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Principles and Case Study of IMSGeo: Automatic Displacement Monitoring System for Construction Sites

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ABSTRACT: Displacement monitoring is a crucial aspect of the construction process, spanning all its stages. Surveying the changes occurring in the structure and its surroundings according to a suitable schedule is fundamental to ensuring work safety and mitigating investment risks. In this article, we highlight the distinctive features of the IMSGeo system, developed jointly by GEOalpin Ltd. and the Warsaw University of Technology (Department of Engineering Geodesy and Measuring Systems). The innovative solutions proposed in the system are characterized by the following integrated features: utilization of advanced adjustment algorithms within a cohesive system, adjustment of a multi-station network, analysis of reference system stability as an integral component of each measurement epoch, reflectless measurement of surfaces and structural elements of objects, presented as a unified 2D or 3D entity, capability to position measuring instruments (motorized/robotic total station) without the need for additional monitoring devices to ensure station stability, implementation of a fully mobile WEB platform for the presentation, interpretation, comprehensive analysis, and archiving of geodata, use of Internet cloud computing for data collection, analysis, presentation, and distribution of monitoring results, ensuring independence from local server infrastructure, user platform functionality designed based on survey research conducted among investors, contractors, inspectors, building supervision representatives, and property managers. The IMSGeo system does not require additional capital investments in infrastructure from investors or contractors and is highly available and scalable. The practical section of the article introduces the IMSGeo system's WEB platform and its implementation on a selected site in Warsaw, Poland.

KEY WORDS: structural health monitoring, geodetic displacement monitoring, geodetic services for investments, construction site safety, engineering geodesy.

1. INTRODUCTION

Systems for monitoring the condition of engineering structures have been developed for many years by both manufacturers and suppliers of geoinformation technologies [8],[13],[14], as well as scientific institutions [2],[3],[4]. There are many dedicated solutions known, the creation of which was inspired by specific needs. For example, the article of Wilde et al. [17] describes the assumptions of such a system in the context of monitoring the roof of the Forest Opera in Sopot. Other, similar solutions have been described in numerous publications [8], [16], [18], [19]. Historically, the period of the beginning and the middle of the 2000s in Poland was characterized by significant activity of geoinformation technology suppliers, especially in the context of implementing key projects of the dynamically developing national economy. Examples of the first and at the same time extremely successful implementations of integrated geomonitoring systems include implementations in the KGHM Polska Miedź SA company, the Bełchatów Brown Coal Mine [5], or during the construction (and the ongoing expansion) of the second line of the Warsaw Metro [7]. In highly industrialized countries of the world, the development of geodetic monitoring systems has been observed for several decades. There are many examples of implementations and technological problems solved on these occasions. Many of them resulted in numerous publications of an interdisciplinary nature. It is worth mentioning here [1],[11], although the list of possible items to cite would certainly include thousands of scientific articles, technical reports, or chapters of monographic studies. There are also many textbooks published in many languages – mainly in English or German [10],[12]. Many similar studies can also be found on the domestic publishing market, for example [15]. Geomonitoring systems are also a dynamic, developing industry in the field of civil engineering. As a rule, however, these are closed systems, focused on the use of specific instruments and programs. In this area, there are practically no solutions with an open structure (so-called "open source"), and the possibilities offered by manufacturers - i.e. modules, functions, and procedures are usually ready-made geoinformatic products. These factors create a demand for flexible, mobile and fully scalable systems that can be adapted to real needs to the best extent possible. Observing current trends in the field of IT, one can notice the dominant role of mobile solutions (from "mobile technologies") developed to a large extent at the expense of sometimes ineffective desktop (stationary) solutions. The current, briefly presented state of

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knowledge inspired the authors to conduct conceptual work aimed at:

- classifying available solutions in the field of geodetic monitoring and highlighting their characteristic features,
- indicating development opportunities in the context of designing new, universal solutions based on the existing state of knowledge and technology,
- proposing an innovative, unique solution that takes into account the contemporary needs of the construction industry and contemporary contractors of geodetic, geotechnical and construction-building works.

The presented topics are the subject of research by the Department of Engineering Geodesy and Measurement Systems, Faculty of Geodesy and Cartography of the Warsaw University of Technology, implementing a grant from the National Center for Research and Development in a consortium with the company GEOalpin Sp. z o.o. As part of this project, an intelligent deformation monitoring system with the acronym "IMSGeo" is being developed, the methodological assumptions and results of the work to date of which are presented later in the article.

2. SYSTEM ASSUMPTIONS

Robotic Total Station (RTS) is one of the spatial geomonitoring technology. It is based on using a total station (automated tachymeter) as a sensor collecting measurement points.

Could we treat the technology such as other geotechnical sensors as piezometers, inclinometers, pressure cells, etc? The main differences are:

- RTS is based on the “ancient” surveying trigonometric method,
- RTS use only a few active sensors (in many cases only one) Total station and a number of passive sensors prisms. Passive sensors don’t work without an active sensor,
- RTS measurements are not collected strictly at the same time – usually we need a few minutes to collect back signal from all passive sensors – prism.

Over the last years we could observe the tendency to replace RTS with structural monitoring due to their higher accuracy.

RTS technology still has many advantages – for example: The installation of passive sensors (prisms) is quite easy. Usually the installation covers quite a big territory and is quite cheap – It does not need cabling or a wireless connection.

Some of them have not still implemented. RTS thanks to collected data in a spatial wide XYX reference system it gives the option of correlating data from others monitoring technologies together. Based on the adjustment with least squares methods we good extend the RTS needs keeping the highest accuracy for this technology.

Intelligent Monitoring System IMSGeo has come back to bases of adjustment theory and implemented it to automated monitoring and has opened this method for the challenge of integrating monitoring data in one high accuracy net reference.

Technological details, as well as differences in the functioning of geomonitoring systems offered on the market, concern both the type of recommended measurement instruments, the method of acquiring, processing and analyzing the acquired data, as well as the possibility of using the program for a given type of design tasks. Among all the common features of the discussed solutions, the following criteria deserve special attention:

- the possibility of remote work with the system ("in the cloud") using mobile interfaces,
- the possibility of integrating automatic measurements of displacements performed with physical sensors (physical monitoring, also known as SHM - from "Structural Health Monitoring"),
- the possibility of handling automatic measurements with geodetic instruments (robot tachymeters, GNSS satellite receivers,
- the possibility of handling instruments from different manufacturers,
- the possibility of using reflectorless measurement technology (in the case of electronic tachymeters),
- the possibility of strict alignment of observations (using the least squares method).

3. METODOLOGY

For the purposes of the IMSGeo project, a dedicated research methodology was developed, which includes the following task blocks:

- development of procedures for automating the process of determining displacements along with the assessment of their significance based on geodetic measurements,
- functional assessment of the implementation of reflectorless monitoring measurements, within which both the implementation and conceptual aspects (selection of optimal grids of points of monitored structural elements) as well as computational aspects (surface approximation methods and point cloud alignment) are tested, as well as interpolation and visualization of the acquired data using various geostatistical algorithms,
- development of an optimal algorithm for aligning observations that allows for taking into account the non-permanent measuring station in the process of determining the displacements of controlled points, within which multi-variant simulations of the alignments of monitored control networks were performed, taking into account the stability or lack of stability of measuring stations,
- development of a "platform" for data exchange with access for the client using cloud computing, within which will be implemented newly developed procedures and algorithms using IT tools and a programming environment.

Test work on the operational efficiency of the system was carried out on a special test field in Łódź (the location of the consortium members’ office – Warsaw University of Technology and Geoalpin Sp. z o.o.), while the functional assessment in indoor conditions (with the maximum reduction of the impact of systematic errors occurring outdoors) was carried out in the Main Hall of the Warsaw University of Technology (Figure 1).

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Figure 1. View of the test stand and the research team in the Main Hall of the Warsaw University of Technology (photo by Oskar Graszka).

According to the assumptions, the presentation of measurement results is realized in the form of a dedicated geoinformation platform (https://imsgeo.geoalpin.pl/login) (Figure 2), in a structured form (collected information is divided depending on measurement techniques and their location). The new, unique solution, unlike similar systems, does not require constant measurement control by a specialist and intelligently identifies both the displacement of reference points and the measurement station. In addition, the so-called "noises" caused by mechanical or meteorological disturbances are defined.

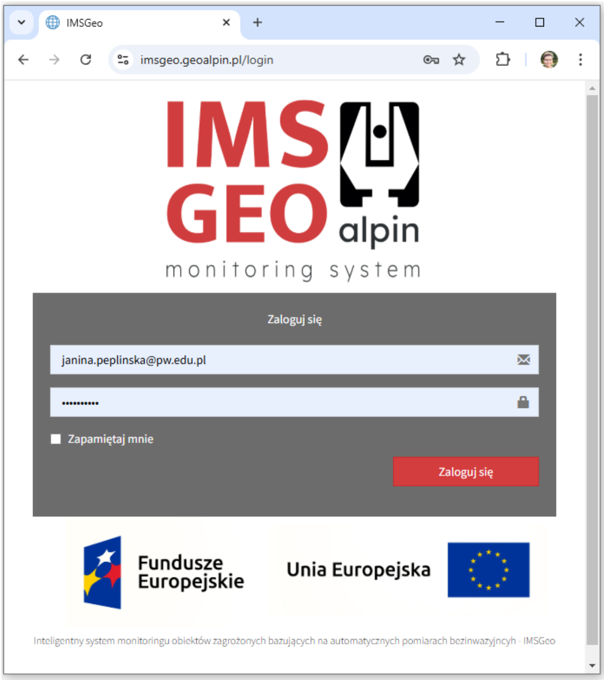

Figure 2. Website of the IMSGeo system.

Before starting to develop a functional analysis of the system and the database, a survey was conducted among experts representing various professional groups interested in implementing the monitoring system: architects, constructors, geotechnics, designers of bridges, roads and railways, hydrotechnics and others (Figure 3).

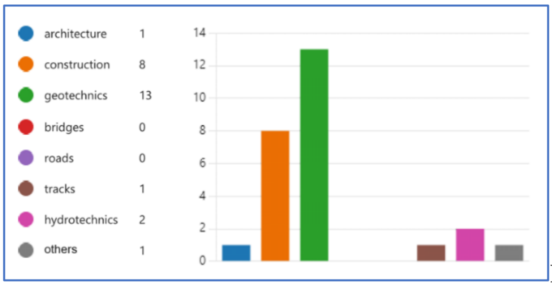

Figure 3. Number of experts participating in the opinion survey on the desired functionality of the IMSGeo system.

Figures 4, 5, 6 present the survey results – answers given to selected closed-ended detailed questions. As can be seen, the greatest interest is in access to data via the Internet platform, and monitoring data are most often used to control the displacement of individual points of the facility, located in critical structural locations, and the data are needed for broadly understood analyses, in particular for the analysis of the risk of construction failure/disaster during the implementation of the investment and in the early phase of operation.

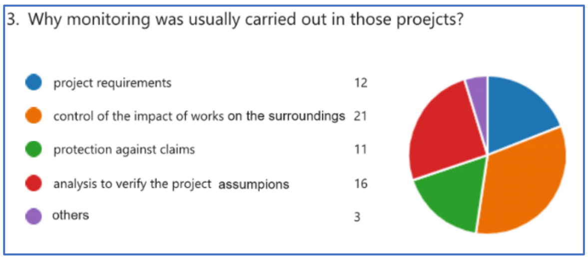

Figure 4. Summary of answers to the question 3: Why monitoring was usually carried out in those projects?

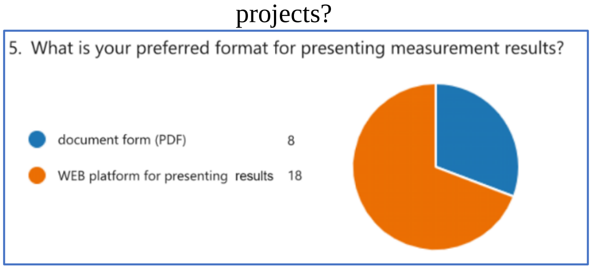

Figure 5. Summary of answers to the question 5: What is your preferred format for presenting measurement results?

Based on the collected opinions and their own experience, the team of authors created the IMSGeo platform, the main functionalities of which consist of the following modules: Map, Graphs, Results, Files and External Data (Figures 7, 8 and 9).

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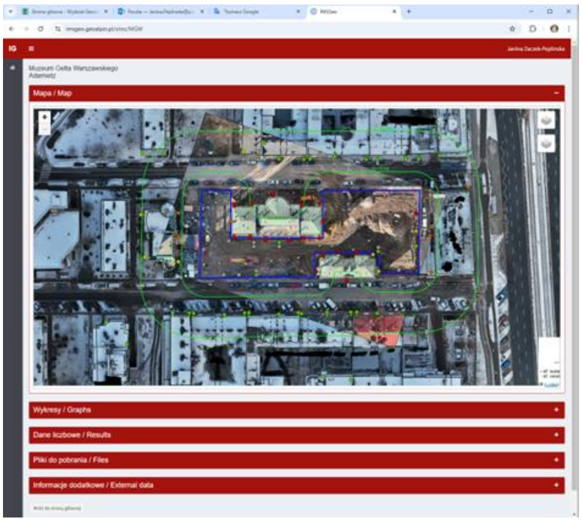

.Figure 7. Main page of the IMSGeo system.

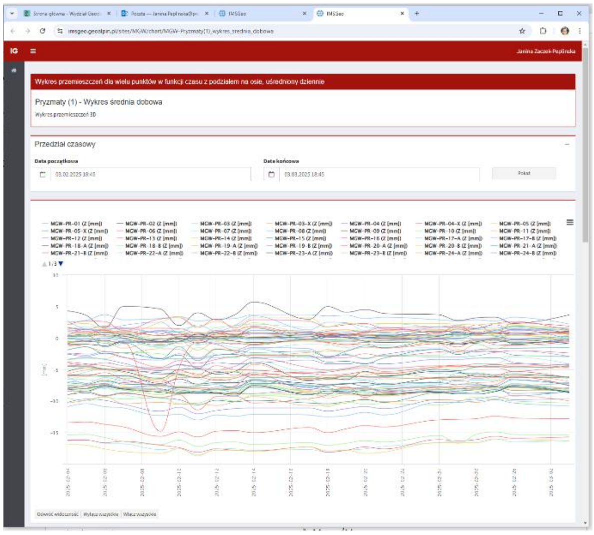

Figure 8. IMSGeo Graphs module: presentation of sample results.

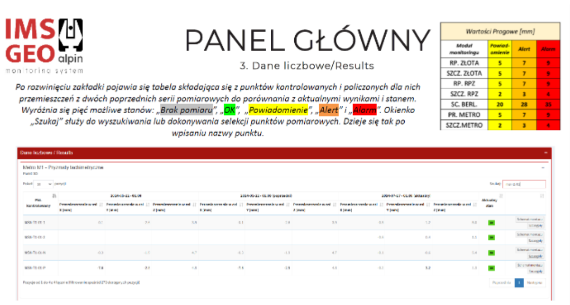

Figure 9. Results module of the IMSGeo system: presentation of the assessment of point displacements: color green means "OK", color yellow means "Notifications", color orange means "Alert", color red means "Alarm".

The IMSGeo geodetic monitoring system has already been implemented on construction sites in the center of Warsaw, and currently a team of surveyors and programmers is working on including inclinometric sensors (probes, horizontal and vertical chains, tilt meters) and hydrostatic leveling techniques in the automatic system. New functionalities are being implemented in the "InteliGeo" project financed by the Polish Agency for Enterprise Development (PARP).

4. CONCLUSIONS

Modern geodetic monitoring systems include both instrumental, teleinformatic and database solutions. Designing such solutions is a complex process that takes into account many elements from the borderline of various fields of knowledge. Therefore, before starting the study work, it is necessary to conduct an in-depth analysis of the current state of technology and define the areas that need to be developed. The authors of the article performed a functional assessment of most of the available commercial and dedicated solutions, characterized by different architectures or philosophies of operation. In relation to the conducted study work, a unique system concept was developed, which is currently being implemented in the form of a project financed by the Polish National Center for Research and Development. In detail, the project concerns the development of technology that allows for automatic performance of fast measurements without the participation of a surveyor, along with intelligent interpretation of results. This will allow for continuous examination of the condition of the object and ongoing assessment of the impact of various factors - e.g. construction works on neighboring buildings. Defined alarm situations (exceeding the permissible displacement ranges) will be automatically assessed, verified and reported. In terms of technical solutions, this approach constitutes a significant innovation in the field of building automatic monitoring systems for engineering objects.

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https://www.gik.pw.edu.pl/zgiisp/Badania-i-nauka/Projekt-POIR.01.01.01-00-0942-21-IMSGeo

https://geoalpin.pl/inteligentny-system-monitoringu-obiektow-zagrozonych-bazujacy-na-automatycznych-pomiarach-bezinwazyjnych-imsgeo).

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