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Section: Technologies of Geodesy and Cadastre

Selected methods of measuring deformations as a part of a system for monitoring structures

Krzysztof Baszkiewicz, Bogdan Kolanowski, Damian Krembuszewski, Dorota Latos, Wojciech Pachelski, Ryszard Sołoducha

Military University of Technology, Faculty of Civil Engineering and Geodesy, 2.S. Kaliskiego Street, 00-908 Warsaw, Poland

Abstract

Real-time evaluation of deformations, like stress, strain, displacements of structure components can provide essential information about the state of the structure. It's very important to assess correctly the condition of the structure, to identify its most important parts to be measured. In order to achieve this goal, it is necessary to choose proper methods of measurements and right instruments. The geodetic techniques of acquiring information about deformations have recently strongly intended for remote methods. This trend can be observed for example in using reflectors for distance measurements, interferometry, scanning or remote sensing methods. Very promising are also approaches employing instruments like clearance gauge or dial gauge. Evaluation of structure deformations is quite sophisticated. It cannot be carried out by geodesists alone on every day routine. The paper presents different measurement methods of deformations for different structures ranging from buildings to bridges, together with the attempt to determine the most suitable ones for each of them. The best technique is chosen based on the accuracy requirements, length of the measurement time and the total cost of the survey including its data processing. Finally the paper takes into consideration that some of the methods need to be backed up by alternative ones and proposes the idea of combining techniques to achieve the goal.

Keywords: measurement methods; geodetic techniques; deformations; state of the structure.

1. Introduction

All engineering structures are subject to diverse distortion both in the course of their construction, as well as in life. In addition to natural factors (static forces), which are gravity load and exploitation, as well as wind, water, unstable ground, etc., usually dependent on the type of structure, there are specific situations with unpredictable factors, with sudden and catastrophic consequences, such as floods, fires, terrorist attacks, and others. All of them require action within the so-called crisis management [7].

In the first case movements and deformation are of long-term and systematic nature, and are studied in a periodic or continuous way, mostly in conditions which allow direct access to an object or to parts of it.There are a variety of methods of geodetic measurement, as well as of measurement processing routines, with a rich history and a well-established methodology, eg. [8–9]. All of the above works treat this issue in fragments, i.e. with respect to a particular type of structure, or using only one type of measurement, or allowing for putting measuring marks or sensors directly on the structure.In contrast to them the proposed here solution is a comprehensive approach, taking into account a wide range of structure design types, measuring conditions, types of hazards, etc.

In addition to the need of rapid response in the event of an emergency, a characteristic in this case is generally no direct access to the object.And hence, the need to use specific methods of measurement, in particular also with no or limited visibility to an object (e.g. due to smoke).It should be noted that the examination of such monitoring are among the innovative and pioneering in the world. The few published work in this area include among others [2], [5–6].

In the second case, however, we are dealing with the need to complete and quick check of status and behaviour of the structure in order to assess types, size and extent of the risks, their elimination or reduction, as well as provision of the information necessary for actions to avoid or limit victims and material losses.This can be done through appropriate monitoring of structures, by which is meant continuous or at high frequency measuring of an object with the rapid (i.e. in

Corresponding author: Dorota Latos. E-mail address: dlatos@wat.edu.pl
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real-time) processing of measurement data, to allow for the current assessment of the state and changes of the structure, as well as of the resulting possibly security threats [11].

The purpose of this paper is to describe a practical concept of just such monitoring system structures in real-time, which, when used for potentially vulnerable objects, should have the following basic functions:

– continuous measurements (or with a high frequency) of geometrical parameters of the object in the three-dimensional (3D) reference frame, using simultaneously a few different independent measuring methods, such as tachymetry, stereo photogrammetry, laser scanning, microwave interferometry and air photogrammetry, together with the relevant geodetic processing and mechanical interpretation of data, as well as their transmission to decision support system [6], [12];
– decision support within the crisis management created with the use of an expert system, knowledge basis of structures and of the results of measurements [1].

The created system is to determine in real-time the changes of object geometry and, on their basis, on the built-in knowledge base and according to operator disposition, to develop guidance for decision maker [10]. The system should allow for implementation of the measures necessary for the proper performance of the monitoring tasksand of the DSS (Decision Support System) such as: configure measurement system with respect to each type of sensor used, initiate and carry out measurement cycle,record the measurements in the database, perform calculations and their visualization, submitting the results of calculations to the expert database, evaluation of changes, along with an interface to all stages of the implementation of tasks.

2. General description of the system

An object of this paper is a real-time system for structure monitoring and decision making support at the presence of disaster risk, both on the ground of the analysis of the structure's 3D geometry changes and of the knowledge base. The system will consist of three parts: a measuring system, the evaluation of the results of the measurements including analysis of distortions, and an expert segment. From the point of view of the system's action its basic functions are illustrated in Fig. 1.

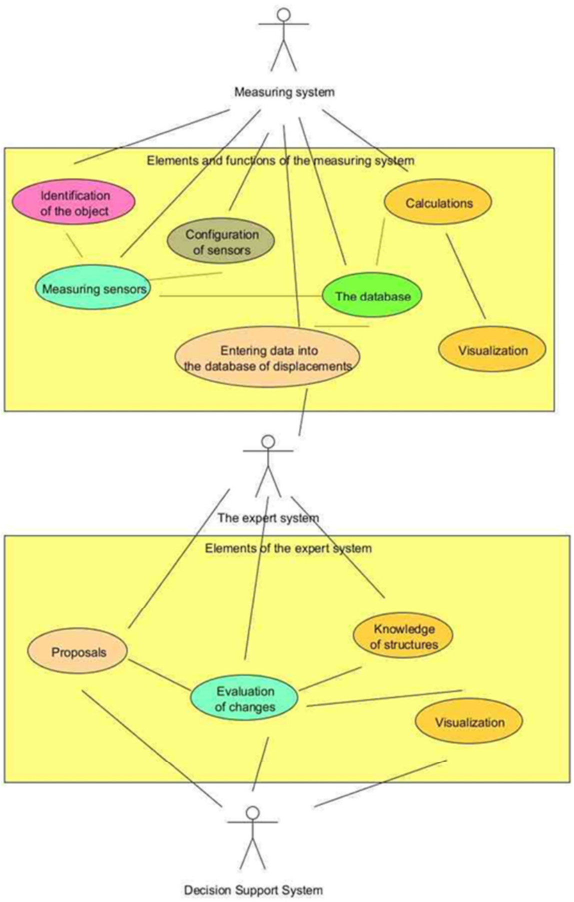

Fig. 1. The system's basic functions (UML use case diagram)

In the diagram illustrated are main functions carried out by the system and competences of its actors. The system is divided between its two main actors and a decision maker. Both parts of the system work in iterative mode whose parameter ending iteration is a command of the decision maker. The role of the actor Measuring System is mainly the preparation and execution of the measurements and their data processing. At each measuring cycle its operation ends with the visualization of results of measurement processing, and then the system continues performing the measurements. At this point begins the action actor of an iterative Expert System. It is designed to make an evaluation of the changes of control point positions with the use of previously stored knowledge base of building structures. The actor ends the cycle after the evaluation is submitted to the Decision System. Then starts the next measuring analysis loop.

3. The measurement subsystem

Determination of geometric parameters is a very important issue related to the estimation of movements of the monitored object. A crucial requirement for determining the movements, which was founded in the preliminary findings, it is to use only external sensors to the monitored object. This means that on the structure are not to be installed any sensors or measurement equipment. It is assumed that the object will not be accessible internally due various reasons, mainly for the security of people while monitoring in the highest risk of disaster. It determines both specific measuring instruments and methods, as well as optimal number of measurements and computational procedures. Issues arising from this assumption are the following:
- determination of the optimal number of control points for a specific kind of the object structure;
- selection of calculation method of spatial (3D) checkpoint coordinates, which is obviously dependent on the type of sensor and measurement data types;
- assessment of the measurement error size and checkpoint location changes should be analyzed in relation to the number of measurement series and statistical distribution, resulting from analytical tests.

3.1. Test measurements

As the first step for verification of initial assumptions about the selection of measurement methods were plain measurements of certain elements of the front elevation of the building. In this experiment it was to determine the accuracy of measurements and the control point coordinates in a local geodetic network. There were chosen three measurement methods:
- terrestrial laser scanning;
- terrestrial photogrammetry;
- direct measurement of checkpoints.

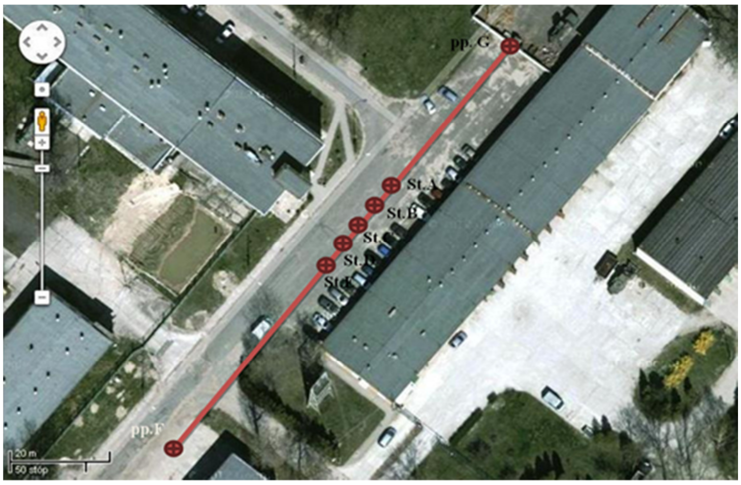

Fig. 2. Deployment of the network points

In order to ensure the quality of measurements it was constructed a geodetic reference (Fig. 2) as a straight line parallel to the test object. It consists of five posts separated from the object at 18m. The reference line was measured of warp was performed by means of the angular – linear instrument Leica TM30, along with Leica GMP111. Adjustment of the measurements was performed by means of the GeoNet software getting the following results:
- Planar coordinates x, y:
  - average point position error: 0.0012 m;
  - maximum position error: 0.0017 m;
- Height:
  - the average error: 0. 002 m

3.1.1. Measurement of control points by the direct

Measurement of the checkpoints illustrated in Figure 3 was performed without using mirrors. Each direction and distance to the points was measured three times by means of the Leica TM30 instrument. Measurement were adjusted by means of GeoNet, thus getting the following results:

- Planar coordinates x, y:
  - average position error 0.0020 m
  - maximum position error 0.0029 m
- High points:
  - the average error 0. 005 m

Fig. 3. Deployment of details selected for measurement

3.1.2. Measurement of control points by photogrammetric method

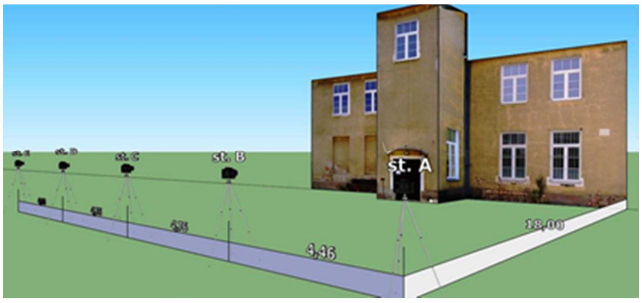

Fig. 4. Deployment of the five terrestrial points of photogrammetric network

The measurements were performed by means of the camera Kodak DCS Pro 14n with Nikon lens of focal length of 24 mm, after proper calibration of the camera by means of the calibration module, attached to the software Topcon Image. The reference network consists ground points, as shown on the Fig. 4. Prior to performing the test shots of the front wall, the camera calibration this process is made on the basis of the. Warp is made up of the five posts. Above each of them successively been set digital camera, as shown in the figure (Fig. 4). On the basis of the measured photopoints it was performed aerotriangulation to precisely determine external orientation elements each photo of a block, including its accuracy estimation [3].

The aerotriangulation consists of 10 photopoints and 7 checkpoints. The process of their adjustment resulted in the following error values:

- Planar coordinates x, y:
  - average position error 0.0020 m
  - maximum position error 0.0036 m
- High points:
  - the average error 0. 004 m

3.1.3. Measurement of checkpoints by the method of laser scanning

The process of acquiring data from the ground-based laser scanning consisted of several stages, such as designing the deployment of scanner positions around the object to be scanned, the choice of the method for joining point clouds together, the choice of the density of grid points, and data processing and modeling. All these elements directly affect the accuracy of the entire development. Measurements were performed by ground laser scanner Leica, model Scan Station 2, with registering shields from each scanner position. The first stage of data processing from the ground-based laser scanner, is their so-called “registration”, which is meant a combination and orientation relative to each other of all collections of points and their filtering.

After creating all necessary planes used for approximation it was made relevant piece of the front wall model. It was then used to perform the analysis of accuracy. Evaluation of accuracy is based on the differences of coordinates of a specific point in the three-dimensional model with respect to its counterpart in the point collection. This method was suggested in the paper by Oude Elberink and Vosselman [4].

On the basis of the obtained results, it was found that the mean error of point position by this method, in a planar system of coordinates amounted to 0.006 m. Higher error values were received for the points on the upper part of the front wall. The average value of error for selected points amounted to 0.007m. As in the case of planar coordinates the error values increase with the height of the front wall.

4. Summing up

The test measurements confirmed the reasonableness of using the methods of precise tachymetry and terrestrial photogrammetry to determine parameters of the displacement vector. At the same time using ground-based laser scanning is controversial due to the ambiguity of identification control points and to increase of point position errors associated with increased vertical angles of observation.

Proposed monitoring system intends using other methods for determining object characteristics, such as microwave interferometry and photogrammetry aerotriangulation with the use of unmanned aircraft (octocopter) equipped with the thermal camera. It is obvious that not all of these methods and sensors can be used to evaluate the geometry of the object, but will allow to collect data about the risks of hazard involved. As a consequence they can serve to enrich the knowledge base of the expert system for structure monitoring.

The ability to employ in an uniform system data of different reliability, of different nature and coming from different sources, requires the use of fuzzy logic for their processing. The realization of the main assumptions of the system assembly will be followed by mathematical modeling and computer simulation, in order to take a conclusive decision on the system configuration.

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