main entrance of the conference venue using the underpass. You can reach the top of the Lighthouse following JISDM signs, either walking along the canal or through the Stavros Niarchos Park.

## Symposium dinner

The symposium dinner will be held at restaurant Agora Riviera which is located a few kilometers outside the city of Athens at Kavouri-Vouliagmeni area just two steps from the seaside. *Agora Riviera* restaurant is one of the most iconic restaurants in Athens specializing in fresh seafood with an emphasis on locally sourced ingredients. Apart from the unforgettable flavors our participants will enjoy a mind-blowing sunset just in front of the decked terrace. Symposium delegates will be transferred from and to the conference venue by bus at no extra cost.



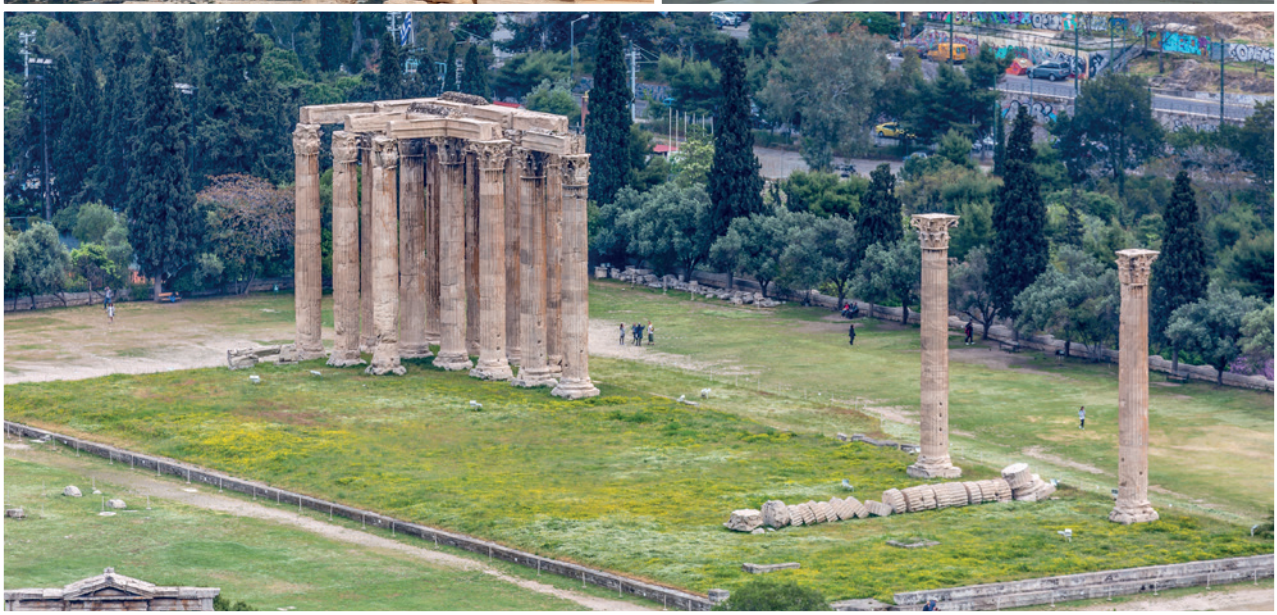

## Map

Use the corresponding numbers on the map to locate a venue.

1. Great Lawn
2. Pine Grove
3. Southern Walks
4. Labyrinth
5. Outdoor Gym
6. Running Track
7. Playground
8. Water Jets
9. Sound Garden
10. Mediterranean Garden
11. National Library of Greece
12. Agora
13. Greek National Opera
14. Lighthouse
15. Panoramic Steps
16. Canal
17. Esplanade
18. SNFCC Lobby
19. Bus Parking Lot
20. Vegetable Garden
21. Canal Steps
22. Buffer Zone
23. Visitors Center
24. GNO Level 5A
25. Outdoor Games Area

- SNFCC Bike Rental
- SNFCC Store
- Shuttle Bus Stop
- First Aid
- ATM
- Info Point

- ΥΦΑ Pharos Café
- ΥΦΒ Agora Bistro
- ΥΦC Coffee & Juice Vans on tour
- ΥΦD Park Kiosk
- ΥΦE Canal Café
- ΥΦF Park Kiosk - Souvlaki




ΖΑΠΠΕΙΟΝ

# ACKNOWLEDGMENTS

Dear participant,

Thank you for attending the 4th JISDM, Athens 2019. We would like to acknowledge the contribution of numerous individuals, public institutions and private companies that helped us in organizing this symposium.

We would like to thank *Eugenides Foundation* for providing us the facilities for the symposium including audiovisual equipment. We express our gratitude to the sponsors of the 4th JISDM, especially Platinum *(Leica Geosystems, GEK TERNA GROUP, GAIA OSE),* Gold *(Ucandrone, Power Public Corporation, Olympia Odos, HELLASTRON, EYDAP),* Silver *(GEFYRA, OSMOS, Attiki Odos, Planetek hellas, Monitera Group)* and Bronze *(PPC Renewables),* along with our media partner *(Sensors MDPI).*

We thank the key players of the symposium; our international co-organizers *(International Federation of Surveyors, International Association of Geodesy, International Society of Photogrammetry and Remote Sensing),* the public authorities and legal entities *(Ministry of Environment & Energy, Ministry of Infrastructure and Transport, Technical Chamber of Greece),* and endorsers *(Hellenic Association of Rural and Surveying Engineers, Hellenic Military Geographical Service, Hellenic Group of IABSE).*

Moreover, we would like to recognize the remarkable work of the Scientific Committee members who have contributed their time to reviewing the manuscripts submitted to the symposium.

Finally, dear attendee, we wish to thank you for your participation and contribution to the 4th JISDM. We hope you enjoy your stay in Athens.

**Prof. Vassilis Gikas**
The 4th JISDM Organizing Committee

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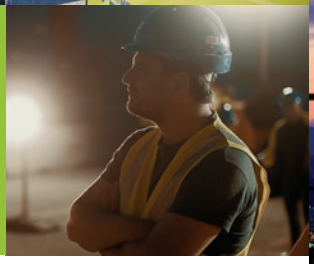

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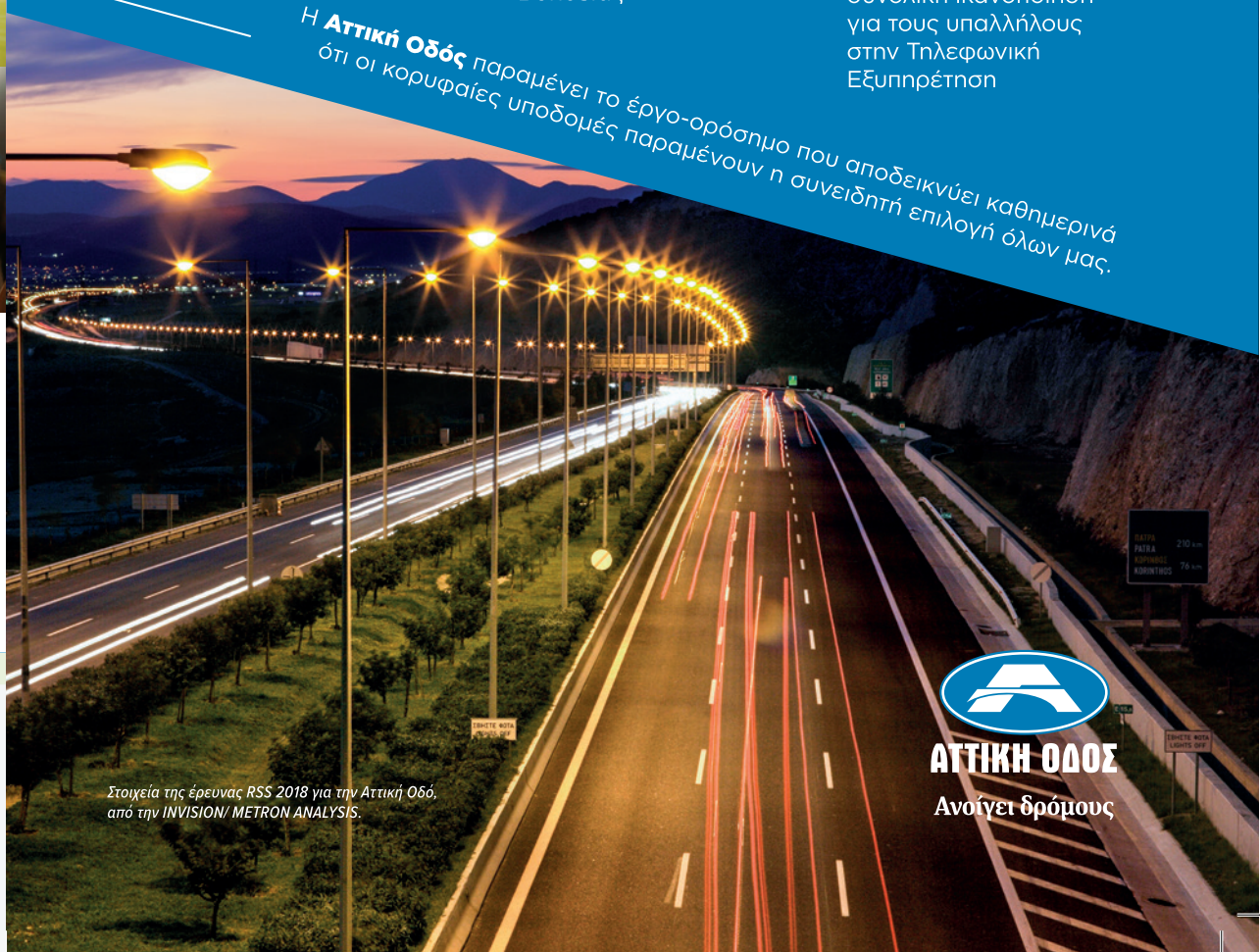

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ΑΤΤΙΚΗ ΟΔΟΣ
Ανοίγει δρόμους

# Αρμονική συμφωνία ζωής

Είναι δίπλα μας, μέσα μας,
ολόγυρά μας. Είναι παντού στον
κόσμο μας. Είναι το νερό που μας
ξεδιψά, μας δροσίζει, μας αναζωογονεί.
Το νερό είναι το περιβάλλον μας.
Η ΕΥΔΑΠ, πιστή στη δέσμευσή της
για υπηρεσίες υψηλού επιπέδου,
προσέχει μέχρι και την τελευταία
σταγόνα νερού που φτάνει στο
σπίτι μας. Με εξειδικευμένη
τεχνολογία και τεχνογνωσία,
σεβασμό στο περιβάλλον
και με πρόσωπο ανθρώπινο
και φιλικό, η ΕΥΔΑΠ φροντίζει
για την ίδια μας της ζωή.

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ΕΥΔΑΠ

Το νερό είναι στη φύση μας

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Γέφυρα Τσακώνας

Γέφυρα Ευήνου

# Η ΔΥΝΑΜΗ ΤΩΝ ΕΡΓΩΝ

Συνεχίζουμε να δημιουργούμε, αντλώντας δύναμη από τα έργα μας. Στην Ελλάδα και στο εξωτερικό: Αυτοκινητόδρομοι. Σιδηρόδρομοι. Λιμάνια. Φράγματα. Υδροηλεκτρικές μονάδες. Σύγχρονα εργοστάσια παραγωγής ενέργειας. Χώροι πολιτισμού, άθλησης και ψυχαγωγίας. Νοσοκομεία. Εκπαιδευτικές μονάδες. Έργα με ιστορία μισού αιώνα. Αποτέλεσμα σύγχρονης τεχνογνωσίας και ανθρώπων με σπάνιες δεξιότητες. Χάρη σε αυτούς συνεχίζουμε να κάνουμε αυτό που ξέρουμε καλά: Να παράγουμε σπουδαία έργα.

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