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Using a 2D laser scanner in investigations of structures subjected to impact of static and dynamic effects

Abstract

The new measuring methods based on the laser scanners, inertial units, laser instruments to control deformation, vibration, and tilt control, are expected to alleviate the assessment of the loss of usable values and safety of utilization of buildings, and engineering constructions in the mining-affected areas. This is of particular importance, first, in the case, of multi-storey, large panel, buildings, exploited for several tens of years, and on the other side, for instance, of bridges or mine shaft towers, being engineering objects subjected to static and dynamic loads. The paper analyses the possibility of using the cheap 2D scanners in the process of monitoring of tilt and deformation of the object, as a function of static and dynamic environmental effects, including mining ones.

Keywords: mining, surface objects, surveying, scanners.

1. Laser scanning in measuring displacement and deformation

The laser scanning became a widely used and popular method in obtaining geometrical information on the analyzed objects, including inventory of underground mine workings, or mining equipment [1].

There has been analyzed the possibility of constructing a measuring system in which the measurements of distance to the object, and selected measuring points is realized by means of a rotatable 2D scanner. Principal parameters were taken into account that must have been a compromise between the required accuracy of measurement, and opportunity to utilize the scanner in the conditions of performing field measurements, including the variant of continuous and automatic monitoring. The parameters taken into account are as follows:

- Range of operation
- Field of view
- Maximal frequency of pulsed laser diode
- Scanning frequency
- Angular resolution
- Measuring accuracy vs. distance, type of reflecting surface, working environment
- Price

An analysis of the market availability, and literature data in accordance with the above mentioned premised resulted in consideration of such solutions as: the scanner: Moduloc LDA 2D (UK), Hokuyo UTM-30LX i URG-04LX (Japan), Acuity 2D AR4000 (USA), SICK LD OEM 1000 i LD LMS series 500 (Germany). Tested in the Laboratory was the LMS 511- 190° scanner.

The literature-based comparative analysis of data relative to testing the measuring characteristics of SICK LD OEM 1000, or LMS 200, and Hokuyo URG-04LX scanners pointed at the advantage of the German solutions, in particular in the conditions of working in difficult environmental conditions [2], [3], [4].

2. Laser scanner: SICK model LMS 511

The source of laser radiation is the Sick LDLMS511 scanner [5]. Shown in Fig. 1 is the scanner installed in the mount designed at the Institute. It is provided with a laser view-finder, the whole being installed in a ball-and-socket joint. The manufacturer declares that the Sick LMS 511 scanner is the optical unit of class 1 of laser safety (i.e. safe for eyes), in accordance with DIN – EN 60825-1 (PN-EN 60825-1) standard, for infrared pulsed emission (wavelength λ = 905 nm),based on the certificate No.50 of July 2007, according to 21 CFR 1040.10. The laser diode of the scanner operates in pulsed mode, with frequency of 100 kHz, while the scanner head rotates with frequency from 25 Hz to 100 Hz. The distance-related beam spot diameter is: distance (mm) × 0.005 rad +13 mm. The LMS511 is originally provided with a monitoring system to control rotation of the head; the system automatically switching the laser diode off in the case of lack of rotation or interlocking of the head. The scanner operating conditions, as specified above, and certified in accordance with the EN 60825-1standard ensure that the radiation intensity neither exceeds 5 mW/mm^2 (39 mW from EN 60825/ 707 mm^2) nor the energy density of 0.1 mJ/mm^2 (1 mJ from EN 60825-1/707 mm^2).

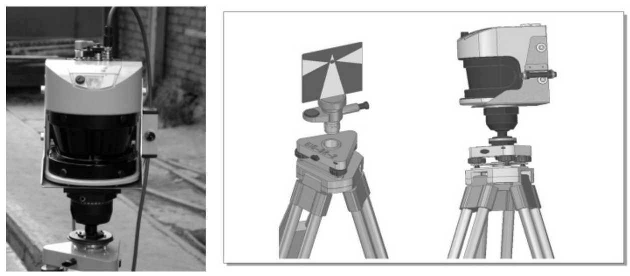

Fig. 1. Method of mounting the scanner with view-finder and measuring off the distance to measuring stand

Parameters of the scanner – catalogue data [5]

Scanning frequency: up to 100 Hz
Working distance: 0.7 to 80 m
Field of view: 190°
Maximal frequency of pulsed laser diode: 100 kHz
Angular resolution: 0.1667° – 1°
Reaction time: ≥ 66 ms
Beam divergence: 5 mrad
Statistical error (1σ) of distance measurement: ± 9 mm
Resistance to external illumination: 70 klux
Operation temperature: 5^{o}C to 40^{o}C
Permissible relative humidity: 85%,
Protection degree: min. IP 65 (DIN 40 050)

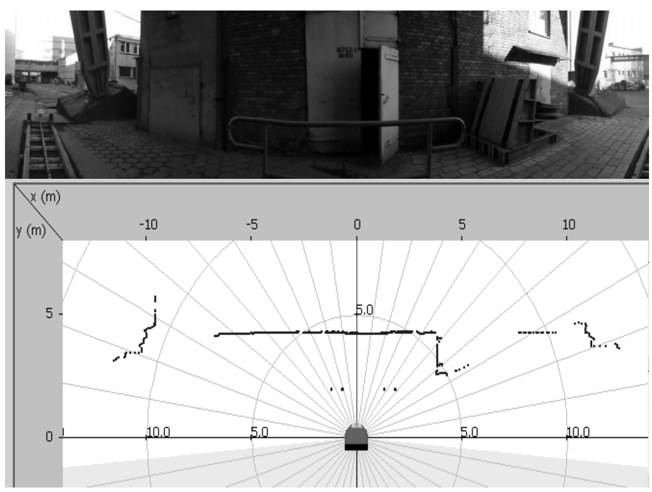

Fig. 2. An example: Scanning profile of northern frontage of shaft top made in the Sopas Sick utility program [6]

The LMS laser scanner of SICK AG production enables to determine the distance to surrounding surfaces at the plane of scanning (with the device fixed), through measuring the time of flight of the optical wave. This enables to create the scanning profiles of the surroundings (Fig. 2) in the plane of scanning, or prepare a spatial map of the object(s) investigated, through moving the measuring unit along a defined axis, or through rotation movement, and program-generated point cloud of measuring points in the Carthesian coordinate system.

3. Laboratory testing

The laboratory testing included the scanning of planes and of movable and steady elements. They have revealed that for an immovable reflecting surface, the maximum deviation of single measurement from the linear regression (for 25 measurements, to the fragment of white surface, 1 m wide) was Δ_{max} = 6 mm, for the 5 m distance. The scanner then recognized each of the objects with a size greater than 4 mm. There was possible to make a statistical readout of the distance to the object plane, with an average standard deviation being σ_{av} = 6 mm, at a distance up to 10 m, with the catalogue-based resolution of ± 14 mm at 30 m.

A novelty were the usability tests of the 2D LMS511 scanner to measure the low-frequency dynamic events. The measuring off was performed to a blackboard 30 cm-length cube place at the vibration table, type APS- 113 Electro-Seis (0.5-100 Hz), with a configuration, as show in Fig.3. The forcing parameters included sinusoidal vibrations with the amplitude of ± 36 mm, at frequency of 1 Hz, and ± 18 mm, at frequency of 2 Hz. The scanner was operating at the scanning frequencies 25 Hz, 50 Hz, 35 Hz i 100 Hz, and angular resolution values 0.1667°, 0.5°, 1°.

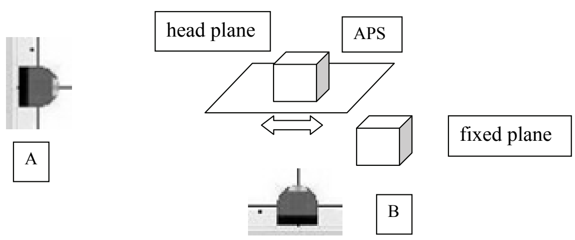

Fig. 3. Schematic diagram of displacement measurement at the oscillating table

Fig. 4 presents the profile of the head-on scanning in the extreme positions of the table. In turn, Fig. 5 presents the parameter scanning profiles for optimal operating conditions of the scanner, i.e. 25 Hz, 0.1667°.

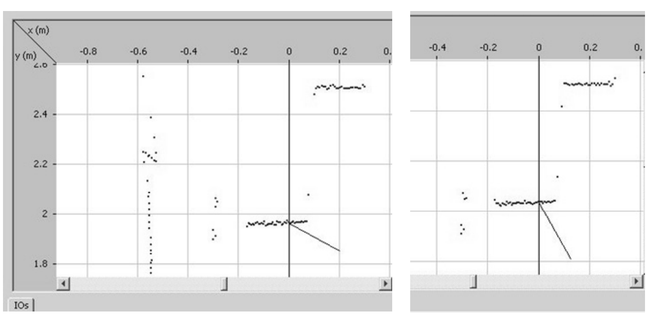

Fig. 4. Extreme positions of the head plane of the cube place on the vibration table, relative to fixed plane outside the table

The selected transformation, scanner-based, parameters of the APS 113 vibration table movements are shown in Table 1.

Tab. 1. Selected results of scanning the movement of the cube placed at the certified vibration table

Parameters of vibration table		Parameters of scanner		Head-on measurement	
frequency	amplitude p-p A_W	frequency	Angular resolution	amplitude p-p A_S*	A_W–A_S
Hz	mm	Hz	grad	mm	mm
1	72	50	0.5	75	3
1	72	100	0.1667	74	2
1	72	25	0.1667	71	1
2	36	25	0.1667	37	1
				Side measurement	
1	72	100	0.1667	75	3
1	72	25	0.1667	70	2

$^*A_S = \Sigma (D_{n1} - D_{n2})/n$

The optimal parameters of the measurement were obtained, both for head on measuring, and parameter-based measuring, in the situation when the scanner was operating at a minimal rotation frequency of the head, but at the maximal sampling frequency (minimal angular scanning resolution).

4. Measuring the displacements of the platform of the mine shaft frame

The Central Mining Institute has, for many years been conducting continuous, automatic monitoring of mine shaft frames and buildings using the CMI-developed laser and vibration sensors installed on the objects investigated [7], [8]. There have been recorded the tilt of the constructions vs. mining exploitation, or hydro-geological impacts, as well as those resulting from the movement of shaft conveyances, and climatic conditions (including insolation). There have been observed the differences in the records obtained at the upper shaft platforms and frame angle struts.

The site tests with the use of the 2D scanner were performed at a shaft frame being monitored, as described above. The distance measurements were performed to the frame in the hoisting axis (Fig. 5), and in perpendicular direction (Fig. 6).

Fig. 5. Scanning along the hoisting axis

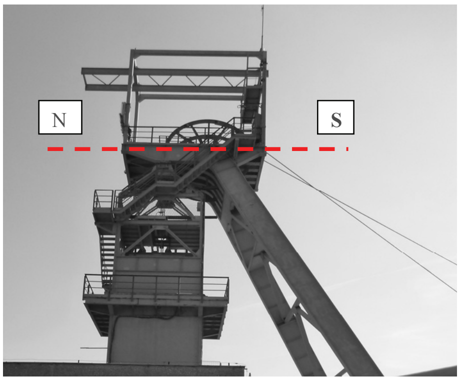

Fig. 6. Position of scanning profile at the frame platform

5. Test results of mine shaft frame

The dynamic measurements were performed during the movement of conveyances in the shaft. Of particular importance were the measurements of displacement of the hoisting pulley platform. An analysis of the scanning profile when shaft conveyances were moving, has revealed high stability (within the limits of scanner resolution) of the platform position from the angle strut direction (S-southern side, Fig. 6). In turn, the northern flank of the platform was moving within the limits of $s \pm 13$ mm, in the E-W direction. Higher stability of platform location from the angle strut side were confirmed by the scanning profiles in the hoisting axis, i.e. from southern side (Fig. 7).

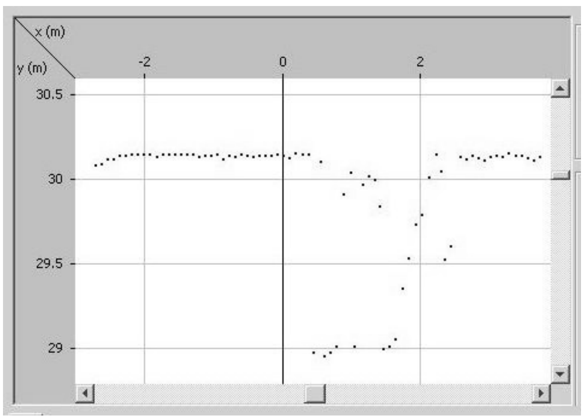

Fig. 7. Window in SOPAS program – Profile of distance to measuring points located at the platform; time 8.00 hrs, temperature of environment 11.5°C; the scanning profiles in the hoisting axis

The measurements of the long-term changes generated by insolation and Cheng of air temperature were conducted within 6 h time of a sunny day, characterized by a wide daily change of temperatures. The measurements were performed from the post located at the west. They were made as follows: relative to the parameter to hosting axis, from 8.00 to 14.00 hrs, with accompanying temperature change from 11.5 to 23.5°C. The results of recording have been presented on the linear graph, where the distances to the same locations at northern and southern parts of the western cross-bar of the platform have been related to air temperature recorded in 0.5 hr gaps (Fig. 8). The insolation of the construction, and change of air temperature has resulted in 11 cm displacement of the northern side of platform, and 7 cm of the southern one. This can be explained by its twist relative to shaft axis, and change of resultant tilt in time. Such reactions of the frame have also been observed with the use of the laser tilt and vibration sensors.

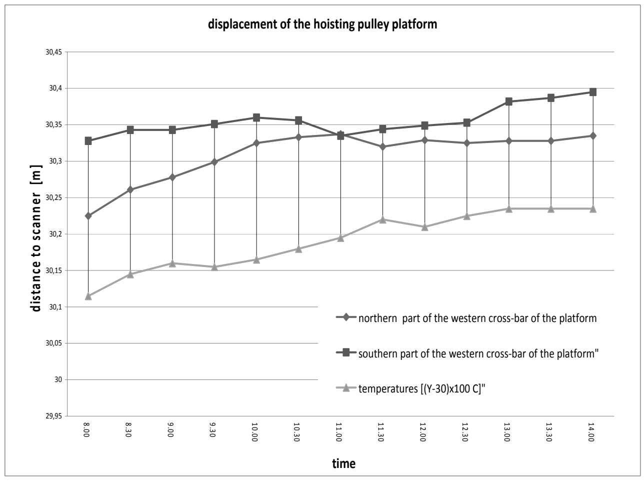

Fig. 8. Change of distance to scanner from northern and southern part of the western cross-bar of the platform (Fig.6) vs. time and air temperature

This fact confirms the graph of displacements converted from the one-day scale for the platform in winter time (also influence by changed of temperature and insolation).

6. Summary

The scanning system presented ensures high angular resolution, within the angle of view of 190°, high resistance to external illumination, and on-line transmission of measurement data through Ethernet connection. The unit has an option of the so-called 5th echo, which enables to keep its functionality, both in the case of inserting in a protective casing with additional glass window, and of operation in adverse environmental conditions (rain).

It is also characterized by high reliability when working in severe weather conditions. It is able to detect small objects at large distances (up to 80 m). It is applicable in measurements of objects and their positioning, also to monitoring of the areas, and avoiding collisions. Based on the program, one can select the zones of particular supervision.

One can also mention the price of the device. It is ten times lower than that of the cheapest phase scanners. However, the phase scanners have better resolution and measuring accuracy.

A number of publications present the examples of applying the scanners, including the dynamic processes of robotics, navigation and control.

The paper has confirmed the usefulness of 2D scanners in monitoring of static and dynamic events, exemplified by recording the effects of mining operations, and climatic conditions on the stability of the mine shaft frame.

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