Smart Transport in road transport infrastructure

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Abstract. Introduction of new technologies in cities through effective interaction between people and modern IT management tools has introduced the concept of «smart city» able to independently manage its own resources, energy, space and information to improve life quality. One of the main components of a «smart city» is «smart transport» using latest communication technologies for efficient movement, monitoring of location, interaction between vehicles and other traffic elements, general traffic safety improvement resulting in a decrease in the accident number (tendency towards zero mortality). One of the ways to expand this field of UAV application is their use for primary photofixation of the accident site, which will both increase the objectivity of the investigation and help to reduce time required for the investigation. Solving problems related to traffic safety in a «smart city» using IT technologies and UAVs — smart transport components results in fast collection of information, including that from hard-to-reach zones, the ability to take pictures from small heights and near objects to obtain high-resolution images. These are a possibility of application in emergency zones without unnecessary risk to life and health of personnel; improvement of the objectivity of primary information from the accident site; the possibility of automatic processing of the primary information with its transformation into the necessary types of formalized documents.

1. Introduction

Modern stages of construction, reconstruction, repair, monitoring or audit of road traffic safety cannot be imagined without the integrated use of terrain data in a geo-information mode, plans and graphs, a set of processes, methods of searching, storing and processing, presenting and distributing information, that is, without modern IT-technologies. IT-technology includes the photogrammetric method, which allows determining the displacement of the vertical and horizontal points of the object under investigation in two and three coordinates. The photogrammetric method consists in measuring the difference between the coordinates of object’s points found from photographs for various stages of observation. The initial observation period is conventionally considered a zero cycle. The photographs obtained in this cycle fix the initial state of the object. The increase in deformations of buildings or structures (or deformations of vehicles in a road traffic accident (RTA)) in the process of observing them are determined by the displacements of the observed points in the photographs of the so-called deformation cycle.

The use of graphic descriptions in schemes and plans is one of the fixation methods during the inspection of the site of a road traffic accident (RTA). The protocol of the accident site inspection contains a description and characteristics of all elements of the accident site. To study the accident site it is necessary to apply the photogrammetric method.
Analysis of the scientific and methodological support to the research in the field of photogrammetry in case of an accident shows that this area has been little studied. And the existing scientific literature describing the scanning process and processing of scan results for the purposes of construction, reconstruction and repair of highways does not provide a complete understanding and solution of practical problems.

2. Statement of a problem

However, the analysis of scientific and methodological support allowed us to identify the results of scientific research of the authors working in the related fields of research. So, A.V. Komissarov in his thesis «Theory and technology of laser scanning for spatial modeling of territories» offers «a system solution to the problem of matching the speed and accuracy of technological operations of laser imaging to the requirements of various branches of the country's economy, by means of developing a theory and technology of laser scanning to collect geospatial data» [1–3, 6, 8, 9, 14].

Scientific research by A.A. Kochneva is aimed at the design of highways based on airborne laser scanning. In her thesis «Development of modified digital terrain models according to airborne laser scanning for road design», all aspects of the application of airborne laser scanning technology for constructing digital terrain models for the design of highways are described in detail [7, 10, 11]. Based on the research, an algorithm for interpolating an array of airborne laser scanning data has been developed, the features of which are low computational complexity and a high degree of rarefaction of arrays of points forming flat horizontal and inclined surface areas. The work done, described in the thesis is impressive, but the accuracy of airborne laser scanning, although it meets the requirements, is far from the accuracy obtained by classical shooting methods. The author considers shooting with unmanned aerial vehicles (UAVs) to be a more rational technology, which provides high-quality images, an accurate cloud of points (up to 3 cm in a plan view and height) and a more favorable price / quality ratio.

D.V. Beregovoy in his thesis «Creating topographic plans based on survey data from an unmanned aerial vehicle and automating the process of interpretation» considers the following situation: «at the moment there are a lot of modern technologies that allow you to create a topographic plan. The most popular and effective ones are a tachometric survey and a survey using GNSS. With high productivity of office work they show low field efficiency [1, 7, 11]. However, it is important to understand that in order to increase the productivity it is much easier to automate office work than what is done directly on site. Therefore, the implementation of an effective method of creating a topographic plan based on technologies such as laser scanning and aerial photography (including using UAVs) is more promising in comparison with other methods».

The results of the patent search confirmed increased attention of specialists over the past 10 years to the development and improvement of UAV structures intended for aerial photography of the terrain [3, 14].

3. Materials and methods

Investigating the accuracy and errors of various methods of ground-based laser scanning application, the author delves into mathematical analysis, on the basis of which he proposes a number of “methodological, technical and technological solutions for laser scanning”, which improve the quality of the measurement processes using ground-based laser scanners and scan processing. Based on the mathematically based conclusions on the optimal method, it is difficult to imagine real time savings when working with ground-based laser scanning when shooting highways.

The technical solutions proposed in the studied inventions and utility models are aimed at increasing the stability of flights of unmanned aerial vehicles (UAVs), improving their control systems, including via secure communication channels, ensuring flight safety.

Inventions and utility models in the field of aerial photography have a very specific, narrowly professional nature. They can be used primarily to provide areas such as aerial mapping and aerial reconnaissance.
The solutions proposed by the authors suggest, among others, improving the quality of aerial photography from the standpoint of distinguishing small objects and obtaining 3D images in photographs.

4. Results
The authors propose a technique for the use of UAVs in road inspection. Let us present the main provisions of the methodology and the algorithm for its implementation. In accordance with the requirements of the regulations, the time of arrival of the road patrol crew to the accident site with victims should not exceed 20 minutes from the moment of notification of the accident. In accordance with the current governing documents, the patrol crew of the traffic police on the site of an accident with victims must take investigative actions together with the investigator of the Investigation Department of Accidents with Victims and Safety of Roads of the Main Investigation Department of the Main Directorate of Internal Affairs of the Russian Federation and the expert on whose territory the incident occurred. The tasks of the patrol crew are the localization of the accident site, its initial inspection, calling for emergency medical assistance if necessary, traffic management in the area of the accident, participation in the preparation of the traffic accident layout plan. The listed range of tasks testifies the absolute necessity of the presence of the patrol crew at the accident site. In accordance with such prerequisites, a phased algorithm for the use of UAVs for photo-recording of the accident site is presented as follows (Table 1).

| Stage | Stage characteristics |
|-------|-----------------------|
| Informing about the accident | The traffic police operational service receives a signal about the accident; it is transmitted to the nearest traffic police station and the nearest traffic police crew |
| Video monitoring of the situation on the road section from the traffic police station to the accident site | The traffic police station, equipped with the unmanned aerial system, sends a UAV to the accident site, which moves to the determined destination point by including in its automated control system the coordinates of the accident site |
| The flight is carried out at an altitude of up to 500 meters, ensuring reliable video monitoring of the situation on the road section from the traffic police station to the accident site |
| Video information from UAV surveillance cameras in real time is transmitted to the monitors at the flight control center of the traffic police station and to the video monitor installed in the traffic police car connected to the flight control center of the traffic police station |
| Traffic management correction in areas close to the accident site | According to the results of video surveillance, the traffic police and patrol car crews make decisions and correct traffic control already in the areas close to the accident site, and based on the information received, the crew can optimize the route of their advancement to the accident site taking into account the inevitable compaction of traffic flows on the road sections adjacent to the accident site |
| The UAV after arrival to the accident site with a given coordinate point is guided in the manual mode from the flight control center for orthogonal hovering over the accident site at an altitude of up to 100 meters |
| After the patrol crew arrives at the accident site and the first priority actions are taken, they organize the localization of the accident site and coordinate actions with the UAV flight control center for photographing |
| The manually controlled UAV drops to a shooting height (approximately 30 meters), is coordinated around the aerial photography center point and takes pictures |
| Photographs from the UAV are transmitted via communication channels to the flight control center in the form of an orthophotomap of the accident section. |
| The orthophotomap is converted to a formalized document type – a traffic accident layout plan using a special computer program in the flight control center |
| The received accident layout plan is sent via communication channels to the computer of the traffic police car, where it is printed and accepted for use in further investigation |
| Upon completion of the UAV photo survey mode, it returns to the place of its permanent deployment in the automatic control mode; in the process of returning it can conduct video monitoring of changes in the traffic situation on the road sections coinciding with its flight route |
In this regard, the use of UAVs to photograph the accident site is considered from the standpoint of automating the initial inspection of this place, increasing the objectivity of fixing all trace factors and the speed of drawing up the necessary formalized documents, the main one of which is the layout plan of the accident.

Solving the tasks of ensuring road safety in a «smart city» through the use of IT technologies and the UAV component of the intelligent transport is based on increasing the objectivity of primary information from an accident site, an opportunity to automate the processing of this primary information and transform it into the necessary types of formalized documents. In this regard, the methodology for the use of UAVs in road inspection is proposed. The practical implementation of the methodology was carried out on the road network of the ring road (the Ring Road) of St. Petersburg. The study of the locations of traffic police stations, locations of accidents concentrations, and typical conditions of their occurrence will allow to formulate the key requirements for UAVs intended for aerial photography of accident sites on this route, namely the normative range, duration and altitude of flights. To substantiate these parameters, it is important to have information about the relative position of traffic police stations on the Ring Road and locations of traffic accidents concentrations. The location of traffic police stations on the Ring Road is fixed; it is known and can be mapped. To determine the concentration of accidents it is supposed to use statistical information on all accidents that have occurred on the Ring Road for the past three years.

To process this information, a special methodology has been developed for statistical processing of data on accidents at the Ring Road of St. Petersburg.

The methodology is based on the division of the entire Ring Road into areas 1 km long with subsequent sampling for each accident site with their characteristics at the time of commission, causes of occurrence and severity of consequences for their participants. In total, about 910 cases of accidents with victims are to be processed.

Then this information is visualized on a detailed large-scale map of the Ring Road and the areas of accidents concentrations are identified.

At the next stage, the distances from the traffic police stations to the locations of accidents concentrations adjacent to them are determined and the probabilistic-statistical estimation of the distances from the corresponding stations to the borders of the concentration zones is carried out. According to the obtained results, the necessary distance of the continuous UAV flight and its time in flight are determined.

The altitude flight regulations are based on the study of data on the presence and characteristics of man-made structures and natural obstacles in areas adjacent to the intended flight routes of the UAVs.

Testing and approbation of the methodology were performed using the example of the Ring Road section between 62nd and 70th km along the inner ring and between 71st and 79th km along the outer ring. In accordance with the above proposals, the flight zones are limited to the ranges presented in Table 2.

| Table 2. The flight zone ranges in the Ring Road of St. Petersburg |
|--------------------------|--------------------------|--------------------------|
| Flight zone range        | Along the inner ring, km | Along the outer ring, km |
| No.                      | 57.7…68.7               | 73.2…84.2                |
| 1                        | 74.4…68.7               | 57.1…67.6                |
| 2                        | 83.1…94.1               | 47.8…58.8                |
| 3                        | 94.7…105.5              | 36.5…47.2                |
| 4                        | 105.3…115.8             | 26.1…36.7                |
| 5                        | 9.5…19.8                | 122.3…132.3              |
| 6                        | 63.8…72.6               | 67.4…78.1                |
Generalized information on the state of road safety in the flight zones, confirming their emergency danger is presented in Table 3, and the scheme of assigning flight zones to the parts of the Ring Road is shown in Figure 2.

Experimental studies of the UAV flight mode for carrying out aerial photography of the accident site have been obtained. The studies included flight tests of a quadcopter to estimate the error of transformation of a photo-video survey into a layout plan, depending on the geolocation point of the quadcopter in the GLONASS system; determining the height of the quadcopter hovering for shooting an accident site; working out the process of transforming aerial photography into a layout plan.

During the flight tests, DJIPHANTOM 3 ADVANCED quadcopter equipped with a video camera was used (Table 3). Technical characteristics of the UAV are given in Table 4.

Table 3 Technical characteristics of DJIPHANTOM 3 ADVANCED quadcopter

| Parameter                        | Value          |
|----------------------------------|----------------|
| Weight, grams                    | 1280           |
| Maximum lifting speed, m/s       | 5              |
| Maximum speed of descent, m/s    | 3              |
| Maximum speed, m/s               | 16 (no wind)   |
| Maximum flight altitude, m       | 6000           |
| Maximum radius of action, m      | 2000           |
| Maximum flight time, min         | 23             |
| Operating temperature range, °C  | from 0 to 40   |
| GPS mode                         | GPS/GLONASS    |

Table 4 Technical characteristics of DJIPHANTOM 3 ADVANCED photo-video camera

| Parameter                        | Value                                     |
|----------------------------------|-------------------------------------------|
| Sensor                           | Sony EXMOR 1/2.3" Pixels: 12.76 M        |
| Lens                             | FOV 94°20 mm                              |
| ISO range                        | 100-3200 (video)                         |
|                                  | 100-1600 (photo)                          |
| Shutter speed                    | 8 s – 1/8000 s                           |
| Maximum size of the photo        | 4000×3000 mm                              |
| Photo modes                      | Single photo                              |
|                                  | Continuous shooting: 3/5/7 photos. Auto exposure bracketing (AEB): 3/5 |
|                                  | Photos with an exposure offset of 0.7 EV. Time-lapse |
| Supported card types             | MicroSD                                   |
|                                  | Maximum capacity: 64 GB                  |
| Video recording modes            | UHD: 4096×2160p 24/25, 3840×2160p 24/25/30 |
|                                  | FHD: 1920×1080p 24/25/30/48/50/60         |
|                                  | HD: 1280×720p 24/25/30/48/50/60           |
| Supported file formats           | FAT32/ex FAT                              |
|                                  | Photo: JPEG, DNG                          |
|                                  | Video: MP4/MOV (MPEG-4 AVC/H.264)         |
| Operating temperature range      | from 0°C to 40°C                          |

A general view of DJIPHANTOM 3 ADVANCED quadcopter is shown in Figure 1.

Traditional software for UAV orientation in flight space provides for its topographic adjustment in the GLONASS system with the launch point coordinates. In our case, this is the point of the permanent UAV deployment (usually a stationary traffic police station). Taking into account the distance from the topographic adjustment point to the accident site of up to 5 km, there is an assumption about the occurrence of a significant error in determining the coordinates of the location of
characteristic objects involved in the accident at the place of its occurrence. This assumption was verified experimentally [5, 13, 14].

The test flights of the UAV were carried out in the waters of the Gulf of Finland along the coastline of a sandy beach near Solnechny settlement in the Leningrad region at a visual communication distance (up to 2 km) at altitudes up to 10–30 meters.

![a) DJI PHANTOM 3 ADVANCED quadcopter general view, b) general view in flight](image1.png)

**Figure 1.** DJI PHANTOM 3 ADVANCED quadcopter: a) general view, b) general view in flight

![The reference diagram of flight zones BLAH for the participants in the KAD of Saint-Petersburg](image2.png)

**Figure 2.** The reference diagram of flight zones BLAH for the participants in the KAD of Saint-Petersburg

The UAV topographic adjustment was carried out at the place of take-off, and the estimation of the error of the program for transforming photography into a layout plan was carried out at a distance of 2 km in relation to objects ranging in size from 0.1 m to 7.0 m. The experiment showed that the transformation error occurs due to the large distance from the launch site to the accident site but it is not systemic and depends on random deviations of the flight path of the UAV and can be up to 15 % [4].

To exclude this negative phenomenon, at the time of shooting the UAV was topographically adjusted not to the place of its launch, but to the characteristic objects located at the area of shooting and the subsequent photo. Such an approach made it possible to reduce the error in the transformation
of photography into a layout plan by up to 1.5%. The tests were carried out on the territory of the Faculty of Automobile and Road Building of SPSUACE at the parking lot of the vehicle inspection station. For shooting, a traffic situation was simulated and the full-scale samples of passenger cars were used. As a result of the study, it was established that to fully cover the accident site with a camera, it is advisable to follow the following recommendations:

- in the event of an accident, accompanied by scattering of vehicles after the collision, full coverage of the accident site in the photograph is achieved when shooting is performed from a height of about 30 m;
- in the event of an accident that is not accompanied by vehicle scattering – from a height of about 10 m. Figure 3 shows the photo of the place imitating an accident from a height of 10 m.

Clarification of the aerial photography transformation algorithm into a road accident layout plan is as follows: a UAV is sent to the accident site, upon arrival at the site the altitude is selected, photographs are taken and the video is shot, all photo and video materials are reflected and stored on the flash card, after the fixation of the accident site the UAV returns to the traffic police station; upon arrival of the UAV the official transfers all information to a personal computer; knowing at least one value, you can use the special software to set all the dimensions and coordinates of the accident site that are used for the layout plan (Fig. 3).

Application of intellectual vehicles in the “smart city” presupposes the introduction of IT-technologies in road inspection, which allows obtaining more detailed and accurate information about the state of the roadway and the environment. It helps to make the right decisions at all stages of the life cycle of highways and is aimed at improving safety. The results exclude gross errors associated with the “human factor”, as a part of the process is automatic. It is possible to assess in more detail both the geometric flaws of the longitudinal and transverse profiles, and the defects of the coating itself.

The article presents experimental approbation of the method of primary inspection of the accident site using aerial photography from an unmanned aerial vehicle.

5. Conclusion
The flight mode of an unmanned aerial vehicle (altitude, speed, trajectory) for aerial photography of the accident site has been substantiated. An algorithm has been developed for transforming aerial photography from an accident site into a traffic accident layout plan; a technique for using UAVs in road inspection has been developed, in particular, processing aerial photography materials in the interests of developing a traffic accident layout plan.

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According to the research topic presented in the article, the authors carry out scientific and practical activities confirming their contribution to the development of intelligent transport systems in a smart
city, in particular the use of IT-technologies in road inspection in order to improve road safety, striving for zero mortality.

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