CONCEPT OF INTEGRATED CONTROL SYSTEM FOR MONITORING GEOMETRIC CHANGES OF THE TEMPORARY BRIDGE CROSSINGS

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1. INTRODUCTION

Since the beginning of 2010 the Centre of Applied Geomatics of the Military University of Technology has worked on integrated control system for monitoring geometric changes of the temporary bridge crossings in the aspects of their health devaluation. Problem becomes serious during natural disasters like floods or earthquakes. Temporary bridges are at that time built during extreme conditions, but it is necessary from strategic points of view for local societies to react to floods infrastructures damages. Providing maximum security level by means of getting continuous information about real technical aspect of a construction to detect any abnormal states could be provided by structural health monitoring (SHM).
Damages of local transport infrastructure caused by natural disasters like earthquakes, floods or avalanches bring very serious problems related to reconstruction of destroyed roads and bridges. This action should be done as fast as possible to enable further rebuilt process. Presently many temporal solutions are used, one of them are military temporary bridges used also as permanent construction for several years (Bartnicki, 2010). Fig. 1 presents adopting of the BLG-67 temporary bridge of 20 m length in Kletno (Kotlina Klodzka, Poland).

Fig. 1. Adopting of temporary military bridge to the civilian use.

In such a situation it is very important to keep permanent supervision of construction's health. Few years backwards it was quite difficult because of necessity of using measurement crew who would stay continuously on the object. Today's market brings up many automated instruments and solutions that can be used for these purposes.
For about twenty years scientists from couple of world famous universities have been working on using GPS data to detect deformations of big structures like tall buildings, long bridges or dams. Construction displacements at objects of this scale are quite large so GNSS accuracies are sufficient. Main elements of monitoring system includes high sample rate GNSS receivers and software able to calculate phase measurements to sub centimetre values. GNSS based structural monitoring systems became common solutions specially at big structures located in dangerous regions (e. g. Celebi and Sanli, 2004; Chen et al., 2001; Knecht and Manetti, 2001; Ogaja et al., 2007; Tamura et al., 2002).
The Centre of Applied Geomatics MUT started studies to develop reliable method of structure health monitoring using GPS phase observations in 2007 (Figurski et al., 2007). Presently two faculties of the Military University of Technology work on such a project: Faculty of Mechanics and Faculty of Civil Engineering and Geodesy. This paper presents the idea of the system for SHM in real-time using different types of sensors (GNSS, displacement sensors, LMS) and results of the preliminary test made at the University upon the BLG-67 temporary bridge.

2. MEASUREMENT TOOLS

Idea of measurements and instruments selection should take into account different mounting and working conditions because of many kinds of bridge types and their locations. For that reason the proposed system will consist of many kind of sensor and solutions. GNSS (Global Navigation Satellite System) will be the main measurement technique, used in both ways: as a constructions geometry changing sensor and as a time scale provider for data integration.
First research taken at test station in Mechanics Faculty (described in next chapter) shows that RTK (Real Time Kinematic) method enables to obtain sufficient accuracy to be alternative measurement solution in this kind of projects to classical geodetic manners. The main advantages of this method are fully automated measurement of 3D coordinates in near real time with frequency up to 50 Hz and easy usage of data streaming. Accuracy of RTK method is about 2 cm for horizontal and about 3 cm for vertical component. The main limitation of this method is the good visibility over GNSS antenna.
Another measurement tool used in the project is inductive movement sensor. It gives a measurements in one direction with high accuracy (1 mm) and frequency up to 20 Hz. Main disadvantage of this sensor is mounting method that needs a stable grappling from at least one side of a construction. In case of studying vertical displacement of long objects using those kind of tools becomes very difficult or impossible. That was the main reason why integration with GNSS and remote levelling was taken into account.
Automated remote levelling with digital survey instruments is another precise method (accuracy <1mm) that will be used. Measurements with this method requires special targets and permanent visibility among target and the instrument and distance among them should not be greater than 50 m. This facts brings another limitations the system.
The last survey technique used in this project is motorized tachymetry.

It gives the highest spectrum of usage because of possibility of automated measurement of angles and distances to special targets mounted on many different places on the object. Disadvantages of this method is very high price of this kind of sensors and low measurement frequency.
From non-geodetic group of sensors digital gyros and accelerometers will be used to provide other types of information about change in construction geometry. Table 1 describes types of sensors that will be used in the project. Fig. 2 presents the idea of integrated system for structural health monitoring.

	Measured parameter	Accuracy	Sampling rate	Reference
GNSS	3D displacement	2 cm vertical 1 cm horizontal	up to 50Hz	WGS 84/ local
Inductive sensor	1D displacement	about 1mm	up to 20Hz	local
Gyro	1,2,3 direction rotations	0.01° - 1°	up to 200Hz	local
Accelerometer	1,2,3 direction acceleration	0.1-1 m/s^2	up to 1000Hz	local
Tachymeter	Angles and distances	angle up to 0.5” dist. up to 0.6 mm	about 5 s	local
Leveling	Height differences	<1 mm	about 2 s	local

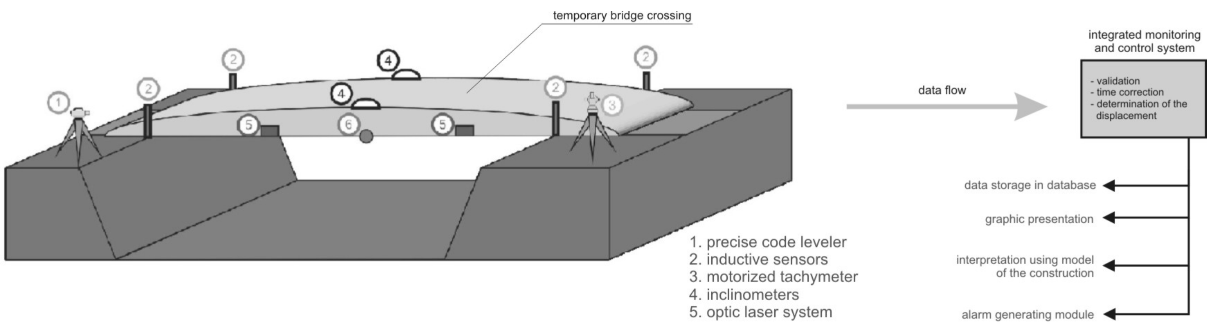

Fig. 2. The idea of integrated system for structural health monitoring.

3. DATA ACQUISITION, INTEGRATION AND COMPUTING

Main idea of integrated multi-sensor system is acquiring different types of measurement information using one precise time scale. This is very important at measurements where high frequency displacements are expected. In this project bridges construction measurements are the main group of objects to monitor. Bridges constructions and destructive forces affecting on these buildings are different kind each so system should be flexible for many kind of data acquisition techniques. It means that different nominal rates should be provide including types of sensors and integration methods. For data fusion Kalman filtering technique will be used (Kalman, 1960). It is a recursive filter that estimates the state of dynamic system of noisy measurements.

The state of the system is often represented as a vector. Kalman filters are applied to linear dynamic systems with discrete values in time. They are modelled on a Markov chain built on linear operators perturbed by Gaussian noise. At each discrete time increment, a linear operator is applied to the state to generate the new state, with noise mixed in, and optionally information from the controls on the system if they are known. Then, another linear operator mixed with more noise generates the visible outputs from the hidden state. Advantage of this technique is possibility of integration of different types of data with different rates and accuracies. Information that flows from the sensors will be filtered to compute final displacement vector, which will be used to compute real health state of the object.

4. PRELIMINARY RESULTS

First measurement test was taken at the Military University of Technology in February 2011 on special test station located in the Faculty of Mechanics. Main task of this work was to investigate possibility of using GNSS RTK solution in the integration process. Temporary military bridge BLG-67 main span element was forced by hydraulic elevator system loaded by 30 t bulldozer. More than 2500 cycles of up and down movement were done. During the test different displacement sensors were use: GNSS, inductive sensors, robotic tachymeter and levelling instrument presented in Fig. 3.

Fig. 3. Deployment of sensors.

Nominal displacement amplitude was about 10 cm. Figure 4 shows results of displacement measurement obtained from GNSS RTK, tachymetry, levelling and inductive measurements. From the group of these instruments leveling and inductive sensors had the best accuracy (<1mm) so they were used as reference for GNSS RTK and tachymetry solutions.

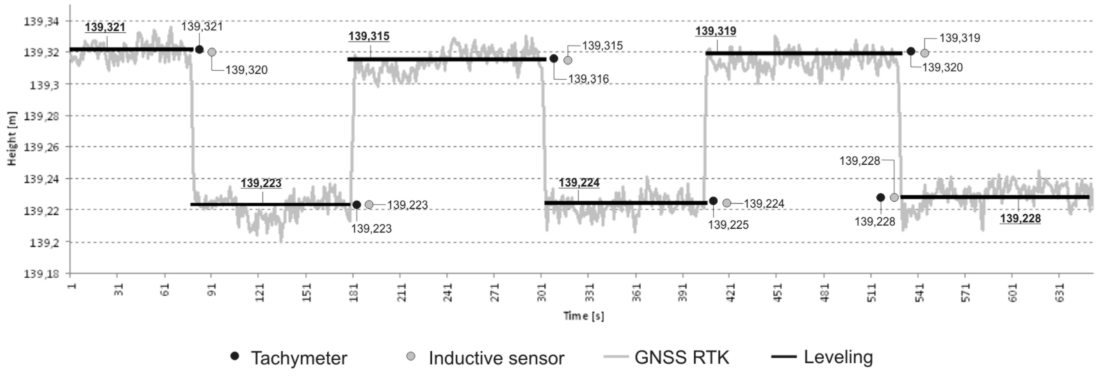

Fig. 4. Comparison between height changes obtained by different measuring sensors.

The test confirmed usefulness of GNSS RTK method in these kind of projects. The main restrictions for keeping high accuracy of vertical coordinate with GNSS RTK method is quality of receiver's clock and continuous service delivering with maximum delay of 3 seconds. Few series of measurement were taken into consideration. Observations were done in the same time of day to ensure quite same observation conditions. For all observation series accuracy of vertical component of multibase RTK solution was about 1 cm.

5. PLANS FOR THE FUTURE

Within next two years it is planned to develop real-time GNSS based measurement system for monitoring of the engineering constructions behaviour. Interdisciplinary project will provide new automatic tool for permanent inspection of construction's health and exploitation safety.

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REFERENCES

Bartnicki A. (2010): „Badania wytrzymałościowe i trwałościowe prototypu mostu samochodowego MS-20“. Biuletyn Wojskowej Akademii Technicznej, 1/2010, str. 197-210 (in Polish).

Celebi M. and Sanli A. (2004): „GPS in pioneering dynamic monitoring of long-period structures“, Earthquake Spectra, 18(1), pp. 47-61.

Chen, Y., Huang, D. and Ding, X. (2001): „Measurement of vibrations of tall buildings with GPS: a case study“. Health Monitoring & Management of Civil Infrastructure Systems, Chase and Aktan, Eds., 4337, pp. 477-483.

Figurski M., Gałuszkiewicz M., Wrona M. (2007): „A bridge deflection monitoring with GPS“. Artificial Satellites-Journal of Planetary Geodesy. Vol. 42 No. 4 2007, pp. 229-238.

Kalman, R. E. (1960): "New methods and results in linear prediction and filtering theory," Research Institute for Advanced Studies Kept. 61-1, Martin Co., Baltimore, Md. (1960).

Knecht A., Manetti L. (2001): „Using GPS in structural health monitoring“. SPIE'S 8th Annual International Symposium on Smart Structures and Materials, 4-8 March 2001.

Ogaja, C., Li, X., Rizos, C. (2007): “Advances in structural monitoring with Global Positioning System Technology: 1997-2006”. Journal of Applied Geodesy, 1(3), ppp. 171-179, 2007.

Tamura, Y., Matsui, M., Pagnini, L.-C., Ishibashi, R. and Yoshida, A. (2002): “Measurement of wind-induced response of buildings using RTK-GPS”. Journal of Wind Engineering and Industrial Aerodynamics, 90, pp. 1783-1793.