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The use of unmanned aerial vehicles in the process of reconstruction of road accidents

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Abstract: The paper presents a proposal for using unmanned aerial vehicles to reconstruct traffic accidents. For this purpose, a traffic accident scene insinuating a collision between two passenger vehicles on a public road was plotted. An unmanned aerial available on the consumer market weighing no more than 900g and equipped with a high-resolution visible light camera was used for the study. It is assumed that the proposed methodology can also be successfully applied to document construction disaster sites.

Keywords: photogrammetry, road accident, reconstruction, unmanned aerial vehicles.

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1. Introduction

Over the past few years, unmanned aerial vehicles (UAVs) have gone from being a technology of the future to become a widely used tool in many areas of life. This applies to both private and commercial applications. Privately, the most common use of UAVs is for commemorating places and events through photography and video. Among the most interesting commercial applications of UAVs entering widespread use is the transportation of goods, including sensitive goods whose transportation time can be crucial such as the transportation of blood, organs, or medical samples. In February 2022, the first regular flights of UAVs for the health service system were launched in Poland. Another very interesting application of UAVs is the monitoring and inventory of construction sites. Thanks to the computer software used to process the photo-video material collected during the flight, it is possible to automatically track changes on the site, and measure the volume of buildings or bulk storage heaps. The use of the possibilities offered by spatial models prepared based on photos collected during a photogrammetric flight seems to be unlimited. In this work, special attention is paid to the application of low-altitude photogrammetry using consumer drones for inventory and reconstruction of road incidents. This solution is slowly becoming of interest to researchers and hobbyists and perhaps in time will enter widespread use by insurance agents and the police. This study is intended to introduce the basic concepts of drone aviation, point out the possibilities and limitations of consumer drone use, and present the procedure for collecting and compiling data from the scene. This study is intended to help encourage potential users to take advantage of the opportunities offered by unmanned aircraft technology in their work.

2. Basic terms

This section will introduce the basic concepts related to the planning and execution of flight operations using unmanned aircraft. This chapter has been developed based on the current legislation including in particular, Commission Implementing Regulation (EU) 2019/947 of May 24, 2019, on regulations and procedures for the operation of unmanned aircraft (PL). (Consolidated version of August 5, 2021), Guideline No. 7 of the President of the Civil Aviation Authority (CAA) of June 9, 2021 (PL) on how to perform operations using unmanned aircraft systems, and Guideline No. 24 of the President of the Civil Aviation Authority (CAA) of December 30, 2020 (PL) on the designation of geographic zones for unmanned aircraft systems.

2.1. Categories of flight operations

Air operations with the use of unmanned aerial vehicles can be performed in three categories: "Open", "Specific" and "Certified". Assignment of the appropriate flight category for a specific operation results from the risk assessment it involves. If the planned air operation falls within the open category or corresponds to one of the standard scenarios (STS) or national standard scenarios (NSTS) within a specific category, there is no need to carry out a risk assessment. Otherwise, authorization for the operation should be applied for, accompanied by a risk assessment. The suggested methodology for assessing the risk of air operations is the SORA (Specific Operations Risk Assessment) methodology. However, this methodology requires adaptation to the specificity of air operations carried out using UAVs, which is mentioned by the authors of the work (Janik et. al, 2021), indicating that this methodology assumes that tt the risk assessment stage, weather conditions, place and flight time are known. The authors of the aforementioned work indicate that in the case of search and rescue missions, these criteria cannot be met. This is similar in the case of flights carried out at the site of a collision or road accident. The European Union Aviation Safety Agency (EASA) developed predefined risk assessments (PDRA). If the planned operation falls within the published PDRAs, there is no need to carry out a SORA analysis. At present, depending on the location of the accident, the implementation of a spatial model of the accident site should in most cases be qualified to the open category - A2 or a special category under the scenarios - NSTS-01 or NSTS-02 depending on the weight of the UAV.

Flights in the "open" category are characterized by low risk related to the performed aviation operation. They apply only to flights within the pilot's line of sight up to a height of not more than 120 m measured from the point of the earth's surface closest to the aircraft. The maximum take-off mass of the UAV (MTOM) may not exceed 25 kg. The "open" category has been divided into three classes of air operations depending on the weight of the UAV and the horizontal distance from people. A1 - for UAVs with MTOM up to 500 g, A2 - up to 2 kg, and A3 - MTOM up to 25 kg. However, in the open category A2, a horizontal distance from people of at least 30 meters (5 m in low-speed mode) should be kept, and in the A3 category, 150 meters from industrial, residential, commercial, or recreational areas (Guideline No. 7 of the President of the Civil Aviation Authority of on June 9, 2021).

Flights in the special category were divided into national standard scenarios describing approximately the nature of the air operation. A pilot performing air operations under this category should have appropriate competencies and submit a statement on the compliance of the air operation with the national scenario. Within the special category, eight national standard scenarios were distinguished (Table 1). National scenarios will be systematically replaced or supplemented by European scenarios. At the moment, there are two such scenarios, STS-01 and STS-02, which are equivalents of identical national scenarios.

Table 1. National Standard Scenarios (NSTS).

NSTS – 01 / STS – 01	Operations in line of sight (VLOS - Visual Line of Sight) and with the view of the first person (FPV - First Person View), using UAVs with an MTOM below 4 kg
NSTS – 02 / STS – 02	Operations in line of sight (VLOS) with the use of UAVs of the multi-rotor (MR) category with an MTOM below 25 kg
NSTS – 03	Operations in line of sight (VLOS) with the use of UAVs of airplane (A) category with an MTOM below 25 kg
NSTS – 04	Operations in line of sight (VLOS) with the use of UAVs of helicopter (H) category with an MTOM below 25 kg
NSTS – 05	Operations beyond visual line of sight (BVLOS) up to 2 km from the pilot using UAVs with an MTOM of less than 4 kg
NSTS – 06	Operations beyond visual line of sight (BVLOS) up to 2 km from the pilot using UAVs with an MTOM of less than 25 kg with the use of UAVs of the multi-rotor (MR) category.
NSTS – 07	Operations beyond visual line of sight (BVLOS) up to 2 km from the pilot using UAVs with an MTOM of less than 25 kg with the use of UAVs of the airplane (A) category.
NSTS – 08	Operations beyond visual line of sight (BVLOS) up to 2 km from the pilot using UAVs with an MTOM of less than 25 kg with the use of UAVs of the helicopter (H) category.

2.2 Geographical zones for the operation of unmanned aerial vehicle systems

Geographical zones are separate structures from the general airspace and impose additional restrictions on flights within their area. They are set to ensure the safety of air operations with the use of UAVs and to protect personal data, privacy, and the environment. These zones are designated independently in the European Union participant countries by the competent authority under Commission Regulation (EU) 2019/947. Under Guidelines No. 24 of the President of the Civil Aviation Authority, the competent authority for determining geographical zones within the Polish airspace is the Polish Air Navigation Services Agency (PANSA). It was decided to separate the structures from the airspace zones known from manned aviation mainly due to the different nature of air operations. To some extent, they correspond to the airspace zone, but also introduce completely new areas relating only to unmanned aerial vehicles. In Poland, based on Guidelines No. 24 of the President of the CAO, the zones presented in Table 2 have been defined. The geographical zone may be defined on the own initiative of the Polish Air Navigation Services Agency or at the request of the interested party specified in paragraph 5 par. 1 of Guidelines No. 24 of the President of the CAA. When defining a geographical zone, its type, period of validity, horizontal and vertical boundaries, and conditions for performing operations with the use of UAVs are specified.

Table 2. Geographical zones applicable in Polish airspace.

DRA-P	Prohibited zone - you cannot perform air operations with the use of a UAV. Flights in exceptional circumstances may take place only for the needs and with the consent of the zone manager, regardless of the weight of the UAV.
DRA-R	Restricted zone - UAV flights may be performed only with consent and under the conditions specified by PANSA or an authorized entity. These zones were additionally divided based on the degree of probability of obtaining permission to perform an air operation. taking into account the relevant competencies of the open or specific category. Additional restrictions resulting from the open category include a ban on flights in the DRA-L zone less than 1 km from the border of communication airports, a ban on flights in the DRA-RM/RL zone without A1/A3 competencies, a ban on flights over 30 m in the DRA-RM zone at a distance from 1 to 6 km from the border of a communication airport without the competence of A2, prohibition to perform air operations at altitudes above 100 m in DRA-RH zones at a distance greater than 6 km from the border of a communication airport.
DRA-RH	Restricted zone with a high probability of approval. Most often it is an area over 6 kilometers from the borders of communication and aeroclub airports. UAV flights weighing up to 900 g and below 100 m may take place without the consent of the manager, over 100, and with a drone weighing up to 25 kg with the consent of the manager - taking into account the limitations resulting from the competencies of the UAV pilot.

DRA-RM	Restricted zone with a medium probability of approval. UAV flights weighing up to 900 g and less than 30 m may take place without the consent of the manager, over 100 and with a drone weighing up to 25 kg with the consent of the manager, after meeting the conditions specified in the flight plan, only with the consent of air traffic control (ATS - Air Traffic Control).
DRA-RL	Restricted zone with a low likelihood of approval. Irrespective of the flight altitude and mass of the UAV, flight only with the consent of the manager, after meeting the conditions specified in the flight plan, only with the consent of ATS.
DRA-I	Information zone (I – Information) – most often these are navigational warnings that help to maintain the safety of air operations
DRA-T	Zone restricted due to the technical conditions of the UAV - (T - Technical restrictions) - define the technical requirements that must be met by the UAV, which is to be used for hang glider operation in the zone
DRA-U	Zone where UAV operations can only be performed using verified services provided within the zone.

3. Photographic documentation of the road incident

Photographic documentation is a set of photos showing the area of the accident, thanks to which allows one to show the place of the accident as accurately as possible, showing all the details there (Prochowski et. al., 2014). The attached documentation of the accident site only facilitates its understanding, reconstruction, and assessment of its causes, however, it cannot replace the inspection report. Photographs are supplementary material and protect against the loss of details that may be of significant importance, and for various reasons were not included in the protocol and the situational sketch (Białek, 1995). Simple photos taken with a camera also cannot be used directly to read geometric dimensions. To do this, you must first convert from the central projection to the orthogonal projection. It happens, however, that despite the use of various techniques, it is impossible to recreate the necessary dimensions due to a poorly made photo. A solution that would facilitate the work of forensic experts in the field of traffic accidents would be access to a surface model that highly reflects the place of the accident, thanks to which they would be able to make any measurements and analyze the place of the accident at any time. Creating spatial models of large objects in the open space is usually based on manual measurement using a total station, measurement using LiDAR (Light Detection and Ranging) technology, or photogrammetry. The first two technologies are either very time-consuming (using a total station) or very expensive (Li-DAR). (McMahon et al., 2021). Thanks to the use of low-altitude photogrammetric images with the use of an unmanned aerial vehicle, it is possible to generate a spatial model with high accuracy at a relatively low cost and in a short time. The accuracy of the obtained model may depend on many factors, including, to a large extent, weather conditions - heavy clouds and sun activity affect the operation of satellite positioning systems, type of ground - more accurate results are obtained on flat terrain, e.g. parking lots, but mostly on the number of photos collected. There have been many works on the impact of the number of ground control points on the accuracy of mapping real dimensions (Lucieer et. al., 2014, Bolkas et. al., 2019, (McMahon et. al., 2021, Javadnejad et. al., 2021) indicating their optimal number is in the range of 12 to 20. Commercially available unmanned aerial vehicles are equipped with accurate satellite navigation systems With a sufficiently large number of photo-points, the mean square error is about 0.012 m for the vertical axis and 0.065 m for the perpendicular surface, increasing with the decrease in the number of photo points to the value of 1.394 m and 0.604 m. In the case of these systems, the effect of the number of photo points is much smaller, for about 20 points the mean square error is 0.055 m for the vertical axis and 0.031 m for the planes, respectively. perpendicular and as the number of photo points decreases, it decreases to 0.056 and 0.083 (Wiącek, 2017). It should be noted, however, that the use of aircraft without an additional ground station and ground checkpoints allowing for the correction of errors of positioning systems on board still provides accuracy significantly exceeding the hitherto used methods of data acquisition from the scene of a road accident. In the future, research should be carried out correlated with the results of expert opinions from accident sites to unambiguously determine whether these data are sufficient or whether greater accuracy is required as in the case of photogrammetric flights performed for measurement purposes in construction areas.

As of today, there is no clear, generally accepted, formalized procedure for performing photogrammetric flights to make 3D models of the terrain, and even more so there are no guidelines for making flights to obtain spatial models of traffic accidents in terms of evidence for forensic experts.

4. Advice on how to carry out a flight on a road accident site

Assessment of the location of the air operation - the air operation should be performed with the consent and on the terms agreed upon with the rescue services or after their activity has ceased, get acquainted with the applicable geographical zone and the rules applicable in it, assess the risk of bystanders appearing in the area flight, recognize terrain obstacles at the scene of the event and determine safe flight altitude limits.

Preparation of the take-off site - before the start of the photogrammetric flight, it is worth securing and marking the take-off and landing site in such a way that there would be no sudden intrusion of people or animals during the UAV counting.

Checklist - it is worth preparing a pre-flight checklist covering the above-mentioned activities and additionally checking the technical condition of the unmanned aerial system.

Flight planning - before starting the operation, it is worth assessing the minimum altitude at which the flight can be carried out, the lower the altitude, the higher the resolution obtained. At the same time, however, as the flight altitude decreases, the process of combining the collected images into a single map or model becomes more complicated, because a smaller area will contain fewer special features. Therefore, the flight should be performed in a circle around the POI (Point Of Interest) or along a plane with parallel lines with a minimum of 70% overlap in the longitudinal direction and a circle and 60% overlap in the transverse direction (Ruzgiene, 2014). The lower ceiling also extends the duration of the flight operation. It is worth performing a flight at a minimum of two heights, i.e. a general plan and a detailed flight, and tilting the camera at an angle to capture details in the vertical direction when creating 3D models, while creating an orthophoto map, the camera should be directed at an angle of 90 degrees towards the photographed plane. The flight can be performed automatically by planning a route using dedicated software, e.g. DroneDeploy, or manually while maintaining the above-described rules.

Flight performance - during the flight operation, if possible, maintain visual contact with the UAV. Constantly control the flight parameters, including the battery charge status and the quality of the control and positioning signal. If an obstacle appears, the operation must be stopped or interrupted.

Resolution - the resolution of the developed model depends primarily on two factors - the camera matrix and the height from which the photos are taken. These two elements determine the Ground Samplelink Distance (GSD). The higher the value of this parameter, the greater the accuracy of the obtained model. For example, taking pictures with a camera equipped with a 50-megapixel matrix from a height of 58 meters, we obtain a resolution of 0.31 cm/pixel while taking pictures from the same height with a camera with a 20-megapixel matrix, the GSD will be 1.08 cm/pixel. To obtain the same GSD value for a camera with a 20-megapixel matrix, the flight would have to be carried out at an altitude of 25 meters. The study presented in this study has a resolution of 1.7 cm/pixel. Typically, mission planning software automatically calculates and displays the GSD value for the planned flyby. In the experimental studies presented in the literature, the GSD value does not exceed 2 cm/pixel, which seems to be a sufficient value for the preparation of a road accident model.

5. Data processing

This chapter presents data collected during a staged road incident on a flat terrain on a gravel road. The DroneDeploy software was used to create a spatial model. The flight was carried out using a commonly available unmanned aerial vehicle with average purchase costs - DJI Air 2s. The technical parameters of the drone are presented in table 3.

Table 3. Selected technical parameters of DJI Air 2S.

Communication	2.4 GHz 5.8 GHz
navigation	GPS, GLONASS
Maximum speed	68 km/s
Ascent/descent speed	6 m/s
Reception	8000 m
Flight time	31 min
Camera	20 Mpix
Matrix	1" CMOS

Aperture	f/2.8
view angle	88°
Stabilization	Trójosiowa
Video resolution	5.4K, 3078p, do 30 fps 4K, 2160p, do 60 fps 2.7K, 1520p, do 60 fps FullHD, 1080p, do 120 fps
Video format	H.265 H.264 MPEG-4
Photo resolution	5472 × 3648
Photo format	RAW, JPEG
MTOM	595 g

The flight was carried out manually in circles around the POI at two heights: 5 and 10 m, and two flights along straight lines. Photographs were taken at intervals of 2 s while flying in a circle at a speed of 2 m/s, obtaining a total of 125 photographs. The total operation time at the scene was 10 minutes. Figure 1 shows the positions where the photos were taken.

In the next step, photos were imported to Agisoft Metashape ver. 1.8.4 to create a spatial model. Modeling was carried out on a laptop equipped with 16 GB of RAM, a quad-core, eight-thread Intel i5 10300h processor, and an NVIDIA GTX 1650Ti graphics card with 4 GB of memory. The total model preparation time was 40 minutes. The result is presented in Figure 2, showing a few selected shots of the 3D model.

All measurements and assessments of the accident site can be performed on a spatial model. This model can be easily analyzed directly in the Agisoft Metashape environment or exported in *.obj format and analyzed in another environment. For example, to obtain a photorealistic render of the created model, you can use the free Blender software (Skondras et. al., 2022). This software is based on the python programming language and creates the possibility of geometry analysis based on created scripts. Figure 3 shows the measurement of the braking distance. The Metashape environment does not have an extensive measurement module, however, the generated model or shots can be transferred to an environment such as the aforementioned blender or other software used by experts, as would be the case with photos taken using the traditional method.

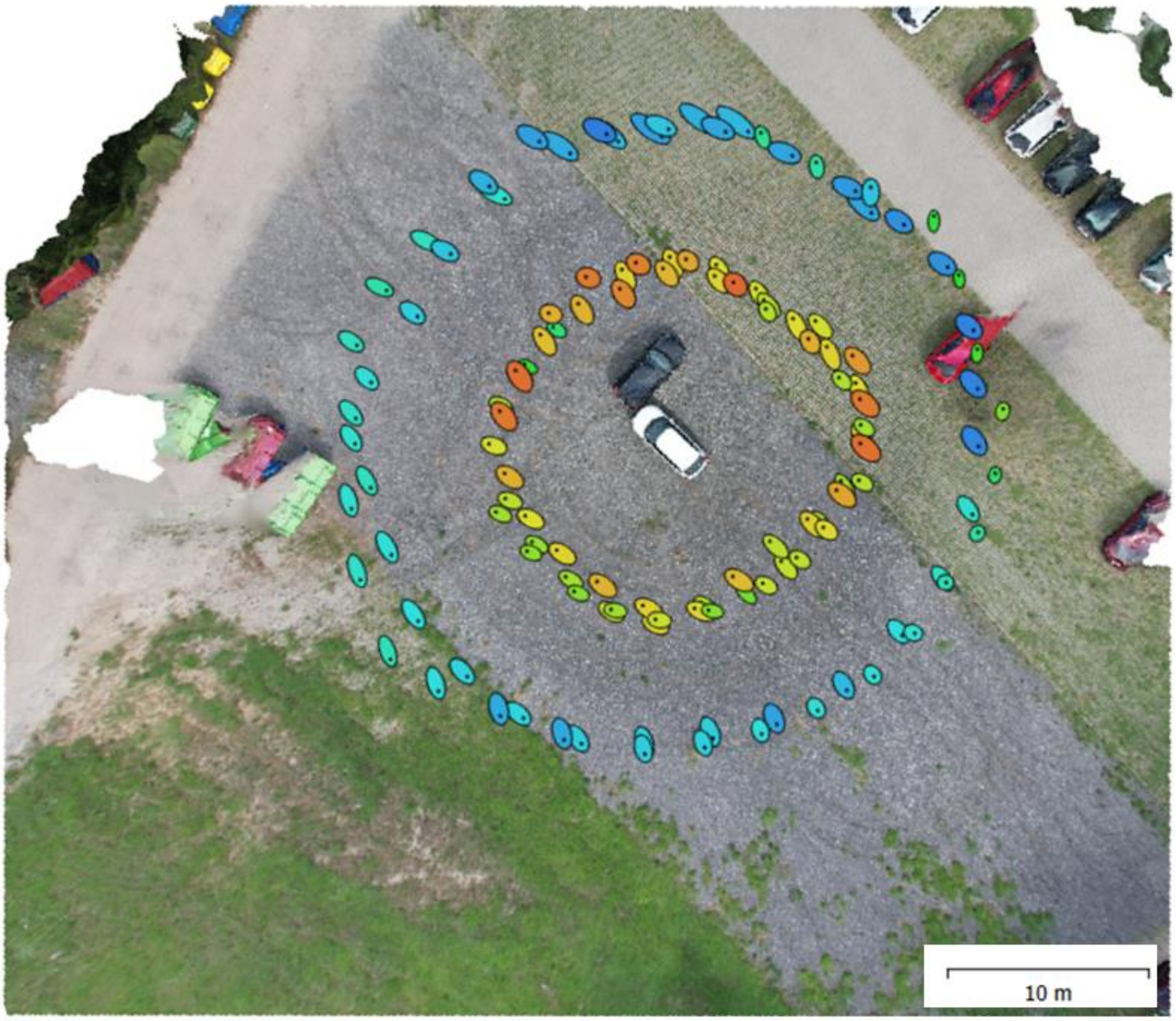

Fig. 1. Positions from which the photos were taken.

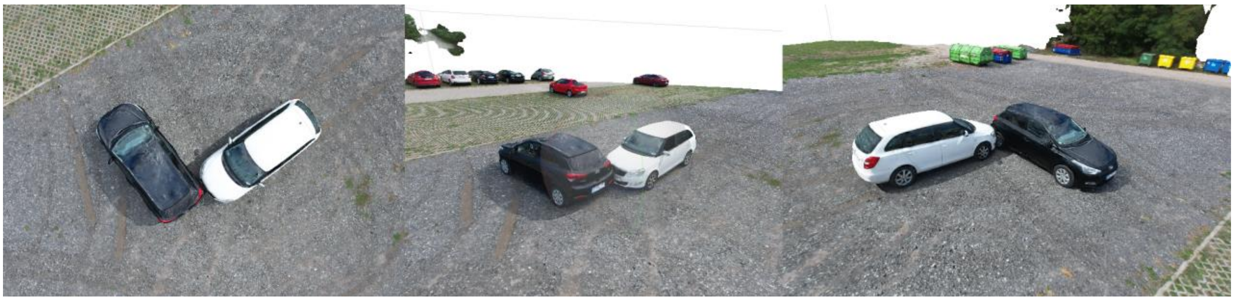

Fig. 2. Selected shots of the 3D model.

Fig. 3. Length of the braking distance.

6. Conclusions

The use of small unmanned aerial vehicles, unlike manned helicopters and airframes, allows the use of the advantages of photogrammetry in a small area also in the city, where tall buildings may be a natural obstacle. Thanks to the possibility of taking pictures at a relatively low altitude, it is possible to obtain high-resolution pictures, and the preparation for the flight does not take much time. A sufficiently large number of photos taken by the rules of photogrammetry allows for the preparation of a spatial model of the accident site with high detail in a short time. The photogrammetric flight can be carried out by a person who is not a specialist in the assessment of road accidents. A well-prepared spatial model could reduce the time that the expert would have to spend on the spot to collect and archive all possible traces of the event. This model can also then be used to analyze the scene of the accident in terms of reducing the risk of another collision in the considered place by analyzing the visibility at the intersection limited by vegetation or buildings.

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