Communication

Fast and High Precise Spatial Documentation of Traffic Accident Site Using Only Low-Cost RPAS

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Featured Application: This proofing of concept may serve as evidence for e.g., Traffic Police of the Czech Republic about the high efficiency, suitability, and usability of RPAS during the traffic accident documentation process.

Abstract: Traffic accident documentation worldwide is generally done by conventional methods (e.g., surveying wheel and steel tapeline) followed by sketch and plan creation. These conventional methods are time-consuming and inaccurate; therefore, they can possibly be replaced by advanced modern methods, using the remotely piloted aircraft system (RPAS) for obtaining data, as well as the structure from motion (SfM) for processing. For the proof of concept, we designed and performed an experiment using low-cost multi-rotor RPAS on an arranged traffic accident involving three cars. The result of this experiment was an accurate 3D model with the possibility of precise measurement. The differences in distances and reference objects’ dimensions were in general below 1% compared to real values. The presented method is time-saving (requiring 85% less time), more precise, and more efficient compared to conventional methods. Moreover, it allows better data reusability, thus is very suitable and can be recommended for usage in routine situations in traffic accident documentation.

Keywords: RPAS; traffic accident documentation; aerial photogrammetry; 3D model

1. Introduction

Remotely piloted aircraft systems (RPAS)—inaccurately called unmanned aerial vehicle (UAV), unmanned aerial system (UAS), or drone—has recently become very popular in different fields of interest worldwide. These incorrect designations are inaccurate because the vehicle is not “unmanned”, there is merely no pilot directly on board. This communication focuses on using low-cost RPAS for traffic accident documentation. Traffic accidents cause more than 1.35 million casualties worldwide each year [1]. The total number of global traffic accidents is quite difficult to estimate. Traffic accidents are documented for two reasons. The first is to document evidence, and the second is to subsequently improve safety around traffic accident sites. Often, two or three vehicles are involved in most traffic accidents [2]. Traffic police in the Czech Republic use conventional methods for traffic accident site documentation, mainly through implementing a surveying wheel and steel tapelines. These tools are fully manual. The authors of [3] introduced advanced methods using geodetic total station with RPAS for aerial images, and they also presented using a camera for terrestrial image rectification. Using an advanced method for documenting traffic accident sites saved approximately 50% of the time compared to conventional methods. Due to their high cost, these instruments are not used widely. It should be noted that traffic accidents have direct and indirect costs. Indirect costs relate to road closures and traffic complications caused by obtaining documentation and the cleaning of traffic accident sites [3].
Several studies [3–8] discuss data usability obtained from low-cost RPAS. The authors of [4] tested the accuracy and effectiveness of this data for traffic accident scene documentation. The authors compared many setting parameters, and their influences on accuracy (overlaps of images, number of images, quality of dense point cloud, mesh processing, etc.). Three ground control points (GCPs), obtained from the global navigation satellite system (GNSS), enter the photogrammetric image blocks processing. The authors of [5] published the article “UAV Image Mosaic for Road Traffic Accident Scene”, describing RPAS image mosaic technology, which includes the utilization of image zooming, scale invariant feature transform (SIFT) feature point extraction, SIFT feature matching, and random sample consensus (RANSAC) feature point purification. The last step of the process is image fusion. The authors claimed that it is possible to measure distances on processed image mosaics. The article does not present the accuracy of the measured distances. The authors also concluded that the SIFT algorithm is robust but takes a long time to calculate. The authors of [2] described many traffic accident scenarios utilizing RPAS. There is, for example, a scenario operating with poor light conditions or darkness. The authors present the possibility of attaching a lighting kit to RPAS. Specifically, the authors used a lighting kit for DJI Phantom 4. The main conclusion is that utilizing RPAS for traffic accident documentation could be more efficient than conventional methods. The authors of [6] tested RPAS usage regarding traffic accident documentation in extreme weather conditions in Kuwait, including high and low temperatures, dusty wind gusts, rain, and low light with good results. They also mention the creation of a 3D model of vehicles. The authors of [7] presented the creation of 2D and 3D models of the traffic accident site. They also used RPAS for large-scale traffic accident (e.g., aircraft accident) documentation [8]. Multi-rotor RPAS were used in all mentioned studies, and the usability of this data was confirmed. However, there is still room for improvement in the speed of acquiring data, the accuracy of the model, and the simplification of the whole process. This study presents the proof of concept and attempts to fill this gap.

When a traffic accident happens, to restore the flow of road traffic, three main steps follow. The first step is to save lives, which is indeed the highest priority. The next step is to document the traffic accident site. The third step is to remove vehicles, cargo, debris, etc., and to reopen the highway or road. Regarding time consumption, the first and third steps are highly dependent on traffic accident locations and the integrated rescue system (IRS), or car rescue service driving distance. These parts can be accelerated by better infrastructure—for instance, more IRS and car rescue service stations or better-equipped emergency vehicles. The time acceleration of these steps is strongly dependent on a huge supply of money. In other words, every second of speeding up would be disproportionately expensive. Regarding the economic cost alone, it is not as efficient and feasible as optimizing the second step. This step can be significantly accelerated with minimal expenses, using low-cost RPAS instead of conventional methods. RPAS utilization decreases the time of traffic accident site inspection (the second step) and enhances the overall awareness of the site situation.

Using statistical data from the national database to justify the differences and improvements, this communication focuses on the situation in the Czech Republic. To elucidate the situation in the Czech Republic, we have included some brief statistical information about traffic accidents as follows. According to [9], 89,446 traffic accidents (where traffic police were involved) occurred in the Czech Republic in 2020, resulting in 470 fatalities, 1536 serious injuries, and 19,270 minor injuries. The total direct costs were almost €212 million, although these numbers are also affected by the COVID-19 pandemic (during which time traffic flow decreased). In comparison, 102,220 traffic accidents with total direct costs of over €353 million occurred in 2019. According to [10], the cost of a closed highway is approx. €145,000 per hour in the Czech Republic. If the time spent on traffic accident documentation could be shortened, a lot of hours and money could be saved. The methodology in general can indeed be applicable outside the Czech Republic too. Herein,
we do not mention or discuss legislation for using RPAS. Firstly, legislation varies in different states throughout the world. Secondly, the IRS may use slightly different rules for using RPAS.

The main goal of this communication is proof of concept. It demonstrates that new methodology using RPAS for traffic accident documentation can substitute conventional methods with many benefits, such as faster acquisition of more accurate data, and faster, efficient, more effective, and precise data processing, data reusability, etc.

2. Materials and Methods

2.1. Current State

Current methods that traffic police in the Czech Republic use involve two main stages. The first includes in situ measuring (using a surveying wheel and steel tapeline, predominantly) and sketch creating (Figure 1a). The accuracy of the measurements is on the order of decimeters. The second step involves creating a plan in the specialized software (in the office) based on a sketch created on a traffic accident site. This plan is in the local coordinate system, with the possibility of measurement (Figure 1b). The amount of time spent creating sketches and plans depends highly on the traffic accident type, including the number of involved vehicles. In the case of the traffic accident depicted in Figure 1, it took approx. one hour to create a sketch and another two hours to create a plan at the office. Sometimes Google Maps, with a combination of initial measurement points, is used to create a plan from a sketch. Traffic police typically use tourist GNSS to obtain the absolute coordinates of the center of the traffic accident site. Using this central point, they can approximately place the plan into the absolute coordinates system, but they do all measurements in the local coordinates system. The measurements are related to the initial measurement point (e.g., a lamp drawn in a technical map); therefore, the absolute position accuracy of the traffic accident site is not important for our investigation [11]. The whole process is quite time consuming, considering this example does not represent a serious accident that involves more vehicles, skids, debris, injured persons, casualties, etc. It could be quite unfeasible to measure and draw every important distance using a handmade sketch. Although traffic officers take many images of the traffic accident site using a digital single lens reflex (DSLR) camera, the resulting pictures are not to scale. Some evidence might be useless in situ and therefore officers do not present it in a plan. Consequently, officers might miss it in further investigations. Moreover, there are gentle differences between measurements, sketches, and plans that different traffic officers create. It is highly dependent on experiences, dexterity, abilities, etc.
2.2. Proposed RPAS Method

We propose that traffic officers, during traffic accident site documentation, should use a multi-rotor RPAS with a 4K digital camera using an optical sensor. This type of RPAS would be small, well equipped, easy to control, and economically available. For proof of concept, we used a DJI Mavic 2 Pro quadcopter, which is equipped with an L1D-20c camera (physical focal length is 10.37 mm = 28 mm in 35 mm format equivalent). It has 20 million effective pixels and a 1” CMOS sensor mounted on a 3-axis gimbal. GNSS sensors utilize signals from the global positioning system (GPS) and the Global’naja Navigacionnaja Sputnikovaja Sistema (GLONASS). The maximum flight time is about 31 min [12]. This RPAS and its data are the only input, which we used to create the final model. No more hardware tools or data entered the whole process. During the proof of concept, we also used a steel tapeline, a laser rangefinder, and some objects with known dimensions—but only to assess the accuracy of the final product.

Testing this proposed method during a real traffic accident was not feasible due to legislation restrictions. Therefore, an experiment took place inside a closed area in Opava in the Moravian-Silesian region of the Czech Republic. We arranged a traffic accident, involving three cars (due to the reason mentioned earlier) and reference objects. Buildings, trees, wires, fences, and construction materials were present quite close to the site. The arranged traffic accident surroundings were rather complicated compared to usual real traffic accidents. The day of the flight was sunny, with a temperature around 25 °C, and the wind speed was 3.6 m·s⁻¹.

Including site reconnaissance, it took us approx. five minutes to prepare the RPAS—unfolding the RPAS, inserting the accumulator, turning on the remote controller and DJI GO 4 application, turning on the RPAS, connecting the remote controller and the RPAS, calibrating the compass and inertial measurement unit (IMU), and waiting for the signal capture from the GNSS and home point setting. The flight time itself took approx. two minutes (the automatic flight would take approx. four minutes). The preparation time is not overly dependent on the extent of the traffic accident site. The flight time is slightly prolonged for more extensive traffic accident sites. No reference objects, like GCPs, are needed for subsequent georeferencing because we obtain the necessary spatial information from the onboard GNSS sensor. The absolute coordinates accuracy is not so important for this purpose; on the other hand, local coordinate accuracy is crucial.

**Figure 1.** Sketch created on traffic accident site (a). Plan in the local coordinate system (b) [11].
Due to the presence of obstacles, we could not use the automatic flight. We conducted four single-grid manual flights, during which we acquired still images and videos. Images obtained during the third flight gave the most suitable results after processing. The flight and camera parameters are shown in Table 1.

Table 1. Flight and camera parameters (third flight).

| Flight Parameters: | Camera Parameters: |
|--------------------|--------------------|
| Flight height: 10 m | Camera maker: Hasselblad |
| Size of area: 20 x 25 m | Camera model: L1D-20c |
| Forward/side overlaps: 70/80% | Camera angle: 90° (perpendicular to the ground) |
| Type of scan: Single grid | Still Image size: 5472 x 3648 pixels |
| GSD: approx. 0.002 m | Resolution: 72 dpi |
| Speed: approx. 1 m·s⁻¹ | F-stop: f/3.2 |
| Flight time (take-off and landing included): approx. 2 min | Exposure time: 1/200 s |
| Flight mode: manual | ISO: 100 |
| Number of acquired images: 27 | Camera trigger speed: approx. 3.5 s |

A general overview is depicted in Figure 2. We positioned three cars (A, B, C) to simulate a real traffic accident, around which we set rectangular (1, 2, 3, 4) and round (8) objects with known dimensions and three points designated to the distance measurements (5, 6, 7). After each of the flights, we measured three distances between given points (5, 6, 7). The trajectory of the third flight is also depicted. To assess the accuracy of the final model, we used objects and points. To assess the accuracy inside and around the arranged traffic accident, we dislocated reference objects and points.

![Figure 2](image)

**Figure 2.** Overview of arranged traffic accident site with reference objects. A, B, C—vehicles; 1, 2, 3, 4, 8—reference objects with known dimensions; and 5, 6, 7—reference points for measurements. Green line represents third flight’s trajectory.

We did subsequent processing completely with Agisoft Photoscan Professional (64-bit) version 1.4.4 [13]. To create a 3D model from sequences of 2D images, we used the structure from motion (SFM) method. Original images, without any transformation or correction, entered processing, as recommended by the software producer. The images’
coordinates were acquired from an onboard GNSS receiver (GPS + GLONASS) and written into the images’ exchangeable image file format (EXIF). These coordinates were further used for automatic georeferencing. After uploading the images, we followed four main steps. Camera calibration should precede all steps. The first step included images of aligning. We found key and tie points over all the images. The second step involved building a dense point cloud. During the third step, we created a meshed model from the dense point cloud. The fourth step included textured model building. After these steps, the model was ready for traffic accident site inspection and measurement. We tested several various settings. The following settings, shown in Table 2, gave the most appropriate results.

Table 2. Agisoft Photoscan Professional (64-bit) version 1.4.4 settings.

| 1. Step (Aligning Photos) | 2. Step (Building Dense Cloud) | 3. Step (Building Mesh) | 4. Step (Building Texture) |
|---------------------------|--------------------------------|-------------------------|---------------------------|
| Accuracy—High             | Quality—High                  | Surface type—Height field (2.5D) | Mapping mode—Generic     |
| Key point limit—10,000    | Depth filtering—Mild          | Source data—Dense cloud  | Blending mode—Mosaic     |
| Tie point limit—4000      | Calculate point vertex—Enabled| Face count—High          | Hole filling—Enabled      |
| x                         | x                              | Interpolation—Enabled    | Ghosting filter—Enabled  |

Point cloud, 3D model, digital surface model (DSM), orthomosaic etc. could be exported and used in selected GIS software.

The computational time was 14 min. The model was computed on a device with the following parameters: CPU—Intel Core i7-8750H, 2.20 GHz, 6 Cores, 12 Logical Processors; RAM—16 GB; GPU—nVidia GeForce GTX 1060 with Max-Q Design, 6 GB.

3. Results

The whole experiment design (including flight path, reference object positions, image processing, etc.) was designed to produce the most accurate ground plan of arranged traffic accidents (in the local coordinate system). This model was supposed to be very similar to the traffic police’s plan, which makes it possible to replace the traffic police’s plan. Regardless of the need for a 2D model, which is usually produced by the traffic police, we created a 3D georeferenced model to be used and treated as a ground plan, with very precise measurements (Figure 3).

A detailed view of the final model is depicted in Figure 4. Every detail (skids, cars parts, reference objects, debris, etc.) is very well visible, the same as in Figure 3.

In addition, this model could be used as a 3D model with the possibility of measurement too (Figure 5). The parallel areas to the camera view axis do not have the same overall graphical quality as the perpendicular areas to the camera view axis, which can be observed on imprecise textures (vehicles’ doors) in Figure 5. If this would be important for traffic accident documentation, a few oblique images should be required and added to image processing.

The graphic quality of the final model was assessed. Accuracy evaluation was determined from the data in Table 3. Regarding the object dimensions, the differences between the reality measurements and the model are 1% or less, except reference object no. 8, which reaches almost 2% in relative terms. Reference object no. 8 is round and lies in the corner of an arranged traffic accident. We assessed the area of reference objects (rectangular or round) and the measurements between points (reality vs. model).

The final model meets the requirements for traffic accident documentation and enhances the accuracy and amount of graphic content. Moreover, using this method extremely shortens the time needed for documentation in situ, and the following processing into the final plan in the office. The time necessary for pre-flight preparations, flight, and subsequent image processing was approx. 21 min.
Figure 3. Perpendicular view of the final 3D model, with an example of measurement.

Figure 4. Detailed perpendicular view of the final model.
Figure 5. Oblique view to final 3D model (license plates were blurred).

Table 3. Differences between reference objects dimensions (reality vs. model).

| Reference Object No. | Real Object Dimension (mm): | Object Dimension in Model (mm): |
|----------------------|-----------------------------|---------------------------------|
| 1                    | 300 × 300                   | 302 × 301                       |
| 2                    | 490 × 399                   | 493 × 399                       |
| 3                    | 400 × 370                   | 401 × 373                       |
| 4                    | 400 × 370                   | 402 × 371                       |
| 8                    | 103                         | 105                             |

Distances between objects: Real distance [mm]: Distance in model [mm]:

- 5 → 7: 10,433 */10,433 **: 10,500
- 5 → 6: 5482 */5450 **: 5470
- 6 → 7: 6031 */6120 **: 6040

Measured using * laser rangefinder, ** steel tape line.

4. Discussion

The utilization of RPAS for traffic accident site documentation could rapidly speed up the whole process. Arranged traffic accident documentation using RPAS took seven minutes, including the time for RPAS preparation and site reconnaissance. Documentation of a real traffic accident depicted in Figure 1 took 60 min [11]. These two examples of traffic accidents are comparable, meaning acceleration is higher than eight times. In addition, unlike the handmade sketch, the model preserves the whole reality. The model formed from the RPAS data can provide better data reusability than sketches and photos taken conventionally at the accident site. The model preserves all information in one complex and coherent dataset. The accuracy of the model is in centimeters, as opposed to the decimeters accuracy of the handmade sketch. The subsequent processing of the images took only minutes, not hours, as in the case of a conventionally created plan. The sketches need to be redrawn into plans using computers, which means the traffic officer has to execute the same work twice. To conclude, the utilization of RPAS makes the whole process of traffic accident documentation faster, more precise, and time effective. Moreover, utilizing this method is safer for traffic officers, since they do not have to move unnecessarily close to the traffic accident site on the road or highway.

There is definitely a need to make the whole process faster. Replacement of conventional methods for RPAS could save more than 85% of the time. Reducing traffic accident documentation from one hour to seven minutes could save more than €127,000 in situations where the highway must be closed in the Czech Republic, for instance. This cost comes out from [10] and includes indirect costs caused by the closed highway.

To evaluate the efficiency of this proof of concept, we compared a few studies to our own study, evaluating major parameters like root mean square error (RMSE), using/not
using GCPs, flight time, overlaps of images, etc. The authors of [7] used two techniques for data acquisition (waypoints and points of interest). RMSE was 43 mm and 59 mm, respectively, flight height was approx. 15 m, and four GCPs were used for georeferencing. The authors of [6] tested the utilization of RPAS in the weather conditions of Kuwait, where a few flights were done. The flight with similar parameters (flight height of approx. 17 m, overlaps 80/75%) reported an RMSE of 85.2 mm. The flight time was approx. 8.5 min. The authors of [2] also conducted a few flights. A comparable flight (flight height of approx. 10 m) reported an RMSE of 10 mm or worse (lower tens of mm). The flight time was approx. 4.8 min, while the processing time of 76 images was 30.3 min. The authors of [4] tried to figure out the best overlap setting. The lowest reached RMSE was 170 mm, with a similar overlap (frontal overlap 75%). The flight height was 65 m and three GCPs were used. The authors of [3] concluded that usage of advanced methods (geodetic total station, photographic rectification or RPAS) can save around 50% of the time necessary to create the traffic accident documentation, compared to conventional methods. The average measurement error is generally approx. 5.3%. Our study had a flight height of approx. 10 m, overlaps 70/80%, flight time of approx. 2 min, processing time of 27 images was 14 min, and the average relative measurement error was 2% maximum. This suggests that modern methods using RPAS are in general rather comparable to each other while presenting better results than currently used conventional methods used at traffic accident sites.

The limitations of RPAS usage for traffic accident site inspection are closely connected especially with weather and site location. Unfortunately, it remains impossible to use low-cost RPAS during rainy or foggy weather. Strong wind is also limiting. Flying in tunnels, under bridges, or under a dense tree canopy is not feasible either. On the other hand, this multi-rotor vehicle does not require a large space for maneuvering, including take-off and landing, since it is a point take-off and landing (PTOL) RPAS. It is also able to hover during flight. Moreover, with a combination of omnidirectional obstacle sensing and automatic flight according to waypoints, it makes flights very simple and controllable. Finally, it allows flying in spatially limited space like urban areas with wires, streetlamps, poles, trees, etc., for instance.

During this proof of concept, only low-cost RPAS (less than £1500) was used to obtain images of an arranged traffic accident. Subsequently, commercial software was utilized. There was no need to use other external devices like GNSS or GCPs. If a very accurate absolute position is needed, RPAS with real time kinematic (RTK) GNSS on board could be used without the need for GCPs [14]. In future studies, we will use RPAS that is a quarter the price but has similar parameters. Utilizing cloud data processing instead of desktop image processing could also make the whole process much faster and cheaper. Images of the traffic accident site acquired from RPAS could be processed into a final model before traffic officers reached their office.

5. Conclusions

This proof of concept successfully confirmed that RPAS utilization can replace the conventional methods currently used for traffic accident documentation. We supported the methodology by creating a 3D model of an arranged traffic accident, assessing the spatial accuracy and graphical content. RPAS utilization combined with this methodology could make traffic accident documentation faster, more accurate, efficient, effective, and safer. Indeed, there are limitations of using RPAS during specific traffic accident localities or weather conditions.

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