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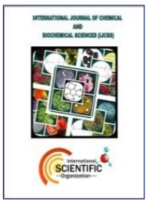

A Systematic Review of Unmanned Aerial Vehicle Remote Sensing Technologies and Methods for Monitoring Anthropogenically Disturbed Lands

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Abstract

In recent years, the application of unmanned aerial vehicle (UAV) remote sensing for monitoring anthropogenically disturbed lands has increased, and the scope of its application has expanded. At present, several reviews have been conducted specifically on anthropogenically disturbed lands. It is necessary to systematically and comprehensively investigate the application of UAV remote sensing of anthropogenically disturbed ecosystems. The purpose of this article is to study the technology of remote land sensing using UAVs to control anthropogenically disturbed lands in Kuzbass, Kemerovo Region, Russia. For the first time, the authors analyze trends in UAV remote sensing applications for monitoring anthropogenically disturbed lands, as well as present common UAV platforms and remote sensing transducers. The application scenarios of UAV remote sensing for monitoring anthropogenically disturbed lands are examined with respect to five aspects: vegetation monitoring, physical and chemical monitoring of soil, soil degradation monitoring, and environmental disturbance monitoring. The article summarizes the current limitations and prospects for developing UAV application. The results of the conducted study will contribute to a better understanding of UAV remote sensing application scenarios in the monitoring of anthropogenically disturbed lands, as well as a scientific background for environmental remote sensing investigations.

Keywords: UAV; Remote Sensing; Anthropogenically Disturbed Lands; Reclamation; Digital Aerial Surveys; Orthophotomap.

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1. Introduction

Digital aerial survey cameras almost completely replaced analog cameras in the early 2000s. There are relatively few publications on using digital aerial survey, studying its information capabilities, adapting modern cameras for consumer needs, and selecting the priority of cameras for different types of studies relevant to the research topic [1]. Unmanned aerial vehicles (UAVs) are flexible, easy to operate, and remotely controlled, which allows them to enter areas inaccessible to humans [2]. UAVs equipped with remote sensing transducers and combined with positioning technology can acquire high-definition remote images of a large area, and their spatial resolution can be accurate to centimeters or even millimeters [3]. The combination of UAV and remote sensing technologies can fully reveal their advantages and provide new ideas for research and practice. Due to the advantages of flexibility and high temporal and spatial resolution, UAV remote sensing technology has been gradually applied in many fields, including geography, ecology, and environmental science [4]. Over the past decade, exponential growth in scientific publications and industry applications of UAVs has been experienced [5], and aerial survey has gradually become the crucial scope of study in many disciplines.

In recent years, UAV remote sensing has been increasingly used for monitoring disturbed lands, however, just a few studies have reviewed the progress in its application [6]. The present study aimed to systematically summarize the progress in UAV remote sensing application in monitoring disturbed lands of coal fields and provide scientific data for environmental remote sensing research. We analyzed the trend of UAV remote sensing for disturbed land monitoring and then studied the common UAV platforms and used remote sensing transducers. Based on this, the application scenarios of UAV remote sensing for disturbed land monitoring were systematically reviewed with respect to several aspects: vegetation monitoring, physical and chemical monitoring of soil, soil degradation monitoring, and environmental disturbance monitoring. Finally, the article discusses the current limitations and prospects of UAV application.

The purpose of this work was to study land remote sensing (LRS) technology using UAVs to monitor anthropogenically disturbed lands in Kuzbass, Kemerovo Region, Russia.

2. Materials and methods

A. Research Object

The experimental site and adjacent territories of overburden dumps of Kuzbass coal deposits are located near the village (Prokopyevsky District) near licensed areas (Figure 1). According to the Scheme of Allocation, Use, and Protection of Hunting Areas in the Territory of the Kemerovo Region No. 80-pg dated November 8, 2016, the research object is located in the territories intended for meadows. According to the data of the Unified State Real Estate Register, the overburden dump, within the boundaries of which the experimental site and the adjacent territories of the overburden dumps are located, has areas referred to the category of designated forest land. Although the experimental site itself is not directly referred to the lands of the forest fund, other parts of the overburden dump, which must be rehabilitated before the land is returned to the forest fund, are in similar conditions.

B. RLS

To perform remote sensing of the experimental site and adjacent territories of the overburden dumps, it is advisable to use a hardware-software complex (HSC) as part of a commercial class high-performance UAV (multirotor systems are preferable due to the small area of the work site), as well as a digital camera, aerial laser scanner (lidar), multispectral camera, radiometric thermal imager, gas analyzer, onboard and ground satellite geodetic receivers, and software for photogrammetric surveying and creating geographic information systems (GIS).

C. Creation of Geodetic Control Survey at the Work Site

Before starting works to increase the accuracy of obtained aerial photography (APH) materials, as well as in the case of surveys using different types of UAVs and payloads, it is necessary to create a single reference point of the base station for all flights [7]. The base station reference point should be a pre-coordinated point in space. For the convenience of its use, it should be located maximally close to the UAV takeoff/landing point. Moreover, the distance of the base station reference point from the extreme points of the work site boundaries should not exceed 20 km. A ground-based global navigation satellite system (GNSS) receiver should conduct records at this reference point during flight operations. In the case of using several UAVs, a special base station should operate, providing real-time corrections arriving directly to the receiver built into the UAV [8].

D. UAV Air Path, Main Survey Parameters, and Favorable Weather Conditions

The UAV air path should ensure minimum flight time by reducing the number of turns and using the longest possible straight lines of a given path. The UAV speed along the route should not exceed 10 m/s relative to ground. The flight altitude and overlapping parameters should be selected based on the resolution capability of the payload with which the UAV is equipped to perform a particular type of survey. Flights should be performed in the most favorable weather conditions, namely, ambient temperature and wind speed should not exceed the UAV performance specifications, and precipitation should be completely absent. It is allowed to perform flights in sub-zero temperatures up to -10°C, provided that the temperature regime of the UAV batteries is observed, i.e., the batteries should be kept warm until the flights are performed. Optimum wind speed should not exceed 5 m/s. It is permissible to perform flights in both cloudy and sunny weather. The solar elevation angle above the horizon should not be less than 12° [9].

E. APH Using a Visible Spectrum Camera

APH using a UAV equipped with a visible spectrum camera should be carried out during the snow-free period. This is necessary to ensure two key aspects:

- Obtaining a real visible situation on the ground;
- Obtaining an accurate digital surface model based on the APH data.

The digital surface model should be used in subsequent surveys to ensure the safety of flight operations and compliance with the specified flight altitude relative to the terrain. When performing other remote sensing methods, compliance with the specified flight altitude, relative to the relief, is conditioned by the fact that certain equipment (aerial laser scanner, gas analyzer) has restrictions on the distance to the surveyed object, as well as by compliance with the required pixel size on the terrain over the entire surveyed area. Most often dumps are characterized by elevation differences of more than 30 m, which can certainly affect not only the quality of collected data (uneven pixel size) but also in general the possibility of acquiring a complete data set (since data in low-lying areas can be lost) [10].

To perform APH, a UAV should have the following minimum performance characteristics:

- Maximum flight duration should be not less than 16 minutes;
- Wind resistance should be not less than 8 m/s;
- Availability of built-in geodetic receiver;
- Availability of visible spectrum camera with a resolution of at least 15 MP.

During the execution of APH, data recording by a ground GNSS receiver with a frequency of not less than 1 Hz should be performed at the base station point.

F. Processing of the Data Obtained when Performing a Geodetic Control Survey at the Work Site

At this stage, data, obtained during the creation of the base station point, should be processed. Data obtained from the ground base station monitoring the execution of APH and data from the onboard geodetic receiver should be equalized. This should be done using specialized software for geodetic measurement data processing [11]. These operations allow for improving the accuracy of spatial photography materials (orthophotomap used for studying the visible situation on the ground and digital surface model used as a relief model, relative to which all other types of LRS are performed) obtained during photogrammetric processing.

G. Photogrammetric Processing of APH Data from Visible Spectrum Camera

APH data processing should be performed using the photogrammetric software, which allows the processing of images acquired with a visible spectrum camera in automatic mode. The photogrammetric processing should result in:

- An orthophotomap in GeoTiff format;
- A digital surface model in GeoTiff format.

3. Results and Discussions

A. Obtaining Data on the Visible Situation and Relief at the Work Site

As a result of the conducted research, three main types of LRS were identified. Earth remote sensing (ERS), which is a space survey of ultra-high spatial resolution. The cost of one image of ERS starts from $2,000 with the minimum amount of surveyed land of 100 km2. Such images have spatial resolution ranging from 2 m with meter geodetic accuracy. A satellite image is shown in Figure 2. Images made using UAV. The average cost of a comprehensive UAV-based aerial survey and visual data processing is about 5,000 rubles/km2. A digital orthophotomap, taken from a UAV, is shown in Figure 3. Manned aircraft imagery. The cost of work performed by manned aircraft amounts to hundreds of thousands of rubles (one working hour costs about 100 thousand rubles providing performance similar to that of a UAV). A digital orthophotomap taken from manned aircraft is shown in Figure 4. Each type of LRS has its advantages and disadvantages, summarized in Table 1. When surveying landfills subject to reclamation, the responsiveness of the survey is not a determining factor in choosing a survey method. When making a managerial decision, it is necessary to be guided primarily by the criteria reflecting the accuracy of the results and the survey area, which determines the economic feasibility of choosing a particular method. To conduct a full-fledged survey of a landfill subject to reclamation, it is necessary to study the visible situation at the work site and the terrain relief to determine the amount of necessary preliminary work to prepare areas of the site, to study the vegetation processes at the site, and to exclude the possibility of the presence at the site of temperature anomalies and possible sources of methane emissions, which can adversely affect the development of planted crops [5].

UAV-based APH has several important advantages, necessary for surveying a given area or object. The camera focal plane can take both vertical and horizontal positions, as well as oblique positions, and even shoot with a rotating lens. These types of APH are called vertical, oblique, and panoramic surveying, respectively [7]. One large graphic file called the air photogrammetric plan of the area is compiled from many photographs obtained. This image can be enlarged to the maximum size, which allows for conducting the most accurate assessment of the features of the projected terrain and determining the dimensions and area of the surveyed land. Vertical APH is indispensable when conducting the initial measurement of a land plot for future construction. Vertical APH allows for a relatively accurate determination of the location, configuration, and actual size of objects and can be used for measurement purposes because it has a nearly constant scale [8].

Oblique APH differs from vertical APH by the fact that it is performed at a certain angle to the object, i.e., the optical axis of the aerial camera lens occupies an inclined position (the canting angle of 45°, 60°, or 75°). Such an approach to construction work control allows for significantly improving the quality and pace of construction, reducing possible risks, and, as a result, saving a significant amount of funds [9]. Contemporary means of terrain observation allow conducting both vertical and oblique APH simultaneously. It is performed by several interlocked cameras or one camera placed in a swiveling mounting [2, 3]. Table 2 shows the capabilities, advantages, and disadvantages of each of the described aerial survey methods. Studying grounds subject to reclamation is needless and does not require oblique and panoramic APH. The key advantage of the vertical APH, based on which a certain method is chosen, is the high measurement accuracy of the spatial data (digital elevation model, orthophotomap) obtained during processing.

B. Obtaining Data on Ground Surface Temperature

Coal fires are monitored by means of thermal imaging APH from a UAV. The results of APH in the thermal range provide a wealth of data to analyze coal fires. Using UAVs is optimal for building detailed temperature profiles of the real ground surface above the fire hearth. When using a UAV equipped with a mapping camera and a thermal imager it is possible to build a 3D model of the terrain in a short time and overlay a surface temperature distribution providing high detailing. The advantages of this method are low cost of work, responsiveness, and no need for dangerous involvement of people and equipment in the immediate vicinity of the fire [4, 5].

C. Obtaining Information on the Absence of Methane Emissions

Kuzbass is a large 335x110 km geological basin, strongly dislocated along its southwestern, northwestern, and northern margins, where coal-bearing deposits are concentrated into very large folds, linearly stretched and broken by large subparallel disjunctives [2]. Toward the center of the basin, synclinal structures become larger, with broad, slightly sloping joints, gradual wrenching of the wings, and formation of brachysynclines. The southern and southeastern parts of the basin are more quiescent. Two productive series are distinguished among the Paleozoic coal-bearing sediments, namely, the Balakhon (lower) and the Kolchugin (upper) series. The coals of the Balakhon series are the most metamorphosed and gas-bearing. Minefields in the southern and central parts of the Balakhon series in the Tom-Usinsky, Mrassky, Kondomsky, Bunguro-Chumyshsky, Aralichesky, and Prokopyevsko-Kiselevsky districts are characterized by the highest gas saturation of coal seams and host rocks, as well as largest resources of free gas in accumulations [7]. Soil air, in turn, is one of the most important factors of plant life. Air oxygen is necessary for seed germination, respiration of plant roots, and soil microorganisms. It participates in oxidation reactions of mineral and organic substances. The oxidation of soil organic matter is accompanied by cycling of carbon, nitrogen, phosphorus, and other nutritional elements. Lack of oxygen weakens respiration and metabolism, and the absence of free oxygen in the soil stops the development of plants.

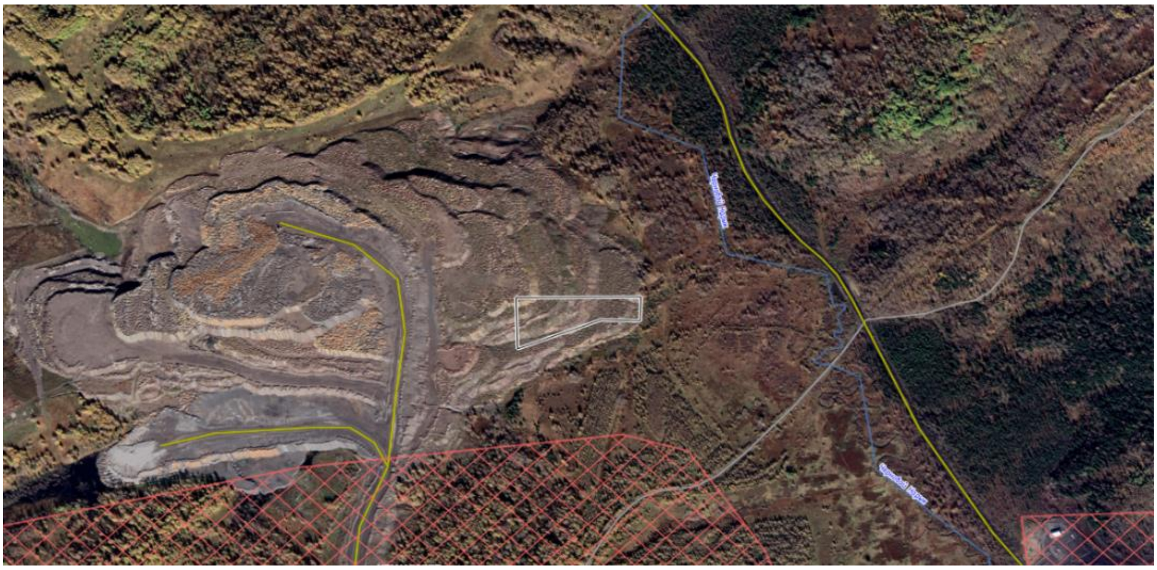

Figure 1. Work site boundaries and licensed areas.

Figure 2. Satellite image (Canopus-B satellite, spatial resolution of 2 m/pix)

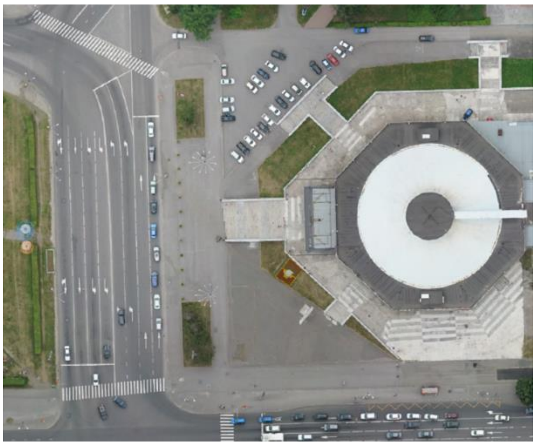

Figure 3. Digital orthophotomap (APH from UAV, spatial resolution of 5 cm/pix)

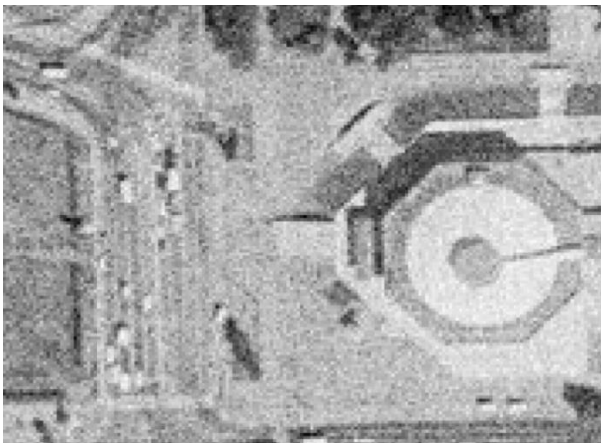

Figure 4. Digital orthophotomap of the spatial data fund (aerial photograph taken from a manned aircraft, spatial resolution of 20 cm/pix)

Table 1. Main Characteristics of The Traditional Survey Method And Various LRS Methods

Criterion	**Traditional survey method (ground-based)**	**Satellite imagery**	**Manned aircraft**	**UAV**
1. Cost	Low at scales of less than 0.2 km^2 (performed by in-house staff)	High (from 2,000$/100 km^2)	High (from 100,000 rubles/flight)	Medium (from 5,000 rubles/km^2)
2. Responsiveness	Medium (from three days)	Low (from one week)	Low (from one week)	Medium (from three days)
3. Geodetic accuracy	Difficult to measure, lacks objective evidence	Meter measuring accuracy	Centimeter measuring accuracy	Centimeter/subcentimeter measuring accuracy

Source: compiled by the authors based on [12-14]

Table 2. Advantages and disadvantages of aerial survey methods.

Aerial survey method	**Advantages**	**Disadvantages**
Vertical APH	– easy creation of high-resolution orthophotomaps; – high accuracy and detail of the obtained data; – high survey productivity; – simultaneous data acquisition in different spectrum ranges; – significant cost savings due to the digital format of all data	– less visual images, gaps are visible when designing a 3D model; – the lens must be necessarily located over the surveying object; – the necessity to maintain constant airspeed, altitude, and heading during aerial survey; – small photographic area
Oblique APH	– high visual informativity; – high measurement qualities, which can be provided by laser location; – using high-quality digital aerial photographs as an information basis; – using oblique aerial photographs as images providing object recognition	– difficulty in taking measurements of objects; – the need to consider the solar position; – the need to fly past the subject at a certain altitude and distance
Panoramic APH	– significantly increases the area that can be covered by a single image; – high informativity; – source of textures for digital 3D modeling of terrain and objects	– inability to measure objects

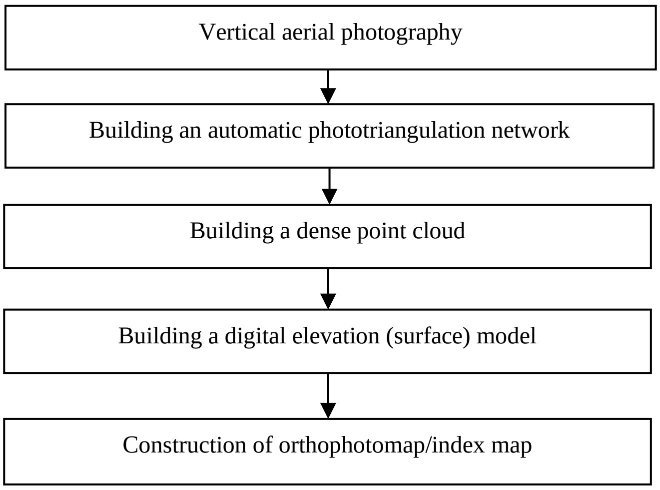

Figure 5. Spatial APH material creation technology

The indirect effect of oxygen deficiency in soil is associated with a decrease in redox potential, development of anaerobic processes, formation of compounds, toxic to plants, reduction of available nutrients, and deterioration of soil physical properties [8]. In places, where methane accumulates in the soil, vegetation is depressed due to the spread of methylotrophic bacteria and organisms in the soil, sharply reducing the concentration of oxygen in the soil, which is consumed for methane oxidation [9]. In this respect, we consider it necessary to carry out work on methane detection. Currently, there are already solutions to this problem based on portable gas analyzers placed on UAV boards. Since gas analyzers mainly have a short application range (up to 50 m), their use is possible only during ground surveys and low-altitude aerial surveys using UAVs. In general, the creation technology of spatial APH materials can be presented in the form of the following diagram (Figure 5). In addition to photogrammetric software, used to analyze the obtained spatial APH materials, as well as data obtained from the gas analyzer, it is necessary to use additional software, such as GIS, which can aggregate various types of spatial data into a single environment in a structure defined by the researcher [13]. The most popular software in this area is ArcGIS, QGIS, etc. It is also possible to create in-house specialized GIS focused on a particular problem, which can be supplemented with special tools, necessary to solve a particular problem of spatial data visualization. Moreover, such GIS are designed both for small highly specialized projects (for example, studies of a land subject to reclamation) as well as for creating full-fledged digital twins of entire cities and regions. One of the important features of GIS is the ability to provide access to data related to different time intervals, as well as the possibility of comparing different data types in a single environment [11, 13].

4. Conclusions

When performing vertical APH, the terrain areas underneath the UAV are imaged, while when taking an oblique APH, mainly the areas lying ahead of or away from the UAV are imaged. The scale of oblique APH is variable; it is large in the foreground, gradually decreasing in the background. Images obtained from oblique APH are more visual and easier to read than images of vertical APH; however, it is difficult to make measurements based on such images. To create spatial APH materials, it is necessary to use a photogrammetric LRS, capable of working with different types of materials. For visualization and analysis of spatial data obtained by different means of cartographic material acquisition and processing, aerial survey materials, geodetic measurements, and additional data, a specialized GIS should be used. Depending on the work performed and expected outcomes, an in-house narrow-focused GIS should be created to ensure the convenience of working with the obtained data.

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