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SYSTEMS FOR SPATIAL AND PHYSICO-CHEMICAL PARAMETERS MAPPING OF ANTHROPOGENIC LANDSCAPE FORMS AND PLANTS FORMATIONS IN MINING AREAS WITH THE USE OF PHOTOGRAMMETRY AND REMOTE LASER SENSING FROM LOW HEIGHT

Selected remote measuring systems were presented suitable for use on Unmanned Aerial Vehicles (UAV) in order to provide data for mapping of spatial and physicochemical parameters of anthropogenic landscape forms, including sinkholes, landfills and plant formations around the urban industrial areas, especially burdened with heavy mining activity. Applications of UAV systems already used by GIG for needs of air pollution monitoring were mentioned. A photogrammetry for needs of mapping of the anthropogenic terrain changes were presented on examples of closed coal mine in Katowice for needs of land reclamation. Applications of photogrammetry from low altitudes for mapping of anthropogenic invasive alien plants formations were presented on an example of Giant hogweed in locations in the municipality of Piekary Śląskie and the municipality Łodygowice of Silesian Voivodeship. New UAV platform was proponed for the remote laser scanning of terrain from a low altitude, comprised of inertial system, 2D laser scanner, and system recorder. Examples of scans obtained using 2D laser scanner in the laboratory conditions were presented. The laser mining scanner with a self-propelled layout for underground applications was also presented for mapping results of underground anthropogenic activities, including applications of 2D scanners not only for mapping geometry of underground workings, but also the interior of test boreholes in a rock mass, as well as for depicting artificially produced fractures for the degassing of the rock mass. The test configuration and introductory results of measurements in external environment of the slope geometry using a laser scanner 2D were also presented.

Keywords: laser scanner, UAV, landslides, landfills, Heracleum

1. Introduction

Both for the urban industrial areas, especially heavy loaded with mining activities, whether in the case of the open pit mines or underground mining landfills and dumps of excavated materials, as well as for the agricultural areas, and

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even the wastelands, everywhere the results of intentional (pits, landfills) or incidental (sinkholes, landslides) anthropogenic impacts on landscape forms are met, including also vegetation formations. Both intentional (crops and forests) and random (invasive plants and their formations).

In order to maintain a sustainable approach to anthropogenic landscape transformations associated with human economic activity, including restoring its close to natural values in all those places where such activities ceased (restoration of the landscape, the revitalization of nature), there is need of a detailed inventory (photo documentation, mapping, including spatial mapping) of such variable in time and space anthropogenic landscape forms and plants formations ([1]-[5]). In general, for a large-scale documentation there exist a number of methods of providing such the documentation, ranging from the usual photography from the ground and air, through the stereoscopic photogrammetric methods and the use of lidar laser techniques, to the satellite SAR and multispectral remote sensing. For example, in GIG the Risk Information Surface System for Upper Silesia areas of abandoned coal mines is being developed, combined the advantages of Google Earth with the still being updated datasets on such anthropogenic changing forms of topography [6]. General information about the formation of such areas with sinkholes and their future dynamics are possible to achieve on the basis of Interferometric Synthetic Aperture Radar (InSAR) satellite maps. Proposed in this paper solutions meet the need for precision mapping and delivery characteristics of individual points on the general maps of these systems. Such formations can be precisely documented with the use of stereoscopic photogrammetric air techniques from a relatively low height or with the use of methods of terrestrial 3D laser scanning using stationary laser scanners [7].

Existing gap in the range of very precise measurements of such formations for a low altitude had been tried so far to be filled using such manned and unmanned platforms as balloon and dirigibles. The possibilities of similar applications there were also opened before the microlight sport. However, only recently, with the development of relatively low-cost and high-performance mobile unmanned, remotely controlled, flying platforms (drones), often referred as Unmanned Aerial Vehicles (UAVs), this area went through an avalanche expansion of applications, from photogrammetry to the detection and analysis of air pollutants examined along the route of passage of such a platform.

The GIG is currently implementing a whole complex of similar projects, among others, the described here system for mapping of anthropogenic forms of the landscape and vegetable formations, using the method of laser-scanning from a mobile platform, from a low and ultra low altitude, assisted by, in parallel conducted, classical photogrammetry techniques, and a spatial orientation (inertial sensors) and location (GPS). This paper is the result of one of such currently conducted in GIG research projects, entitled: "The development of a remote laser system for determining the geometric parameters of landfills and mining dumps", GIG no 11311056-172. Such a system allows to specify detailed spatial maps and determination of precise dimensions and volumes of landscape anthropogenic forms, such as landfills or mining heaps. In addition, such a system can be equipped with a specialized, depending on the area of application, systems for remote detection of gases. This will allow, for example, to determine the maps of methane emissions from different forms of anthropogenic-like landfills, coal pit mines and coal deep mine shafts, or from bio-waste processing systems [8]. It can also allow the identification and location of the self-heating areas of the mine dumps and coal landfills, where it is combined with increased emissions of this and other gases. As well as the location of the potential and developing outbreaks of fire on the basis of remote and direct (detected directly above the point) detection of fire gases. Another possible area of application combining both techniques (scanning photogrammetry and detection of trace amounts of vapors and gases) will be the location and mapping of areas where some invasive plants occur, e.g. from the family Heracleum, which are characterized by the emission of volatile furanocumarins.

2. Lidars and laser 2D and 3D scanners

For remote laser scanning of surface area lidars (Light Detection and Ranging) currently are used. They use impulse laser beam for scanning surrounding environment and measure the time of flight TOF (Time-of-Flight) of diffuse optical pulse. They can be used to determine the distance from 1 meter to several kilometers. To increase their range of application, very short pulses of laser NIR (Near Infrared Range) radiation are used.

The scanning LIDAR system collects data on the distances to the different points within the specified area using mirrors deflecting the beam. Most of them work in a similar way as 3D laser scanners, using the simultaneous rotation around its axis by 360 degrees. Much more accurate 2D and 3D laser scanners use in the measurement process the low power lasers of continuous operation with a modulated beam and phase measuring of a distance typical for a laser rangefinders. Due to their lower power of laser beam they allow to measure much smaller distances (up to several tens of meters). In difference from the LIDAR and the laser scanners 3D which are very expensive, their 2D laser scanners counterparts achieve very economically prices, on an order lower, which makes them an attractive alternative for measuring particularly the relatively small geometrical topography forms. Their apparent disadvantage is that they need to be extra tilt or move for obtaining effects comparable to 3D scanning. A sample solution will be discussed latter, however, which, by using independent spatial orientation system, provides the same satisfactory results, especially when using relatively low cost UAV for the scanning of the test area from a low altitude. The advantage of such solution is that (in particular while ensuring uniform air path way at a set altitude, which, in the case of currently available such airborne platforms, is not a hard task) that an uniform cloud of points is obtained, based on data gained in a cylindrical (and not spherical) co-ordinates. It should be noted that some of the lidar systems (e.g., HDL-32E Lidar Sensor) having a limited range (e.g., 80-100 m), intended to co-operate with the UAV, achieve comparable accuracy (about 2 cm) [9] .

In the agriculture and forestry lidars are already used to control formations of plants and crops. In addition, adequate filtering of the images (clouds of points) can often remove vegetation formations (for example, a canopy of the less dense vegetation cereals, forests and scattered shrubs and, e.g., Giant hogweed) to display the surface of the ground. It allows also to determine height and thus often also the nature of the vegetation. In the latter case, the particularly useful scans may be obtained from a low height, allowing not only to determine the height of plants, but in particular, even the recognition of certain species by imaging of the shape of particularly large-sized leaves. This may be of particular importance in the mapping of formations of such alien invasive plants, as, for example, some species of Heracleum of an anthropogenic origin in the specific area, which leaves reach sizes of the order of half a meter and more. This should also allow to distinguish them from similar sized leaves of other natural native species (e.g., some species of the Asteraceae family, such as white and common butterbur, *Petasites albus* and *Petasites hybridus,* which more oval leaves also achieve comparable sizes). Such plants should additionally be easily identifiable on the basis of parallel photogrammetric data.

3. The photogrammetry and remote laser system for determining the geometric parameters of mining landfills and dumps from a low height

Figure 1 presents a schematic diagram of the system for photogrammetry and remote laser determining of the geometric parameters of anthropogenic landscape forms and plants formations, based on 2D laser scanner co-working with an inertial sensor of orientation and position. The laser beam in the extreme positions 5 and 6 sweeps along line 7 the surface area during the UAV platform flight over it. In the case of periodic inspection of the same area, a series of natural or artificially introduced benchmarks 8 can be distinguished or distributed on it. Figure2 collected the first three elements of the test equipment.

A set of tested three basic elements of the system for remote laser scanning of surface terrain area includes (from left to right on Figure 2): inertial system, laser scanner 2D, and a system recorder with 64 GB memory, running under Windows 10.

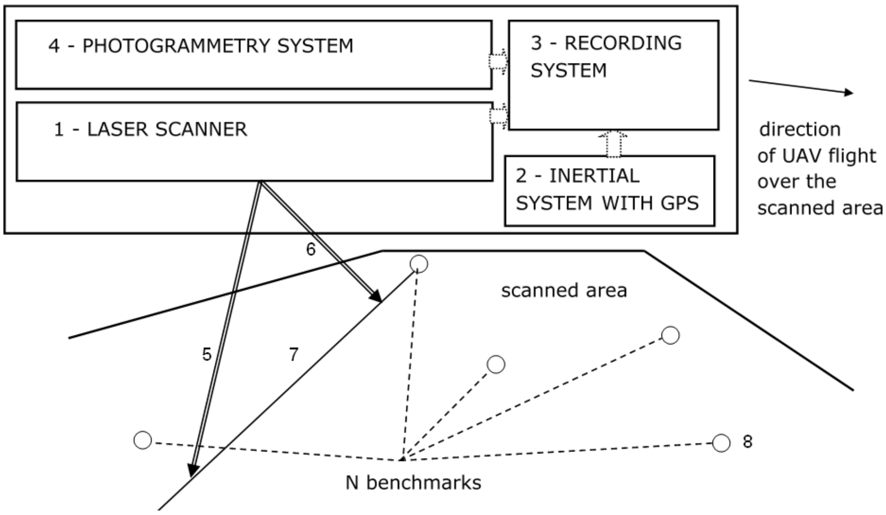


Fig. 1. System diagram of photogrammetry and remote laser for determining the geometry of the anthropogenic forms of land

Rys. 1. Schemat systemu fotogrametrii i zdalnego laserowego określania geometrii form antropo-genicznych terenu

Fig. 2. A set of three basic elements tested of the remote laser scanning terrain system

Rys. 2. Zestaw testowanych trzech podstawowych elementów systemu zdalnego laserowego ska-nowania terenu

4. Photogrammetry from low height

To support the system of laser scanning (especially in the case of 2D laser scanners of lower resolution, which decreases proportionally with the altitude from less than 2 cm to almost 20 cm for changing distance of scanning from 1 m to 10 m above the ground surface) the photogrammetry is useful for precision imaging of scanned formation for the needs of its specifications (of the surface type in the case of technical objects, and of the genera in the case of plant species).

Figure 3 presents UAV systems used in the GIG to photogrammetry of land from a low altitude and for remote control of other physico-chemical parameters of anthropogenic forms and formations.

Figure 4 presents a picture of land subjected reclamation of closed coal mine in a City of Katowice, and illustrates the removal of the temporary disposal of mineral wastes of the remediation process. This photo was made from an UAV platform, in October 2016, from a height of 60 m.

Fig. 3. UAV systems used by GIG

Rys. 3. Systemy UAV wykorzystywane w GIG

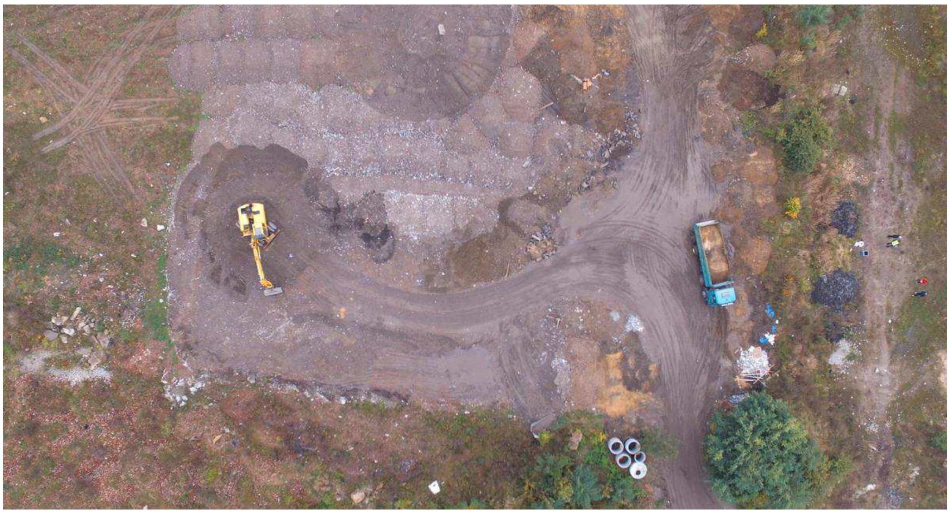


Fig. 4. Land reclamation at the terrain of closed coal mine in Katowice (photo by Tomasz Ko-mandera, GIG)

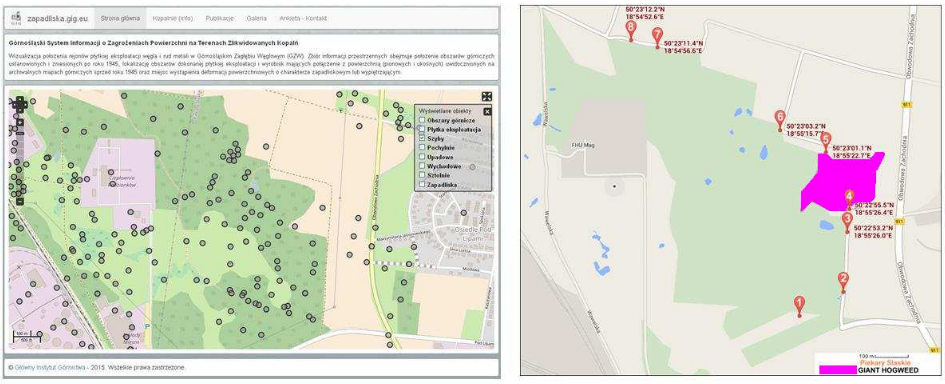
Rys. 4. Rekultywacja terenu zamkniętej kopalni węgla kamiennego w Katowicach (autor zdjęcia: Tomasz Komandera, GIG)

5. Anthropogenic formations of invasive plants on Abandoned Mine Lands

In addition to regular formations of agricultural crops and forests, to the anthropogenic impacts on a vegetation the introduction may be accounted of the invasive alien species of plants to the rural environments, which formations spread further in the environment in a partially random (by seeds dispersed randomly further by water, wind, humans and animals), and partly conditioned by their, usually not excessive, vegetation requirements.

Another illustrations (Fig. 5 and Fig. 6) demonstrate on an example of alien invasive plants from genus Heraclea, the deployment of such invasive anthropogenic formation of plant species on, also changed as a result of human activities, areas of the manifold of sinkholes being results of past mining, presently in the form of partially overgrown little ponds. Figure 5 shows a partially wooded area of uncultivated forest Kocie Górki in the Municipality Piekary Śląskie - wooded area of wasteland marked by numerous points of past mining activities, forming in many places overgrown with swamp plants vegetation sinkholes filled with water. On the north-eastern edge of the visualized area the adjacent Giant hogweed formations are spreading. The individual, identified locations of them were marked by position data obtained from the GPS system. These formations are particularly difficult to remove due to the fact that they adhere to an area of overgrown, partially flooded sinkholes (Figure 6a).

Figure 6b illustrates the on-going within the Municipality Łodygowice in the Silesian Voivodeship invasion of tight formations of these plants, brought there in the recent past to this area by a man, and presently penetrating freely the currently uncultivated areas, as well as the areas of traditional agricultural economy. Both the pictures were taken from a low height by a system UAV.



(a) (b)

Fig. 5. Areas of past mining (a) with alien invasive anthropogenic vegetation formations (b)

Rys. 5. Tereny przeszłej eksploatacji górniczej (a) z obcymi inwazyjnymi antropogenicznymi formacjami roślinnymi (b)

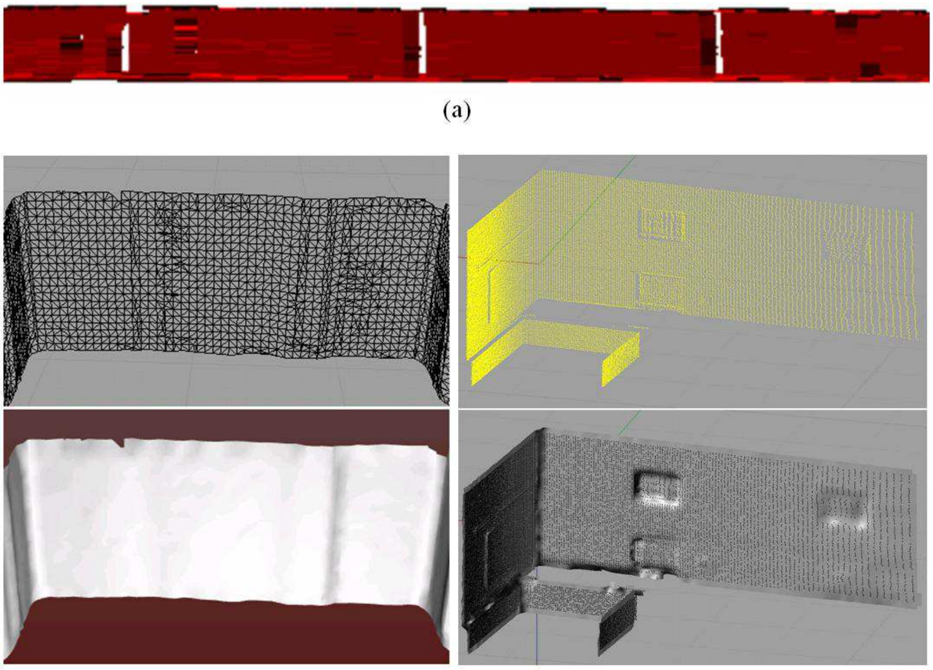
(a) (b)

Fig. 6. Difficult to remove formations of Giant hogweed in the Municipality Piekary Śląskie (a) and in the Municipality Łodygowice (b) in Silesia Voivodeship

Rys. 6. Trudne do usunięcia formacje barszczu olbrzymiego na terenie Gminy Piekary Śląskie (a) oraz Gminy Łodygowice (b) w Województwie Śląskim

6. Tests in laboratory scale of elements of the 2D laser scanning

Figures 7 - 11 illustrate tests in a laboratory scale and their results both on examples of laboratory facilities, as well as in ambient conditions for a little



(a)

(b) (c)

Fig. 7. Examples of scans obtained using 2D laser scanner in the laboratory conditions for the ceiling of the corridor (a) and (b), and laboratory facilities (c)

Rys. 7. Przykładowe skany uzyskane z wykorzystaniem skanera laserowego 2D w warunkach laboratoryjnych dla sufitu korytarza (a) i (b) oraz pomieszczenia laboratoryjnego (c) slope. Figure 7 shows an example of scans as obtained by the 2D laser scanner in the laboratory conditions. Figure 7a illustrates the value of ceiling albedo for a long stretch of the corridor, Figure 7b presents 3D rendering of short section of the ceiling of the corridor, and Figure7c shows the cloud of points and 3D rendering of the interior of a laboratory room.

In the absence of using the device to control the position of the scanner, it turns out that the key condition is the possibility of conserving an even movement of the head of scanning device. Figure 8c shows developed in the Laboratory of Laser Technology GIG patent solution, which enables the replacement of costly scanner 3D with a precision measurement system that uses 2D laser scanner, only, which additionally allows to obtain the same resolution along one horizontal axis of measurements, which makes it particularly useful for imaging, usually inaccessible from the air, forms of anthropogenic tunnels and mine workings ([10], [11]). Figure 8b shows an example of a single scan of a 2D interior of mining corridor obtained with the use of this system. A complete set of such scans can form the entire cloud of points allowing the precise imaging of geometry of the mine working.

(a) (b)

Fig. 8. The laser mining scanner in a self-propelled layout (a) and a single transverse scan of the excavation (b)

Rys. 8. Górniczy skaner laserowy w układzie samojezdnym (a) i pojedynczy poprzeczny skan wyrobiska (b)

Figure 9 shows the 2D scan of the interior of the test borehole made in a coal rockmass, and depicts an artificial fracture created in it for degassing of the rockmass.

Figure 10 illustrates the measuring post during the scanning of geometry of the slope with the use of 2D laser scanner, in configuration for outside tests. Example results obtained in these tests using the external 2D laser scanner system were shown in Figure 11.

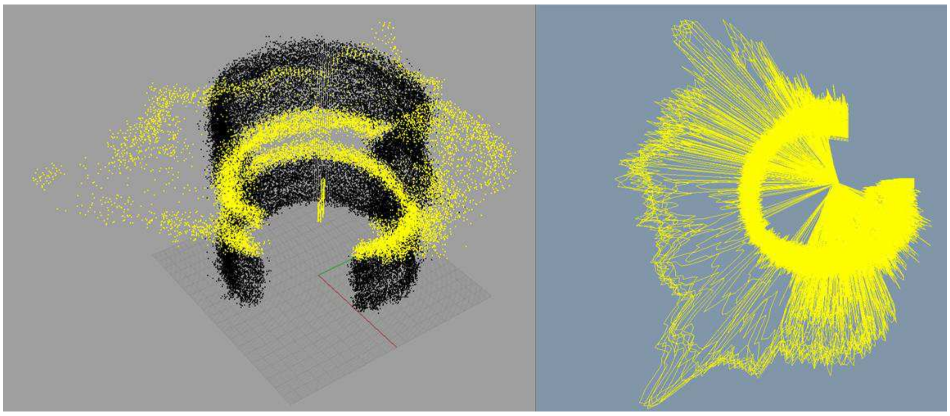


Fig. 9. 2D scan of the fracture in a rock mass obtained from the interior of test borehole

Rys. 9. Skan 2D szczeliny w caliźnie górotworu wykonany z wnętrza otworu badawczego

Fig. 10. Measuring the slope geometry using a laser scanner 2D

Rys. 10. Skanowanie geometrii skarpy, z wykorzystaniem skanera laserowego 2D

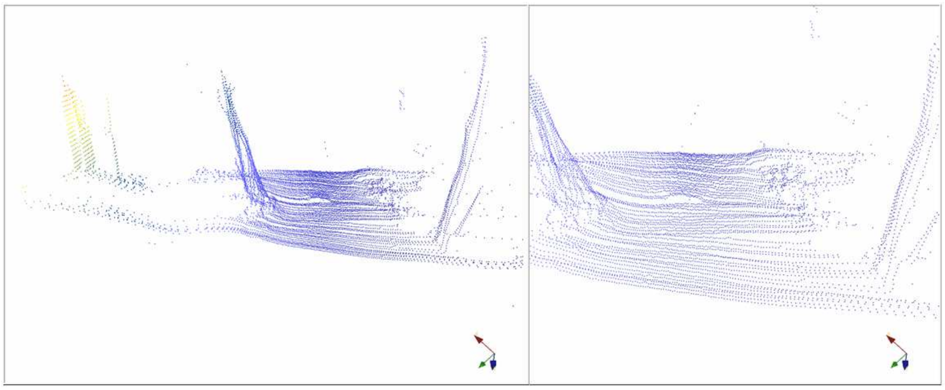


Fig. 11. An example of the results obtained for external testing of 2D laser scanner system

Rys. 11. Przykład wyników uzyskanych dla testów zewnętrznych systemu skanera laserowego 2D

7. Summary

A series of records for different anthropogenic forms, from dumps and landfills in the liquidated mines, to formations of invasive plants artificially introduced in a more or less intended way to areas of the former mining and agricultural areas were presented. The described above research were targeted on determining the usefulness of applying photogrammetry and 2D laser scanning methods from a small height with the use of UAV for needs of mapping and recognition of different types of anthropogenic geometrical objects and plant formations. This techniques proved their usefulness for the depicting of ground area derived from the UAV from the low height of up to 60 m for both the objects of geotechnical, as well as for the plant formations.

Thus the purposefulness of using two complementary modern research methods was confirmed: In addition to the In-SAR satellite interferometry, the UAV platform for low-altitude remote laser scanning, consisting of an inertial system, a 2D laser scanner, and a logger system. The application of both methods will certainly lead to a more accurate identification of surface deformations in the GZW.

For verification of an image, obtained while using multiple flights at longer intervals of time, it may be useful to apply a system of good visible from the air constant reference benchmarks. In conditions of the difficult geometry of the anthropogenic forms, requiring constant changes in UAV altitude of flight, it is necessary to use a parallel system of spatial orientation, such as on-board inertial sensors with GPS.

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SYSTEMY MAPOWANIA PARAMETRÓW PRZESTRZENNYCH I FIZYKOCHEMICZNYCH ANTROPOGENICZNYCH FORM KRAJOBRAZOWYCH I FORMACJI ROŚLINNYCH NA TERENACH GÓRNICZYCH Z WYKORZYSTANIEM FOTOGRAMETRII I TELEDETEKCJI LASEROWEJ Z NISKIEJ WYSOKOŚCI

Streszczenie

Omówiono wybrane zdalne systemy pomiarowe przydatne do wykorzystania na mobilnych bezzałogowych platformach latających, w celu dostarczania danych dla mapowania parametrów przestrzennych i fizykochemicznych antropogenicznych form krajobrazowych, w tym zapadlisk, wysypisk i formacji roślinnych wokół zurbanizowanych terenów przemysłowych, zwłaszcza obciążonych ciężką działalnością górniczą. Wymienione zostały zastosowania systemów UAV wykorzystywane już przez GIG dla potrzeb monitoringu zanieczyszczenia powietrza. Wykorzystanie fotogrametrii dla potrzeb mapowania antropogenicznych zmian ukształtowania terenu zostało przedstawione na przykładzie poddawanego rekultywacji terenu zamkniętej kopalni w Katowicach. Zastosowania fotogrametrii od mapowania z niskich wysokości antropogenicznych formacji obcych roślin inwazyjnych zostały przedstawione na przykładzie barszczu olbrzymiego dla wybranych miejsc jego występowania w gminach Piekary Śląskie i Łodygowice, w Województwie Śląskim.

Została zaproponowana nowa platforma UAV do zdalnego laserowego skanowania terenu z niskiej wysokości, składająca się z układu inercyjnego, skanera laserowego 2D i układu rejestratora. Przedstawiono przykłady obrazów przestrzennych uzyskane za pomocą skanowania laserowego 2D w warunkach laboratoryjnych. Przedstawiono również skaner laserowy 2D do zastosowań górniczych w układzie samojezdnym do mapowania wyników podziemnych działań antropogenicznych, w tym zastosowań nie tylko do skanowania 2D geometrii wyrobisk podziemnych, ale również wnętrza otworów badawczych w górotworze, jak również do obrazowania przestrzennego sztucznie wytworzonych szczelin dla odgazowania górotworu. Przedstawiono również konfigurację testową oraz wstępne wyniki pomiarów w środowisku zewnętrznym geometrii skarpy przy użyciu skanera laserowego 2D.

Słowa kluczowe: skaner laserowy, UAV, zapadliska, składowiska odpadów, Heracleum

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