

UAV OBSERVATIONS OF CHANGES IN ROAD GEOMETRY IN A MINING AREA

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Abstract

Unmanned aerial vehicles (UAV), commonly known as drones, are becoming increasingly widely used in engineering works. Their use is supported by the speed of measurement while maintaining appropriate accuracy. At the same time, a huge advantage is the remote mapping of large areas – without the need to compromise safety in areas at risk, often inaccessible. UAV measurements are used to inventory both engineering facilities and the area itself, including those affected by mining operations. The obtained results provide a basis for verifying their condition, and ultimately constitute a source of data necessary to determine repair actions. The article presents the possibilities of verifying the condition of the road using low-altitude photogrammetry using an unmanned aerial vehicle. The observations allowed checking the current geometry of the object subject to mining impacts against the design assumptions.

Keywords: UAV measurements; Low-altitude photogrammetry; Road monitoring; Mining impacts.

1. INTRODUCTION

Buildings are exposed to external factors throughout their entire operating cycle. Additionally, buildings located in mining areas are subject to mining impacts, which manifest themselves in the form of displacements and mining shocks [1,2,3]. Given the observed mining impacts, the control of the technical condition of the facilities is an important issue, primarily due to the safety of their use. [4]. An example are residential buildings tilted from the vertical [5], linear objects such as roads [6], railways [7] and many others. In mining areas, monitoring is performed cyclically. The frequency of measurements is adjusted mainly depending on the progress of exploitation works. The influence of both continuous and discontinuous deformations is observed on linear objects such as roads. It contributes to the change of geometric features of the road, including the originally designed: grade line inclinations or cross-sections [8], [9]. Additionally, the changes are accompanied by phenomena such as improper drainage [10]. It is considered particularly

important to reveal discontinuous deformations characterized by a break in the continuity of the medium, including Linear Discontinuous Surface Deformations [11]. Linear discontinuous surface deformations are caused by the concentration of the edges of the exploitation walls, approximately in one vertical plane [12]. In the case of road structures, discontinuous deformations significantly deteriorate the condition of the road surface, creating a threat to the safety of its use [13]. At the same time, the layers that make up the pavement structure are loosened, which in turn reduces its stiffness. All this reduces the fatigue life of the pavement, which results in frequent repairs. [14].

The basis for verifying the technical condition of objects are geodetic measurements that provide a result in the form of value, direction and sense of the object's displacement. Most often, observations come down to situational and height measurements in order to determine the coordinates x , y , z . The greater the number of measurement points, the better the mapping of the analyzed object. Therefore, the task of

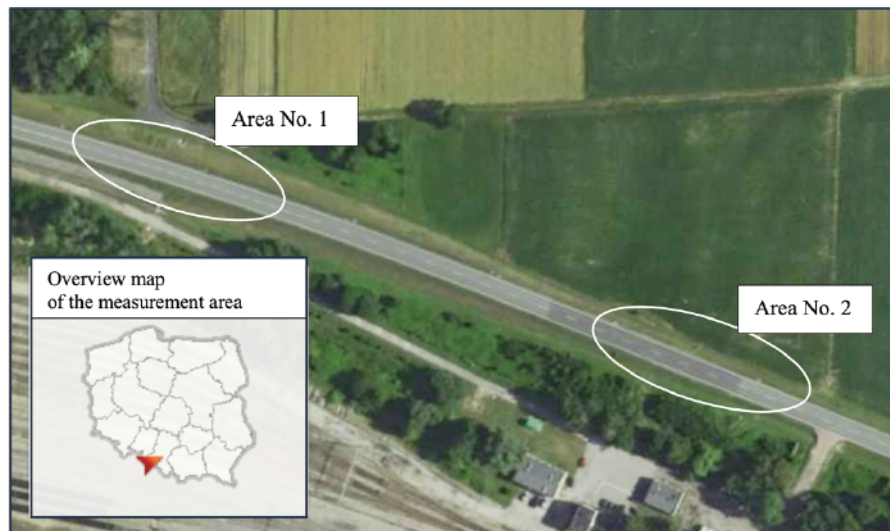


Figure 1.
Location of road areas subject to UAV measurement

modern measurement methods is to generate the largest possible amount of measurement information in the form of a so-called dense point cloud. For this purpose, both ground-based [15] and airborne [16] LiDAR methods, photogrammetric measurements [17] and satellite techniques, i.e. InSAR radar interferometry [18] are used.

Over the years, unmanned aerial vehicles have gained their widest application. In engineering tasks, they are currently used in the inventory of buildings and the terrain itself [19,20]. Thanks to the possibility of performing measurements remotely, measurements of hard-to-reach objects are also carried out, where direct measurement using classic techniques would be difficult to perform while maintaining basic safety rules. Examples include tall objects such as chimneys, masts, and poles [21]. Remote measurements are extremely useful in large areas, including construction sites. Such monitoring allows for constant control of the progress of construction works, with the possibility of taking measurements without endangering the safety of workers [22,23]. This also applies to high slopes, the stability of which should be regularly verified [24,25]. In addition, there is an increasing use of unmanned aerial vehicles in mining companies during measurements of spoil dumps and inventory of mining areas. [26].

Cyclic observations of movements are a valuable source of information about the condition of objects and terrain. The results obtained provide a basis for verifying their condition, and ultimately constitute a source of data necessary to determine repair actions.

2. CHARACTERISTICS OF THE RESEARCH AREA AND MEASUREMENT METHODOLOGY

2.1. Description of the research area

The observations were performed on two sections of a provincial road located in the southern part of Poland (Figure 1). The road consists of two lanes with the KR6 traffic category [27], which corresponds to the penultimate category of the highest traffic load.

Since 1974, the area has been subject to the influence of underground mining, currently conducted at depths of over 1000 m. Mining impacts reach category IV mining terrain, which contributed to the deformation of the terrain, including damage to the road surface. The observed effects of impacts include continuous deformations – unevenness of the surface (area 1) and linear discontinuous surface deformations in the form of transverse cracks of considerable width and mutual displacement of the edges of the surface in the vertical plane (area 2).

2.2. Measurement methodology

The article presents the results of UAV observations of road geometry changes in a mining area. The basic research used to assess the road condition was a measurement using low-altitude photogrammetry. The research was carried out using a multi-rotor weighing over 1.3 kg. The equipment had a camera with a 1-inch 20 MP matrix. A mission was planned over each research area with the following flight settings:

- Flight trajectory (double grid) usually dedicated to 3D models;
- Flight altitude 50 m, which translates to an image pixel of 1.1 cm;
- Speed 4 m/s;
- Camera angle 80 degrees;
- Coverage of transverse and longitudinal photos 80%.

The stages of the task implementation for area 1 and area 2 are presented schematically below and in Figure 2.

The photogrammetric measurement was adjusted to the national coordinate system by measuring six (previously marked) ground reference points in the terrain using GNSS technology with the RTK-RTN kinematic technique.

1.a) Terrain vision, marking of ground reference points and their measurement using GNSS technology

1.b) Low-altitude photogrammetric measurement

1.c) Photogrammetric processing: image alignment, ground reference points identification, dense point cloud generation



Figure 2.
Location of road areas subject to UAV measurement



Figure 3.
Generated dense point cloud of the research area

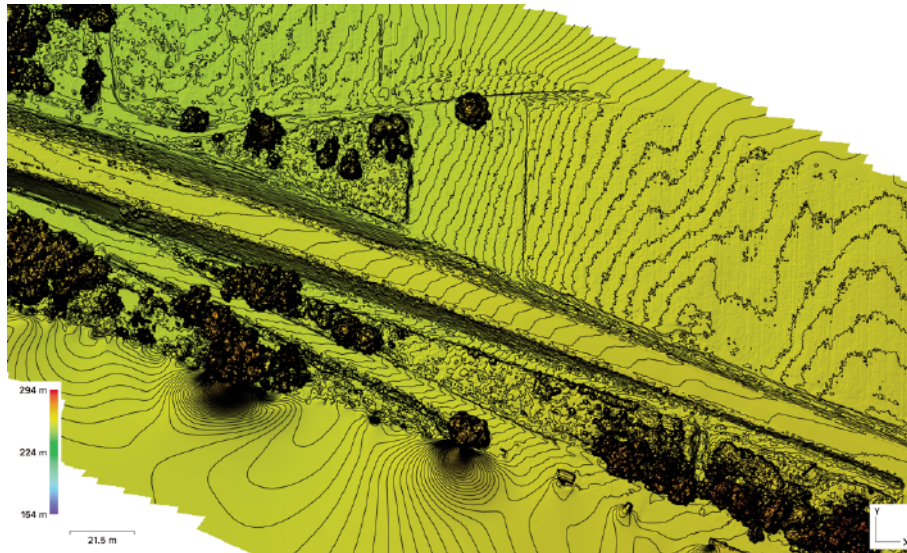


Figure 4.
Hypsometry of the research area

3. LOW-ALTITUDE PHOTOGRAMMETRIC MEASUREMENT RESULTS

At the stage of photogrammetric processing, a specialist program initially aligned the photos and then indicated the ground reference points. In this way, the photogrammetric measurement was fitted into the applicable x, y, z coordinate system. Further activities came down to generating a dense point cloud, ultimately with a density of 327 points/m². This stage allowed for reading the coordinates of the measurement points, as well as generating profiles.

Additionally, the obtained elevation data were presented in the form of a DEM (Digital Elevation Model), where the shape of the photographed area was determined using a colour scale and contour lines.

4. UAV OBSERVATIONS OF CHANGES IN THE GEOMETRY OF ROADS AFFECTED BY MINING INFLUENCE

4.1. Observations of changes in the inclination of the grade line and cross slopes of the road

a) region 1 – area of continuous deformation

Field measurements allowed to show changes in grade line inclinations and crossfalls of the tested road section. Before the mining deformations became apparent, the road condition was in line with the design assumptions, according to which the designed gradeline inclination was 0.5% and the crossfalls should be -2.00%. For comparative purposes, three sections were marked out on the roadway in the area of the culvert according to the chainage:

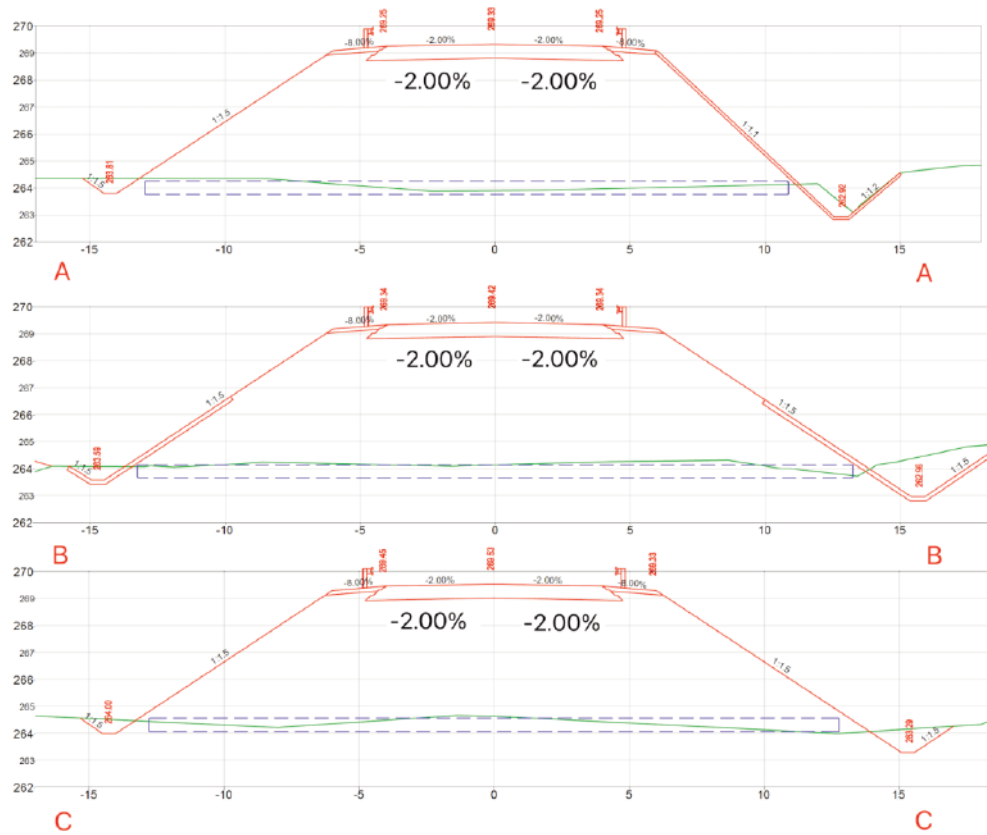


Figure 5.

Sections characteristic for road sections according to the chainage: 0+980.00 (section A-A), 0+998.00 (section B-B) and 1+020.00 (section C-C) - as-built condition

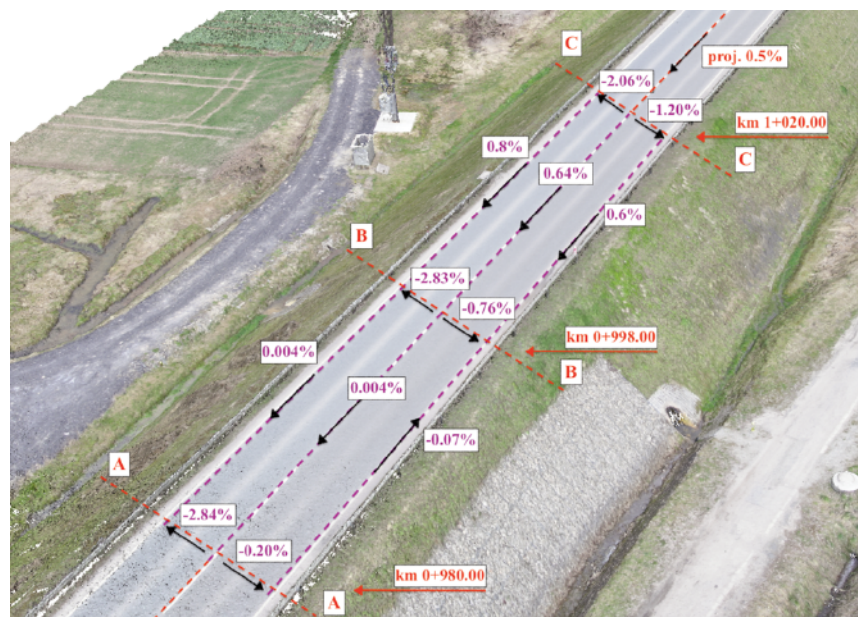


Figure 6.

3D model of a road fragment with defined cross slopes for sections according to chainage: 0+980.00 (section A-A), 0+998.00 (section B-B), 1+020.00 (section C-C) and grade line for the axis and edge of the road

0+980.00 (section A-A), 0+998.00 (section B-B) and 1+020.00 (section C-C). Characteristic cross-sections of the sections adopted in accordance with the design assumptions are shown in Figure 5.

The ground ordinates obtained as a result of photogrammetric measurements enabled the calculation of the actual cross slopes and road grade lines on the indicated road sections (Fig. 6).

Referring to the design data on selected sections of the roadway, an increase in the crossfall values for the left lane of the roadway (from -2.00% to -2.84%) and a simultaneous decrease in the slope on the right lane (southern lane) (from 2.00% to -0.20%) can be

observed. Mining deformations caused uneven changes in the grade line inclination in relation to the design assumptions, i.e. the designed value of 0.5%. The inventoried grade line inclinations indicate a decrease in inclinations (to approx. $0.04 \div 0.07\%$) from the western side of the road and an increase in inclinations from the eastern side (to approx. $0.6 \div 0.8\%$). These changes are a derivative of the formed subsidence basin and unfortunately indicate a significant flattening of the western section. Unfortunately, the shape of the southern lane from km 0+980 to km 0+998 does not ensure proper drainage of rainwater, which may create dangerous conditions on the road.



Figure 7.

An example of pavement damage revealed in the area of Linear Discontinuous Surface Deformations

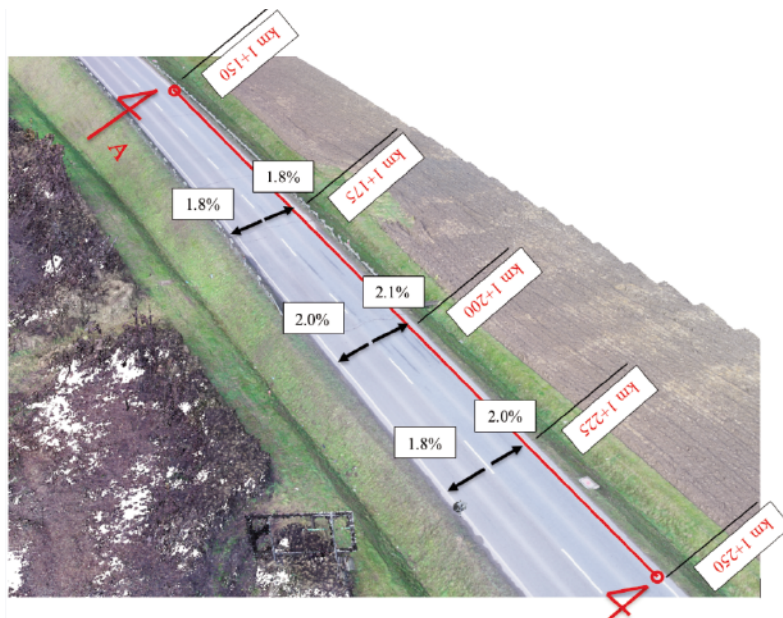


Figure 8.

3D model, a fragment of the road in the area of Linear Discontinuous Surface Deformations with specific cross slopes on selected sections and the indicated longitudinal section A-A

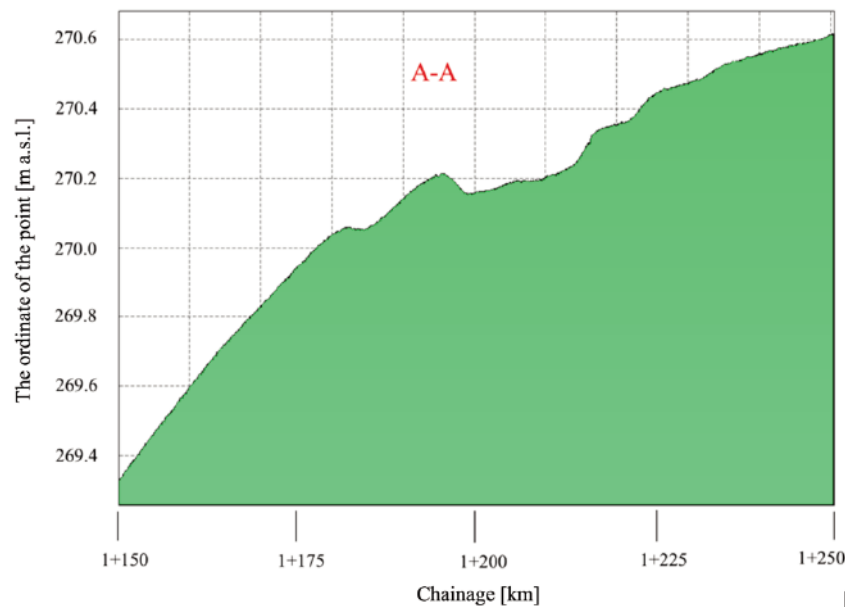


Figure 9.
Longitudinal section A-A in the area of Linear Discontinuous Surface Deformations (LDSD)

b) region 2 – in the area of Linear Discontinuous Surface Deformations

In area 2, as a result of the exploitation, a zone of discontinuous deformations was created over a length of approx. 60 m. The course of these deformations was characterized by cracks with a direction close to the transverse direction to the road axis (Fig. 7). Photogrammetric measurements performed using an unmanned aerial vehicle allowed for a detailed analysis of changes in the road shape.

The cross slopes have changed relatively little, because compared to the designed slope of 2.00%, the measurements indicated values from 1.80% to 2.10% (Fig. 8). The largest changes concerned the shape of the grade line (Fig. 9). The presented profile indicates very significant deformations of the grade line, characterized even by local counter slopes. These changes caused a deterioration in driving comfort, and above all, they affected the safety of road users. In such cases, the only way to restore evenness is to perform profiling milling, and in the period from the occurrence of such unevenness to the commencement of repair work, it is necessary to reduce speed.

5. SUMMARY

The article presents the possibilities of using low-altitude photogrammetry using a drone to observe the condition of a communication facility. This method allows for the identification of surface damage with

appropriate detail. Additionally, remote measurements do not endanger the safety of the person performing the measurement. Typically, positional and height measurements performed using angular-linear techniques using a total station or GNSS satellite technology require direct entry to the road.

The possibility of observing changes in the geometry of the surface, including cross slopes and the inclination of the grade line, constitute a valuable source of information for the proper management of the facility, including corrective actions.

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