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Paweł Ćwiąkała, Wojciech Jaśkowski, Olga Sukta

THE CONCEPT OF A MEASURING UNIT FOR MONITORING THE STABILITY OF AREAS AT RISK OF LANDSLIDES

Summary

The article presents the concept of a measurement unit for monitoring landslide risk areas. The unit is a part of an innovative integrated system created for long-term measurements. The apparatus allows to measure the changes in baseline lengths between the points mounted on the ground. Configuring the system and measurement equipment will allow automatic measurement and remote data transmission. This paper presents the components of the measuring system and the sample implementation of the system in the area adjacent to the landslide in the Milówka village (hamlet Prusów). The first results of measurements are also presented. It is worth mentioning that both single item and the proposed system may support the decision-making procedures in order to determine the suitability of land for investment purposes.

Key words: risk areas, landslides, long-term monitoring, integrated system

INTRODUCTION

The most dangerous risks for the population are floods and landslides as directly affecting the greatest number of people. The importance of the problem is shown by numerous national and regional programs to prevent these tragedies. One example is the ISOK project (the computer system of the national protection against exceptional risks) co-financed by the European Community. The project aims to provide an effective system of national protection against exceptional risks. The collected data are used to construct risk maps and preparation of risk alert information system [http://www.gugik.gov.pl/projekty/isok 2012]. The system created within the research in the form of a group of integrated sensors, bridges the gap between the overall diagnosis of the site and the decision about the necessity of monitoring a specific area. Data from this system can be useful for the settlement of disputes for compensation presented by the property owners adjacent to the landslide. Within the decision-making process of monitoring two stages can be distinguished. The first is to define areas of risk, and the second is the decision to conduct the monitoring of the area. The described system, which in principle can be constructed at low cost, will support the decision-making process. It may constitute an intermediate stage of selection areas that should be covered by monitoring more widely. If an area (such as landslide or mine) is defined as the danger area, then in the intermediate stage of decision-making process the low-cost measurement system may be established. It can record any deformations and their values. If the observed values will exceed the threshold, then the observations can be applied on a larger scale.

THE CONCEPT OF MEASURING SYSTEM

Surveying measurements carried out so far have had the nature of periodic monitoring [Pielok 2002]. Measurements using physical sensors were also carried out in a time intervals [Pielok, Józwik, Jaśkowski 2004]. Not always both types of measurements were performed at the same time, making it difficult to subsequent analysis and inference. Data were analyzed after the field measurements (as postprocessing). Therefore the results were delivered late. Rapid development of tools for measuring physical quantities, their transmission and process gives the possibility to create systems that will be able to conduct measurements in a continuous mode. This paper discusses the concept of establishing such a system based on solutions applied in other fields of science in integration with measurements performed with surveying instruments.

Most measurements carried out surveying instruments are stored in the cache memory of device. The same solution is applied to other sensors that measure physical values (strain gauges, inclinometers etc.) – the results are sent through the data acquisition cards and recorded in the device controllers. Modern ICT solutions allow controlling multiple sensors and surveying instruments, as well as data recording and their subsequent analysis by a single device. Such a tool consists of a controller and a set of measurement cards [www.ni.com 2012]. The controller is responsible for controlling various components of the system by measurement cards. The control includes time synchronization of performed measurements, their analysis and recording. Management of system work is performed by a computer program, which determines the working conditions of individual elements, such as sample rate, filtering, data analysis and data recording. Data acquisition cards can be combined with measurement units by using link cables or via wireless communication (Bluetooth, WiFi) and allow to send information in two directions. At the stage of the system configuration the information related to the parameters of its work is sent to the measuring device and after start working the measurement results are received from the device. Choosing the connection is primarily determined by the distances between the system elements and the amount of data to be transmitted. Data acquisition cards allow full operation of sensors which measure strain, vibration, relative displacement, atmospheric parameters etc. In addition, controllers of measurement cards allow on-line presentation of results. A schematic diagram of the system is shown in Figure 1. Displaying results can be done by the monitor connected to the device or through the website where observations are presented. If a situation occurs that may create danger it is possible to inform the system manager about risk through SMS or e-mail.

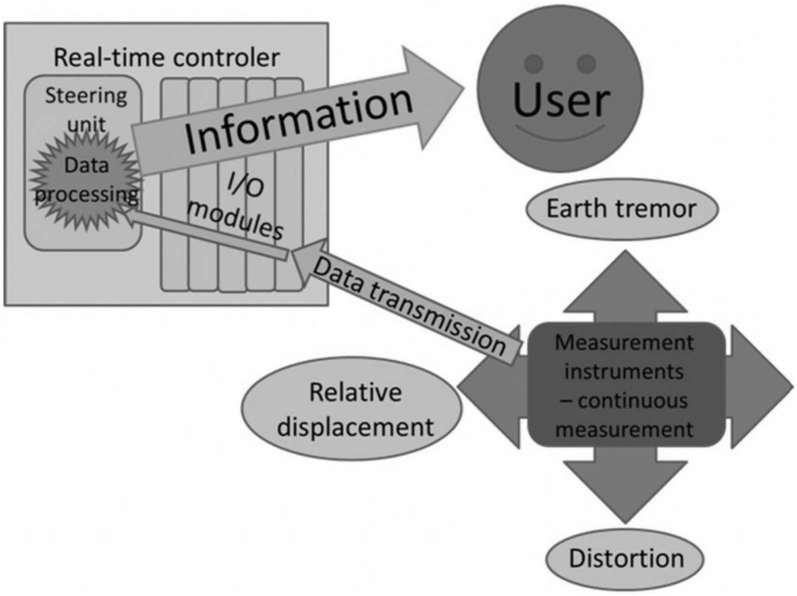

Figure 1. Diagram of a measurement unit

The presented system is designed to pre-monitoring which is used to confirm or reject the necessity of performing measurements for the area on a larger scale. This system consists of six physical sensors connected to the controller integrating data. As the physical sensors, the potentiometers of the SVP 45 group by the TELPOD company were used. These sensors allow the measurement of the slider position. By proper configuring the field base it is possible to study the relative movements of pairs of points [Jóźwik, Jaśkowski 2010]. These sensors allow the measurement of relative displacement with high accuracy at low manufacturing cost. More extensive description of the system configuration will be discussed on the example of landslide in Milówka.

DESCRIPTION OF THE TEST OBJECT

The object on which the system is being tested is a natural landslide in the Milówka village (in the Carpathians in the Żywiecki Beskid Mountains). The recent separation of colluvial masses occurred in August 2010 after long heavy rainfall. The landslide covers an area of 11 hectares and its vertical range is 117 meters. On the landslide there are longitudinal and transverse cracking of the ground of length up to 25 meters. Main scarp has a maximum height of 7 meters, while the remaining secondary scarps have height from 0.5 to 11 meters. The landslide forehead is 15 meters height. After the end of the landslide movement the forehead descended to the border of the Salamonka stream and the asphalt road at the bottom of the slope, cutting off access to the inhabited areas in the upper part of the stream (in the Prusów hamlet). Furthermore, activation of the landslide caused damage to four houses and five farms. The unpaved roads were also destroyed. They had enabled access to the inhabited areas in both landslides slopes, as well as outside them, on eastern side. Currently, the research project "Studies of the kinematics of surface mass movements using ground radar interferometry" (the project of Ministry of Higher Education, No. N N524 4658 39) is conducted to determine displacement of the landslide [Szafarczyk, 2012]. Figure 2 shows the location of the monitoring system (SM) on the area covered by the landslide.

Figure 2. Photo of the landslide area in Milówka (https://maps.google.pl/)

DESCRIPTION OF THE MEASURING UNIT INSTALLED ON THE TEST OBJECT

The proposed measurement system has been implemented on the presented landslide in Milówka. The system is mounted above the upper scarp of landslide (Fig. 2). Diagram of the measuring unit is shown in Figure 3.

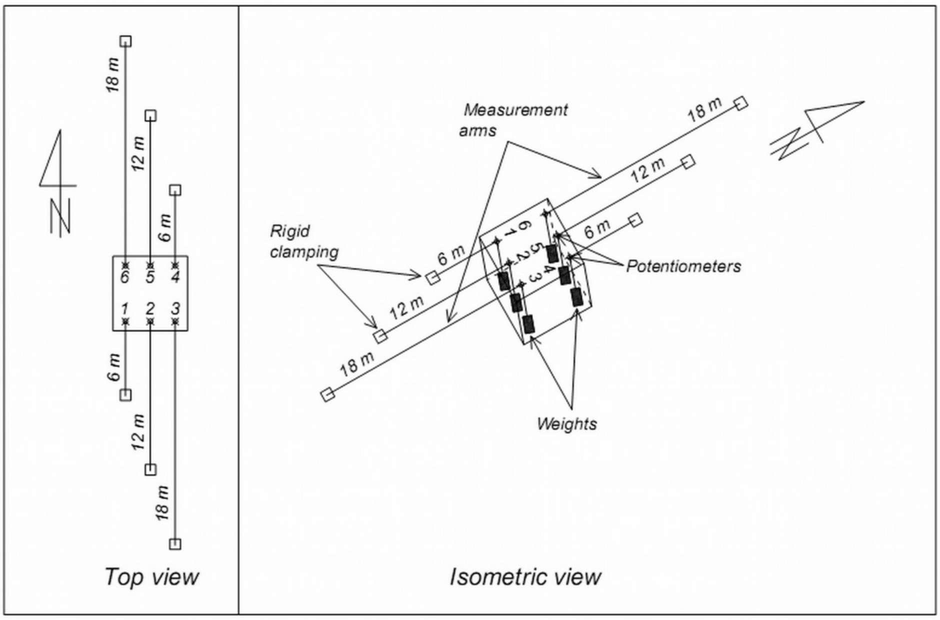

Figure 3. Diagram of the measuring unit installed on the test object

The system consists of six linear displacement sensors. The TELPOD SVP 45 resistive sensors were used. They provide high accuracy of displacement (approx. 0.3 mm) and high sampling rate [Ćwiąkała, 2011]. A useful range of measuring is about 35 mm for each of them. The steel cords are fastened to the sensors. At the ends of measuring arms they are connected rigidly to rods fixed in the ground. The weights are attached to the steel cords in order to tension them. Measurement arms have 3 lengths: 6, 12 and 18 m. Different lengths allow the monitoring of relative changes in the position of pairs of points in the area of landslide and recording any movements in different places. The device has also a thermometer installed, which allows to record temperature during the measurements.

In the system a remote recording to SD card is applied, as well as sending the measurement data by a GSM module every 24 hrs. In addition, the system sends daily SMSs indicating the correctness of the system operation in the field.

PRELIMINARY RESULTS OF MEASUREMENTS

The first stage of system preparations for field work was the calibration of sensors. This consisted of determining a constant multiplicand, which is used to convert the voltage to linear value of displacement for each sensor [Ćwiąkała 2011]. The calibration procedure was performed using an electronic caliper of 0.02 mm accuracy. The constant multiplicands were determined on the basis of 6÷8 points within the useful range for each sensor.

The intermediate results for the sample sensor are presented in Table 1.

Table 1. Intermediate results for the sample sensor

Point number	Caliper [mm]	Sensor [mm]	Difference [mm]
1	35.03	35.04	-0.01
2	30.03	29.98	0.05
3	25.15	25.13	0.02
4	20.06	20.08	-0.02
5	15.15	15.16	-0.01
6	10.26	10.27	-0.01

The linear characteristic for these sensors was also checked and no deviations were observed. On the basis of Table 1 we can speak of high-accuracy measurements.

Following the calibration steps, sensors were mounted on the measurement tables and placed on the ground. Figure 4 presents the measurement tables mounted in the center of the measuring system. In this figure a trench ready to install the anchor end points and measurement tendons can also be seen.

First tests of the system allowed the stability analysis of the land exposed to landslides to be carried out. Raw observation data was converted and reduced to the changes in relative positions of pairs points: central point and point at the end of the tendon. In the Figures 5 and 6 the graphs of changes in relative positions of pairs of points are presented. The data was recorded in the period between 18 May 2012 and 13 June 2012. In the Figure 5 the changes in the mutual position of points located below the center point (closer to landslides) can be observed. The values of the position changes did not exceed 1 mm in this case. It is worth noting that the points distant from each other by 6 and 12 m is characterized by almost identical movement, while the 18 m distant points displaced less than 2 other pairs. In the authors opinion this shows irregularities of deformation the process of the slope. Figure 6 shows the changes in relative positions of points lying above the central point. These changes are higher and achieve almost 2 mm. In this case the relationship is evident: the longer the measurement, the greater displacement: from 1.5 mm for 6-meters base to 1.9 mm for the 18-meters base. In all graphs the daily changes in the distances between points can be seen. Probably, it is the impact of temperature and humidity changes affecting ground or measurement sensors. It should be noted that the measurement arms are made of steel cables, which change their length as a result of temperature. Also, the moisture which settles on the sensor fibers, affects their work.

Figure 4. The field work

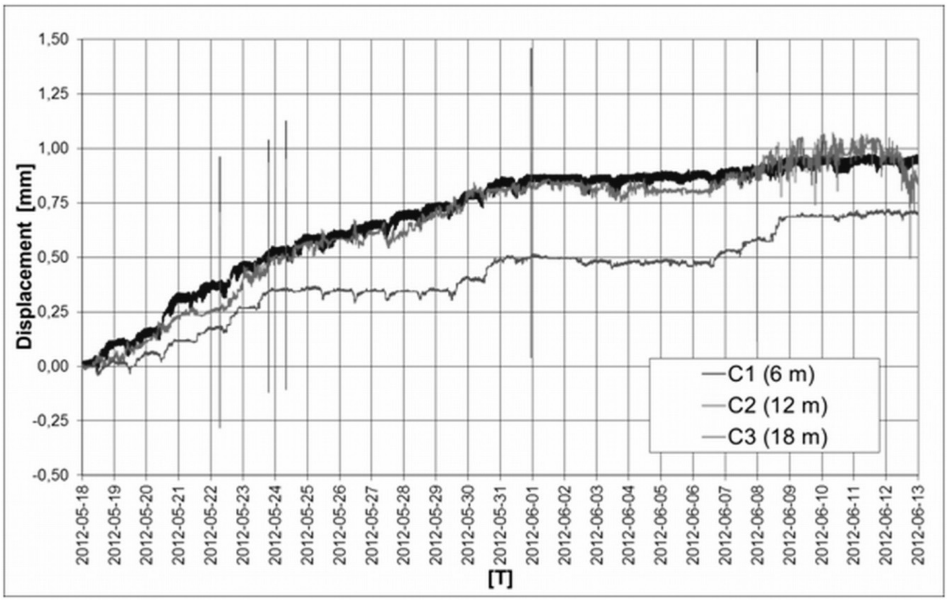

Figure 5. Graphs of length changes of cables no. 1, 2, 3

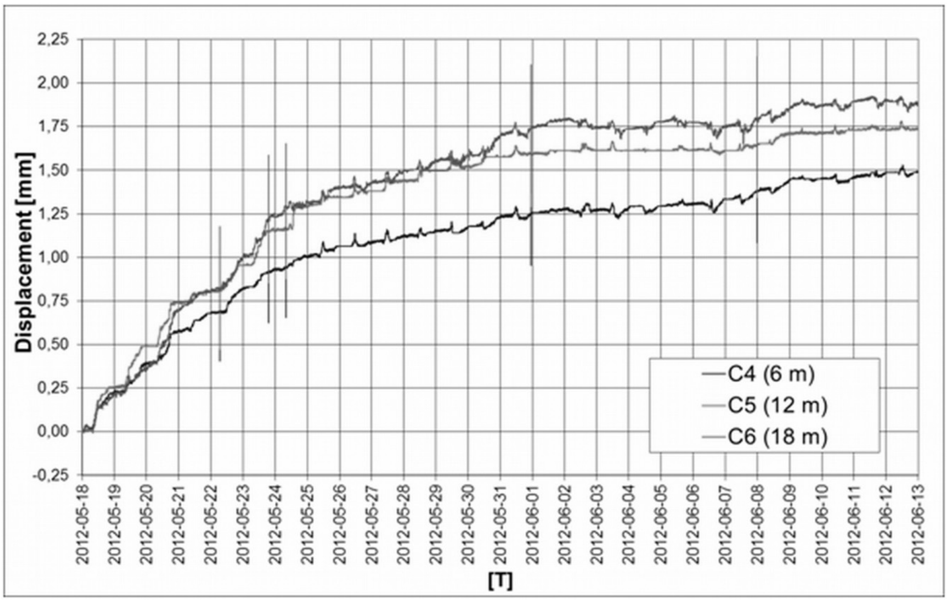

Figure 6. Graphs of changes in relative positions of pairs of points 4, 5, 6

CONCLUSION

Recently conducted displacement measurements have used practically no data integration, which could improve the efficiency of the measurements [Behr at al. 1998, Koo at al. 2010, Park at al. 2010]. Continuity of measurements allows the supervision of an object under different conditions and recording dynamic short-term phenomena which are difficult to predict and monitor by periodic measurements requiring planning and execution at certain time intervals.

The control measurements of displacements carried out recently, both relative and absolute, are not integrated and the individual devices do not transmit information between each other. Data integration is therefore a technological need and meeting it is only a matter of time. It was made by Leica Geosystems, company which create the GeoMoS system but is oriented to its own units and geotechnical and meteorological sensors. It should be noted that the solution proposed in the paper is a relatively cheap system both in terms of hardware and software. The planned systems developed under the research will be several times cheaper than the commercial solutions and consisted of components suitable to specific sites and areas.

The results of this type of equipment can contribute to the creation of a concept of integrated monitoring of endangered areas or object important from social point of view. Another aspect is to assist the decision-making process by ability to create an integrated system for monitoring the stability of buildings in the risk areas. All conducted research, extension and improvement of existing measurement systems are designed for human security and disaster prevention.

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REFERENCES

Behr J.A., Hudnut K.W., King N.E., *Monitoring Structural Deformation at Pacoim Dam, California Using Continuous GPS*, Seismological Research Letters, vol. 69, No. 4, 1998, str. 299-308.

Ćwiąkała P.: Ocena wpływów eksploatacji górniczej na powierzchnię i obiekty budowlane na podstawie ciągłego monitoringu przemieszczeń poziomych - rozprawa doktorska. AGH Kraków, Kraków, 2011.

Jóźwik M., Jaśkowski W.: *Monitoring przemieszczeń rurociągu na nasuwkach kompensacyjnych.* Zeszyty Naukowe Politechniki Śląskiej, Górnictwo, IX dni miernictwa górniczego i ochrony terenów górniczych: konferencja naukowo-techniczna: Wisła, 20–22.06.2007 Wydawnictwo Politechniki Śląskiej, Gliwice 2007.

Jóźwik M., Jaśkowski W.: *Rezystancyjny system pomiarów zmian długości pomiędzy znakami pomiarowymi*. Zgłoszenie patentowe, P-392572, 2010.

Koo K.Y., Brownjohn J.M.W., List D., Cole R., Wood T., *Innovative structural health monitoring for Tamar Suspension Bridge by automated total positioning system*, Proceedings of IABMAS – The Fifth International Association for Bridge Maintenance and Safety, Philadelphia, USA, 2010.

Park H.J., Yun C.B., Shin M.H., Lee J.J., Park S.Y., *Development of structural health monitoring systems for railroad bridge testbeds*, Proceedings of IABMAS – The Fifth International Association for Bridge Maintenance and Safety, Philadelphia, USA, 2010.

Pielok J.: *Badania deformacji powierzchni terenu i górotworu wywołanych eksploatacją górniczą*. AGH Kraków Wydział Geodezji Górniczej i Inżynierii Środowiska, Kraków 2002.

Pielok J.: *Wyznaczanie powierzchniowego tensora odkształceń na terenach górniczych w oparciu o pomiary geodezyjne*. Uczelniane Wydawnictwa Naukowo – Dydaktyczne AGH, Kraków 2005.

Pielok J., Jóźwik M., Jaśkowski W.: *Telemetryczne systemy pomiarów zmian długości z komputerową rejestracją wyników*. Warsztaty Górnicze z cyklu „Zagrożenia naturalne w górnictwie", materiały sympozjum, Polska Akademia Nauk. Instytut Gospodarki Surowcami Mineralnymi i Energią, Wydawnictwo IGSMiE PAN, Kraków 2004.

Szafarczyk A.: *Możliwości wykorzystania naziemnej interferometrii radarowej w monitoringu osuwisk*, Infrastruktura i Ekologia Terenów Wiejskich = Infrastructure and Ecology of Rural Areas / Polska Akademia Nauk. Oddział w Krakowie. Komisja Technicznej Infrastruktury Wsi ; 2012.

http://www.ni.com/ [access: 20.06.2012]

http://www.gugik.gov.pl/projekty/isok [access: 20.06.2012]

https://maps.google.pl/ [access: 20.06.2012]

Dr. inż. Paweł Ćwiąkała
pawelcwi@agh.edu.pl
Dr inż. Wojciech Jaśkowski
jaskow@agh.edu.pl
Mgr inż. Olga Sukta
sukta@agh.edu.pl

AGH University of Science and Technology
al. Mickiewicza 30, PL-30-059 Kraków
tel. 48 12 617 44 86