DOI 10.4467/21995923GP.16.001.5478 GEOINFORMATICA POLONICA
15: 2016

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APPLICATION OF AIRBORNE LASER SCANNING IN MONITORING OF LAND SUBSIDENCE CAUSED BY UNDERGROUND MINING EXPOLOITATION

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Keywords: LIDAR airborne laser scanning, continuous ground deformation, subsidence basin, underground terrain exploitation

Abstract

Laser technology is relatively new and is just being developed, nevertheless, it has been widely applied in various areas of geodesy. This article presents a method of use of measurements based on airborne laser scanning to find the range of continuous land deformations (subsidence basin) caused by underground exploitation of coal deposits. A short theoretical introduction on laser scanning is followed by a discussion of data collection and processing of a point cloud. Methods of presentation of results and the possibilities created in effect are shown. The resume discusses pros and cons of airborne laser scanning measurement.

ZASTOSOWANIE LOTNICZEGO SKANINGU LASEROWEGO DO MONITOROWANIA OSIADAŃ TERENU WYWOŁANYCH PODZIEMNĄ EKSPLOATACJĄ GÓRNICZĄ

Słowa kluczowe: lotniczy skaning laserowy, LIDAR ciągłe deformacje terenu, niecka obniżeniowa, podziemna eksploatacja terenu

Abstrakt

Technologia laserowa jest stosunkowo młoda i dopiero się rozwija, pomimo to znalazła szerokie zastosowanie w różnych dziedzinach geodezji. W niniejszym artykule przedstawiono szerzej sposób wykorzystania pomiarów z zastosowaniem lotniczego skaningu laserowego do opracowania zasięgu powstałych ciągłych deformacji terenu (niecki obniżeniowej) wywołanych na skutek podziemnej eksploatacji złoża węgla kamiennego. Po krótkim wstępie teoretycznym, wprowadzającym w tematykę skaningu laserowego, zaprezentowano etapy pozyskiwania danych i obróbki chmury punktów. Następnie przedstawiono sposoby prezentacji uzyskanych wyników i możliwości jakie daje. W podsumowaniu określono zalety i wady przeprowadzonego pomiaru za pomocą lotniczego skaningu laserowego.

1. LASER TECHNOLOGY

1.1. Types of laser scanners

Laser scanners use a laser beam for quick and precise measurement of distance from the station to the measurement point. There are a few types of the device. Scanners can be classified, first of all, in relation to the range up to which scanning can be performed. These are short-distance scanners with their range up to 100 meters, medium distance scanners which scan within the range from 100 meters to 1500 meters and long-distance scanners. It is agreed that long-distance scanners scan at distance 4000 meters, although actual potential

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of the scanner is bigger, however, no measurements on longer distances are taken because of problems with processing of collected data. Laser scanners can be also classified according to their mode of operation: time-of-flight and triangulation scanners. The first group includes time-of-flight scanners (TOF) and phase-based scanners.

As particular scanners operate differently, it can be stated that every type of scanner has different properties and can be used in different geodetic measurements depending on the final result that one wants to obtain. Time-of-flight scanners are slower, a bit less precise but offer a bigger range (from circa 100 meters up to a few kilometers). Therefore, they are mostly used for landscape monitoring, recording of objects and processes in geomorphology and geology, topographic and mining works. On the other hand, phase scanners are quicker but at the expense of shorter range (from a few up to about 100 meters). Such scanners are used mostly in architecture, civil engineering, energetics, etc. (IGIPZ 2016).

1.2. Measurement methods and their application

Not only does the type of scanner influence the properties of a measurement. There are three basic measurement methods depending on what platform a laser scanner is installed. These are:

- Terrestrial Laser Scanning, TLS,
- Mobile Laser Scanning, MLS,
- Airborne Laser Scanning, ALS.

In terrestrial laser scanning a scanner is placed on a geodetic tripod. The measurement is based on polar survey, that is, on a simultaneous measurement of distance and vertical and horizontal angles. This measurement allows for exact determination of coordinates of surveyed points with accuracy to circa 0.001m even in difficult measurement conditions (bad light, small air transparency) in underground coal mines (Sokoła-Szewioła, Wiatr 2013). Terrestrial laser scanning has the disadvantage that the range of activity is small. Therefore, this measurement method is used when a high degree of accuracy is required and the scanning area is small. Terrestrial laser scanning is applied in underground mining, e.g. in development of a visualization of an underground mineworking (Sokoła-Szewioła, Wiatr 2013) or in stock-taking of a historical underground (Mikoś et al. 2011). It is also helpful to do a laser scanning in measurement of untypical geological phenomena including karst phenomena in calcite caves (Mikoś et al. 2011). TLS is used on the ground for stocktaking of monuments (Kędzierski et al. 2008a) and engineering structures (Kędzierski et al. 2008; Gawałkiewicz 2015), assessment of mining damages in the form of cracks, deviation of structural elements of buildings or engineering structures from a vertical line, etc.

In mobile scanning a scanner is mounted on a car, a boat or a railway vehicle. Similarly to terrestrial scanning, coordinates of measurement points are calculated on the basis of measured angles and distances. The very vehicle is provided with a GPS system which determines the location of a scanner. Accuracy and density of scanning depends on the velocity of the ride. It is most convenient to use such type of measurement for an elongated object of measurement and the required measurement accuracy is up to circa 0.03m for surveys of details and 0,01m for altimetric surveys (Szadkowski 2009). Such measurement gives the advantage that the measurement process is accelerated and the costs of data collection are smaller. In mining industry this method was applied in monitoring of a shaft deformation (Adamek 2015) and of a shaft station deformation (Adamek, Bałchan 2011). A laser scanner, mounted most often on the head of a shaft well or a hoisted vessel, can be used for stocktaking of lining geometry and elements of a shaft reinforcement elements, measurement of rectilinearity of vessel trajectory, clearance between guides and working planes of shaft slideways (Lipecki 2013). Mobile laser scanning can be also used for stocktaking of flood embankments, measurement of the volume of dumping grounds on heaps (Warchoł 2014), stocktaking of overground and underground pipelines, stocktaking of high voltage power lines, stocktaking of technical conditions of poles and power lines, stocktaking of railway lines (Leszczewicz et al. 2013) and many other applications.

The last measurement method – airborne laser scanning, involves measurement of distance from a flying plane (helicopter) to a point of land surface with simultaneous permanent measurement of the location of the plane (using GPS) and determination of present angle of inclination of the platform on which the scanning head is mounted (using INS navigation system). All measurements must be performed at the same time and must be synchronized (Wężyk 2014); only then a satisfying accuracy up to 0.15m can be obtained for altimetric survey and 0.10m – 0.20m for point by point survey (Warchoł 2014). Measurement based on airborne airplane scanning offers the biggest range in comparison with the two other methods described here. Therefore it is applied in situations where the scale of the project covers a large or very large area. The parameters of the scan depend on the required accuracy of measurement. If the flight takes place from a lower height, the range of picture will be smaller but the very measurement is more accurate. As the distance between the scanner mounted in an aeroplane (helicopter) and the surveyed area increases, the scanned area increases but the measurement increases as well. Airborne laser scanning is applied in:

- 3-D city models (virtual walks),
- design of the course of roads and their monitoring,
- design, stocktaking and operation of railway lines,
- registration of high voltage power lines,
- management of natural resources (Wężyk, Solecki 2008),
- analysis of flood threats (Warchoł 2014),
- monitoring of coastal area and water structures (Dudzińska-Nowak 2007),
- monitoring of architectural structures.

Airborne laser scanning is also applied to measure the range of permanent land deformation (subsidence basin) caused by underground exploitation of coal deposits (Kuźnicki 2011). The process of data collection and preparation of results for this purpose is described below.

2. STAGES OF LIDAR DATA COLLECTION FOR MONITORING OF LAND DEFORMATION

2.1. Preparation of the flight and its plan

Each work and geodetic survey requires some preparation. In airborne scanning it involves calibration of parameters of the laser instrument, of GPS and INS and determination of optimal parameters of the flight. Particular values of parameters can be interdependent, therefore, determination of optimal parameters is a complicated procedure that requires a lot of precision and experience.

An instrument is calibrated on a test field. It is a big flat area (e.g. a football pit, a runway) with a determined number of control points. A big building with a flat roof should also be situated within the boundaries of the test field. Land control points and building corners are measured using a suitable method (static or dynamic) using GPS. Then a flight over the test field takes place in two contrary directions and an additional one in a perpendicular direction. The results of each flight are compared with each other and with measured control points. The presented calibration method is a long process; therefore, sometimes a simplified calibration method is applied.

Flight planning is the next stage in data collection. When the registered object is elongated (e.g. pipelines, flood embankments, roads), it is covered with a single row. Bigger objects with a bigger surface are covered with parallel rows with about 20–30% coverage between adjacent scanned land areas (Kurczyński 2014).

When monitoring of land deformations caused by land exploitation is also one of the objectives of airborne laser scanning, time of flight is important as well. The first measurement should be done before the commencement of the planned exploitation on a given area to register landform, situation of buildings and surface infrastructure. The objective of the first measurement is also to detect all deformations of land, buildings and engineering structures, which took place before the planned exploitation and possibly to take steps to protect these structures against further damages.

The following flights should take place after the commencement of exploitation. As exploitation progresses permanent deformations on the surface increase, therefore, the longer is duration between flights, the bigger land deformations will be recorded. When exploitation is finished, after termination of rock movement the last flight can be performed to determine the final range of the subsidence basin.

In planning and execution of flights one should consider parameters of laser measurements. Particular flights should be executed with the same parameters and with the same accuracy. The same parameters and the mode of area coverage with rows in both (or more) flights causes that, in spite of different measurement times, similar accuracy of results is obtained. Therefore the final effect (determination of isolines of land depression) is more reliable.

2.2. LIDAR data collection

An airborne laser scannig system consists of an overgroud segment and an aerial segment. The first is made up of an overground referential GNSS station and specialist software, the operator for processing, processing and generation of product results (off-line mode). The aerial segment is made up of:

- laser range finder,
- flight trajectory positioning system based on GNSS,
- INS (inertial navigation system),
- Frame digital camera,
- data recording block,
- a flight planning and management system.

Flight planning and flight management includes a plan of flight over the observed object, developed earlier. During the flight a GNSS receiver determines the current position of the plane and displays information on the monitor in a graphic and digital form, which allows the pilot precisely direct the plane along planned row axes.

Video cameras, directed downward, record land belt which is scanned simultaneously. Every recorded still frame has its own number and exact time to synchronize data from laser scanner with the video recording. Video recordings are very helpful for later data interpretation, filtration and classification of points.

2.3. Levelling of the results

Every geodetic measurement is connected with a systematic error. Therefore, the results should be always levelled. In ALS systematic errors are mostly connected with lack of coaxiality of GPS and INS and with INS drift. These errors can be found easily through a comparison and adjustment of laser data from different flight bands.

The levelling procedure consists of two stages: the first one relates to determination of tie points and control points and the second relates to transformation. The points which are in coverage bands and make it possible to adjust rows that follow each other are tie points. Points with known co-ordinates (situated on corners of buildings, corners of big flat areas, etc.) are control points and are used in the process of transformation of land model into the effective (or other final) coordinate system.

2.4. LIDAR data processing and filtration

In the result of an executed measurement, a point cloud was created, that is, a set of points in the coordinate system with known coordinates X, Y, Z, which represents land points against which laser was reflected.

A point cloud is obtained in an automated way, however, it is not the final product. A point cloud should be processed and filtered in the way which depends on what the final effect is to be (DEM – Digital Elevation Model or DLSM) and on the ground form, coverage and the level of urbanization. These processes are executed after the flight and require specialist software and equipment with big computational potential.

Classification of points for a respective land layer is the first stage of data processing. The following layers are distinguished: land surface, low vegetation, medium vegetation, high vegetation, buildings, points below the surface (so called noises), unclassified. The classification process is automatic; however, it is never free of errors. Therefore, a manual correction of erroneously classified points is usually carried out. After this stage a Digital Land Surface Model (DLSM) is obtained.

The next stage involves surface filtration, that is, a transfer from a numerical model of land coverage to the surface model. Therefore, points classified as vegetation, buildings, etc. should be removed. Filtration algorithms are not perfect, so in this case also a manual correction of obtained points should be carried out.

The filtration process can be omitted when data from laser scanning are to be used for determination of the range of impact of underground exploitation. As in result of underground exploitation land settles evenly with all objects located on it, one can analyse the overground situation from two subsequent measurement periods, both on the basis of DLSM and DEM.

2.5. Presentation of results

Data presentation is the last stage. At present, software for cloud processing (e.g. Tiltan – Tild, TerraScan, VRMesh Survey) offers the possibility to present data in the form of a colour three-dimensional point cloud or a 3D model.

With two point clouds from two ALS measurements at different time one can observe the form of land subsidence caused by mining exploitation.

In this case a cross-section through both clouds or through chosen points along the same line is the simplest method of data presentation. Figure number 1 (Fig. 1.) presents an example of such cross-section. It shows points that are classified as land surface points from two measurement periods. The value of land subsidence can be measured easily and on any point of the

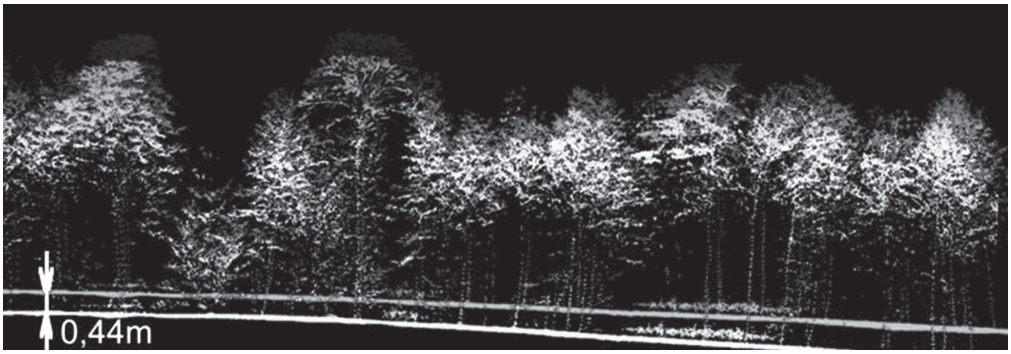

Fig. 1. Cross-section through points classified as 'the ground', executed at two different measurement times
Rys. 1. Przekrój poprzeczny przez punkty sklasyfikowane jako „teren" wykonane w dwóch różnych okresach pomiarowych

cross-section line using the basic tools offered by software for a point cloud processing.

Computation of volumetric surface between the surface from the first and the second period is another method of data presentation. In this case it is better to use DEM than DLSM. At the first stage, for every measurement period one shall generate levels that correspond to surface height on the ground, on the basis of ground points, using specialist software. Then over the isoline map for the base surface, that is, the surface scanned in the first flight, one shall place isolines of the secondary surface and create a third map, which presents the distribution of differences between isolines from the first and the second (or a further) flight. This allows for creation of a picture of distribution of subsidence on a big area in the form of subsidence isolines.

When isolines are superimposed on a geodesic map or on contour of exploitation, a new presentation of obtained data is created (fig. 2a, 2b).

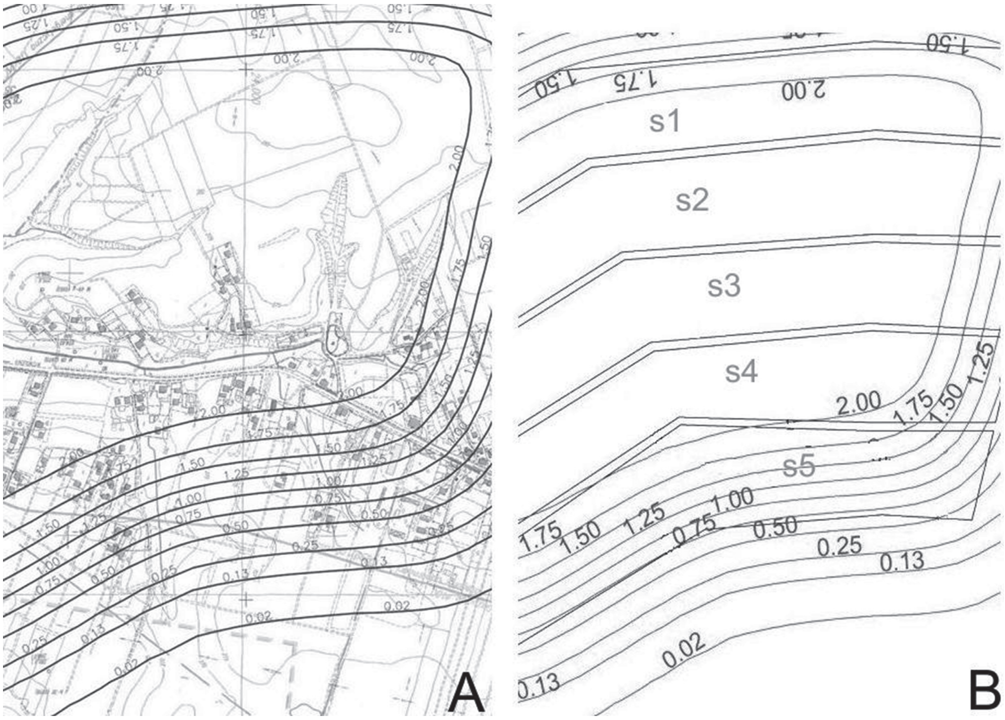

Fig. 2. Isolines of land subsidence generated on the basis of data from ALS presented on: a) a geodesic map, b) exploitation contours
Rys. 2. Izolinie obniżeń wygenerowane na podstawie danych z ALS naniesione na: a) mapę geodezyjną, b) kontury eksploatacji

Regardless of the chosen mode of presentation, a legible picture of continuous deformations of area where they take place and of deformation of engineering structures located there is created.

3. RESUME

As mentioned in the article, airborne laser scanning has a wide range of applications and new ways of its use are still appearing. It results from the fact that ALS has a lot of advantages. The most important is the possibility to do land surveys on a very big area and with high density of measurement points. Such measurements on the same area, done using traditional tacheometric method, GPS or overground scanning would be more labour and time consuming, and by that, more expensive.

The possibility to carry out measurements regardless of time of the day and in almost all weather conditions (except for dense clouds and fog which limit penetration of a laser beam) is a big advantage of ALS. Therefore, measurements can be planned and one does not have to worry if they will be executed or not which may take place in the case of photogrammetric measurements.

ALS measurements allow for execution of measurements in places which are inaccessible or where access is difficult. Such measurements provide complete and detailed data on a given object. The very measurement is non-invasive; therefore, it can be used for almost any object (except for water reservoirs and objects which are made of materials that absorb laser beams, i.e. tar, asphalt).

High automation of measurement which eliminates human errors, omissions, etc. is another advantage of the method. ALS measurements are very precise: precision is up to 0.10–0.20m.

Huge potential of processing of final results is one of the biggest advantages of airborne laser scanning. It includes three-dimensional land model, a digital model of land coverage, a digital land model, outlines, maps. Additionally, presentation of results, as in the case of measurements of continuous land deformations caused by underground exploitation relates to the surface and indicates location of mining damages, duckings and overflow lands with high level of exactness and is a source of knowledge for local administration and mine owners. It helps to react quicker and to accelerate decision-making processes.

ALS, similarly to all existing methods, has some disadvantages. The biggest include high equipment (a laser scanner) and software costs. This is the reason that so few companies offer airborne laser scanning measurements.

Another disadvantage is the volume of measurement data, which makes data processing longer and requires equipment with high computing potential.

Land subsidence monitoring caused by underground mining exploitation using airborne laser scanning is a relatively new solution. There are not many mining areas that have been surveyed in this way. Nevertheless, it can change in the future as laser technology is being developed constantly.

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