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Short Communication

Conception of 3D Scanner Applied to Surface Digital Recording of Rock Mass Experimental Modeling

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Abstract

The mining industry is a source of widespread mining damage which can be counteracted in advance, especially when planning future exploitation. To fulfill the task, laboratory analogue modeling devices are used. They can experimentally model the geodynamic evolution of tectonic structures. The results of the experiments are 3D surfaces whose geomorphology should be digitally recorded. Our paper presents the construction of a 3D scanner that allows for modeling surfaces to digital recording as well as the measurement methodology. The possibility of applying the MSMA actuator to drive the scanner also is examined.

Keywords: analogue modeling, 3D scanner

Introduction

The mining industry is a source of widespread mining damage that generates considerable costs related to their repair. In certain cases this is an existing state whose origin is beyond our possible influence. The adverse phenomena may, however, be actively counteracted during the current operation phase and when planning future exploitation. In order to carry out such activity, one needs tools to model the rock mass behavior depending on the geological structure and the planned mining method. An example of such a device used for experimental modeling of the geodynamic evolution of individual tectonic structures and an entire rock mass can be a laboratory analogue modeling device called MAST-1. The Institute of Geological Sciences of the Polish Academy of Sciences in Wrocław [1] is in possession of the test stand, whose design and construction together with the control system was manufactured by the authors of the paper.

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Standard analogue modeling devices are usually squeeze boxes in literature known also as 'sand boxes' [2], where sand is used. Salt also is applicable [3]. Generally construction is quite similar to each other and they are variations of a simple box with one mobile wall [4]. In the newest constructions the interaction of two indenters also can be found [5]. The construction of the presented device is more advanced and enables us to carry out more complex research.

The results of the analogue modeling experiments are three-dimensional (3D) surfaces presenting geomorphology as well as cross sections of examined materials. The 3D surface should be digitally recorded, which means that its detailed shape is created by collecting real-world object data [6]. Our paper presents the construction of the test stand with a 3D scanner. The methodology of data acquisition and its conversion into 3D digital images also is explained.

In the industry a lot of 3D scanner solutions are known [7], e.g.:

a) rotary table scanners with the reorienting part being scanned
b) portable 3D scanners
c) joint manipulator with laser scan-head end effector
d) coordinate measuring machine with laser scan-head (Cartesian coordinate machine)

For the purposes of scanning the results of the laboratory analogue modeling, the devices (a) cannot be used because of the need for moving the model from an analogue machine to a rotary table. During the experiment a dry experimental material, mostly quartz sand, is applied to simulate the mechanical behavior of a tectonic structure in the natural environment under controlled laboratory conditions. The sand portable scanners (b) are inaccurate while finding the points of reference due to such unstable groundwork. Solutions (c) and (d) are similar to each other; however, the use of a joint manipulator as a carrier for a laser scan-head makes the investigated application functionality of dimensioning the model interior useless. On the other hand, in industry coordinate measuring machines are well known and are employed mostly in machine part measuring. In summary, a solution (d) seems to be the best from the point of view of both the required functionality and economic issue.

The above solutions (from (a) to (d)) are only a means of scanning movement over a scanned object. A different problem is an appropriate scanner (transducer) selection. The distance measurement in the case of dry materials such as sand is not a typical application of proximity laser transducers. In the technical specifications the producers do not include information about the method of adjusting the transducer parameters to dry materials or even sometimes they exclude such materials from the group of measurement objects. That is why the only reasonable option was to carry out some additional experiments with different types of laser transducers.

In most situations a single scan will not produce a complete model of the object. Multiple scans are required to obtain full information about the surface being modelled. During the experiment it was assumed that the laser transducer would move over the surface with a trajectory presented in Fig. 1 (a). Segment length l along the *x* axis would depend on the modeling surface size while t segment along

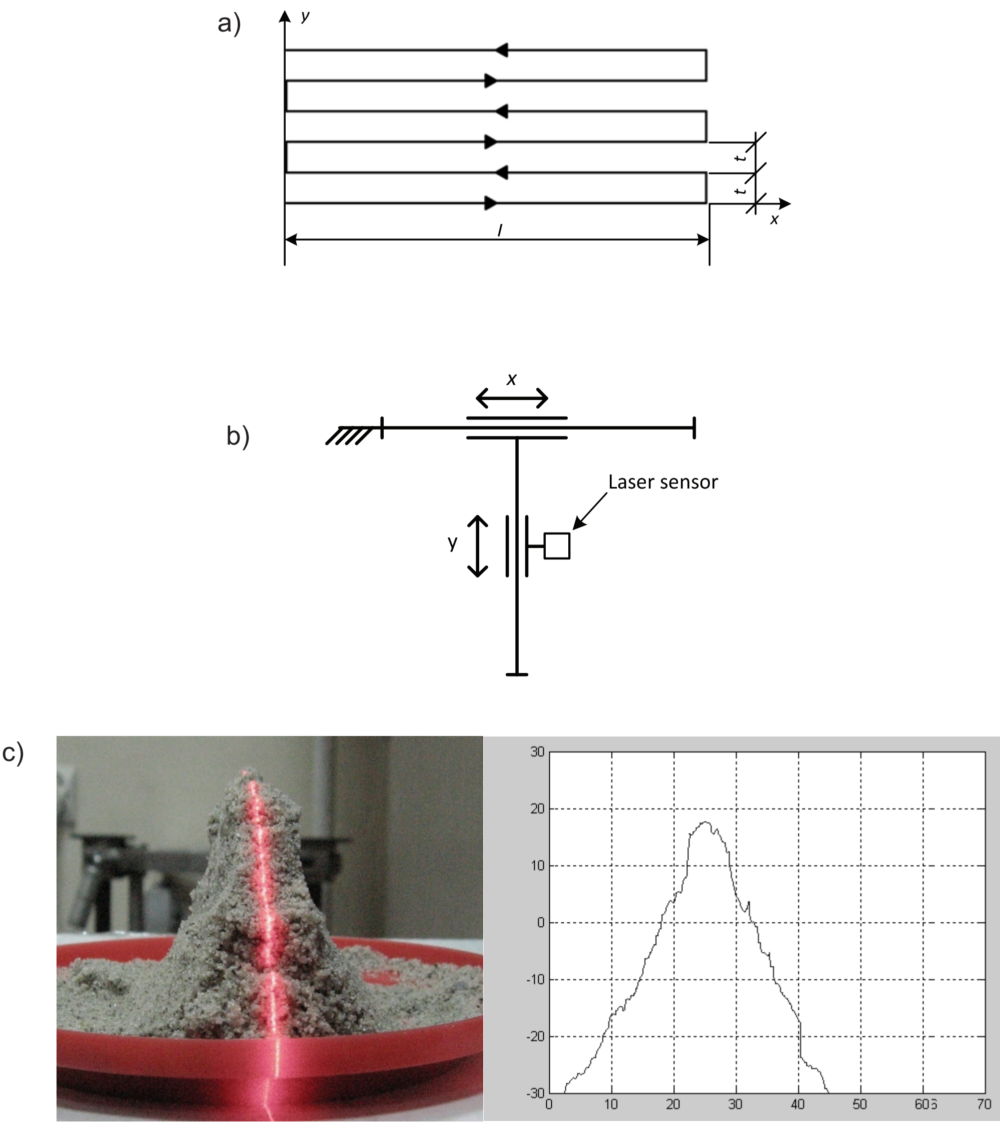


Fig. 1. The conception of the test stand for surface scanning: a) laser transducer trajectory over a surface, b) the kinematic scheme of the device, c) an example of applying the profile transducer ZG-WDS70 to a sand surface [11].

the *y* axis would depend on the type of transducer used. A laser transducer consists of a sensor and a signal conditioner. The usage of single-point laser measurement sensors is economically justified but it requires more scans (lengthening the measurement time). On the other hand, profile laser sensors, known as 2D sensors, allow entire shapes, including both height and width, to be measured simultaneously via a wide laser beam. The main advantage of such sensors is the requirement of only one axis movement. However, the solution is much more expensive and it can generate some artefacts. The kinematic scheme of the device is presented in Fig. 1 (b).

Within the framework of experiments carried out, three types of the transducers were examined:

- Profile transducer with a beam of 70 mm width, 60 mm height measurement distance, and 631 pixel resolution: ZG-WDS70 made by Omron
- Profile transducer with a beam of 23 mm width, 25 mm height measurement distance: ScanCONTROL 1700-25 made by MikroEpsilon
- Single-point transducer with 200 mm measurement distance: OptoNCDT 1401:200 made by MikroEpsilon

The width parameters of both profile transducers, which are very expensive and difficult to rent, were insufficient to apply to the real analogue modeling surfaces. In spite of this, they were tested on dry material samples to detect possible problems that may occur in future experiments. A sample of applying the profile transducer ZG-WDS70 to a sand surface is shown in Fig. 1 (c). That is why the main part of the experimental results presented in the paper, were obtained with the use of the single-point laser transducer. As a direct drive in *x-y* axis the magnetic shape memory alloy (MSMA) actuator is considered [8].

Experimental Procedures

The experiments were carried out on the test stand presented in Fig. 2 (a). The sensing head is an autonomous device that can send digital data through the RS232 port or by a standard current analogue signal of 4-20 mA. The controller attached to the system allows us to accurately adjust the sensor parameters as well as display the measurement values. The controller was connected to a PC computer

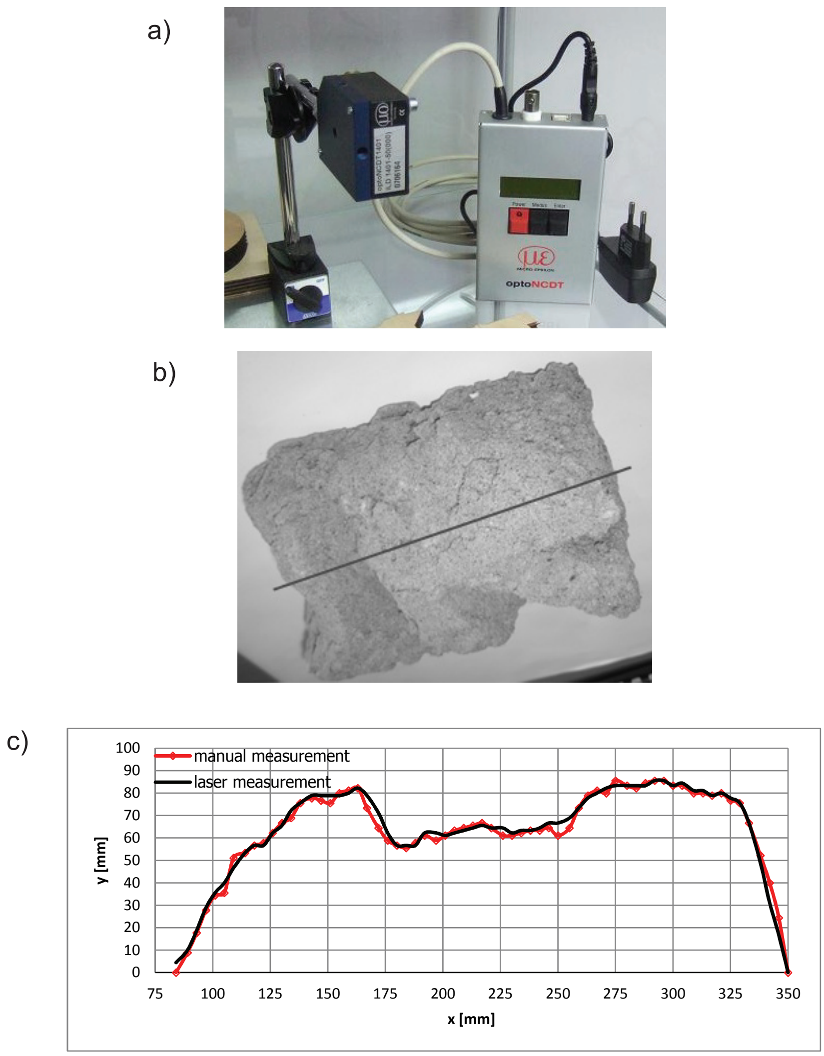


Fig. 2. The one-point laser transducer OptoNCDT 1401-200 test stand [3]: a) overview, b) sample, c) comparison between the data obtained from the laser transducer and manual measurement.

through a USB port where the dedicated program for data acquisition was created. The program was written in the MS Excel environment using the Visual Basic for Applications language [9].

During the experiment the measurement of the chosen profile of the sample moving at 0.2 m/s speed was performed (Fig. 2 b). The sample was moved manually by using a simple power screw. The sensor was fixed to the stand. The additional direct manual measurement by using a vernier calliper gauge was also made. A comparison of the data obtained from the laser transducer and the manual measurement is presented in Fig. 2 (c). Assuming that the manual measurement is the basic one, the maximum absolute error for the laser transducer was 0.4 mm.

The principia of using the one-point laser sensor for 3D scanning is to create a point cloud of geometric samples on the surface of the subject. These points can then be used to extrapolate, that is to reconstruct, the shape of the object. The points create a net described by triangulation algorithms among which the Delaunay triangulation is commonly used. It allows us to digitalize a surface consisting of equilateral triangles.

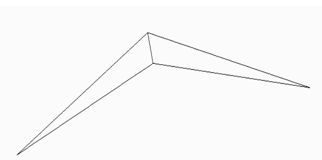
A lot of different software programs for creating solid figures from measurement data are available on the market, e.g. MeshLab. It was decided that the files with measurement data would be the polygon file format (PLY) type. A file description of an object as a collection of vertices, along with properties such as color and normal direction can be attached to these elements [10]. A Polygon File Format object definition is simply a list of (x, y, z) triples for vertices and a list of faces. This core information allows us to create a 3D object that represents the surface created after executing the analogue modeling procedure. In figure 3 the use of a PLY file is presented: starting from a file contents and a surface sample formed from two triangles (a), to finally obtain 3D surface (b).

Conclusions

This paper presents the concept of a 3D scanner applied to surface digital recording of experimental modeling of the influence of rock mass on the natural environment. After finishing the modeling in the geodynamic evolution of tec-

a)

Line number	Content of a PLY file			
1	ply			
2	format ascii 1.0			
3	comment przykladowy plik			
4	obj_info dwa trojkaty			
5	element vertex 4			
6	property float x			
7	property float y			
8	property float z			
9	element face 2			
10	property list uchar int vertex_indices			
11	end_header			
12	-1	0	0	
13	0	1	0	
14	1	0	0	
15	3	1	2	
16	3	0	1	2
17	3	1	2	3



b)

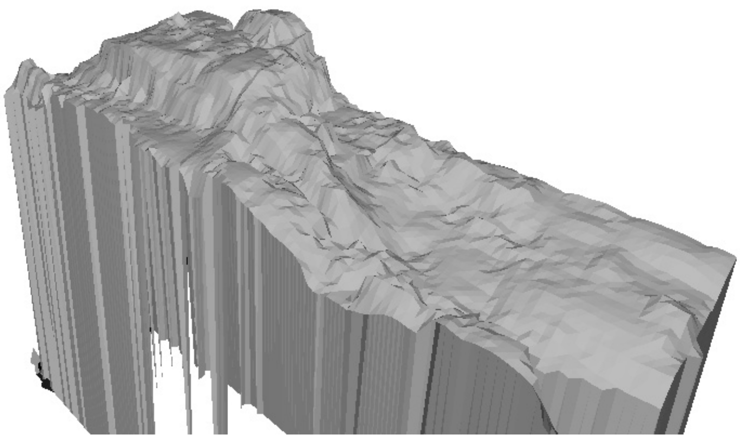


Fig. 3. The use of a PLY file: a) content of a PLY file and a surface sample formed from two triangles, b) a sample of 3D surface generated from a PLY file [3].

tonic structures the standard procedure is to use a ruler and other manual measurement devices to estimate the experimental results. The obtained results from manual measurement are inaccurate and the surface shape details are lost after the experiment is finished. The concept described in the paper of applying a 3D scanner allows us to digitally record the results and create 3D pictures. During the experiment a loose experimental material (quartz sand), thus difficult to measure its surface, is applied to simulate the mechanical behavior of tectonic structure in the natural environment. This difficulty was solve by applying an appropriate laser sensor. The experimental results – especially the obtained final 3D surfaces – clearly indicate the possibility of better counteracting widespread mining damage, especially when planning future exploitation. As a result, it can contribute to the preservation of the natural environment.

Further research will focus on creating a fully automatic test stand where, as a direct drive in the *x-y* axis, the magnetic shape memory alloy (MSMA) actuator is considered. It can significantly increase the accuracy of the measurement. The test stand will on its own scan and digitally record the experimental modeling surfaces which allow us to verify the repeatability of the analogue modeling results.

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