EMERGENCY RESCUE MANAGEMENT SUPPORTED BY UAV REMOTE SENSING DATA

B. Weintrit [1,2], K. Bakuła [1], M.Jędryka [2], W. Bijak [2], W. Ostrowski [2], D. Zelaya Wziątek [1,3], A. Ankowski [4], Z. Kurczyński [2]

[1] Department of Photogrammetry, Remote Sensing and Spatial Information Systems, Faculty of Geodesy and Cartography, Warsaw University of Technology, Warsaw, Poland
[2] Astri Polska Sp. z o.o., Warsaw, Poland
[3] Institute of Meteorology and Water Management - National Research Institute, Dam Monitoring Centre, Legionowo, Poland
[4] The Central School of the State Fire Service in Czestochowa, Częstochowa, Poland

Inter Commission III/IV

KEY WORDS: crisis management, levee monitoring, remote sensing, UAV data, automatic orthomosaics

ABSTRACT:

In the proposed SAFEDAM system, aerial and satellite-based information is used for the monitoring of river bodies, flood monitoring during the event, and for post-disaster damage assessment. UAV constitute a valuable source of information about the current situation in the field during the operation of emergency services. Time is crucial, and the basic assumption to use UAV remote sensing data is to make them available immediately after landing. Therefore, the approach of automatic orthomosaics created based on the exterior orientation of the transmitted images using direct georeference was selected instead of sophisticated automatic on-the-fly image-matching and georeferencing. The article conveys the justification for selecting this option in order to process orthomosaics with lower localisation accuracy in a short time. The developed algorithm takes into account the elements of exterior and interior orientation of the camera as well as the digital terrain model. The evaluation of the orthomosaic was conducted based on theorthophoto created in post-processing. Thanks to the approach used, images from the platform are available in the near real time on the screen of the interventional mode of the SAFEDAM system and are an extremely valuable and informative source of data. The system also integrates tools, which support the management of the action and prepares site documentation.

1. INTRODUCTION

Flooding is one of the most destructive natural disasters faced by people nowadays. Dense river networks render floods the largest hazard in Middle Eastern Europe. Over the past 20 years, the number of floods has increased. For this reason, it is necessary to improve the quality of national crisis management in order to better respond to threats when they occur. The effective system for levees monitoring is crucial in every phase of crisis management, from prevention to response and even to estimation and assessment of the consequences of a crisis situation. The SAFEDAM system has been developed over the course of two years as part of the project 'Advanced technologies in the prevention of flood hazard', financed by the National Center for Research and Development. It is an example of a system operating in two configurations and combining multi-source remote sensing data (Kurczyński and Bakuła, 2016; Bakuła et al., 2018). The idea of the system is to facilitate data collection in time when a disaster does not occur and when it is allowed to reliably assess the condition of the levee infrastructure and estimate the hazard, with the purpose of creating hazard and risk maps. In case of flood cataclysm, the relevant services have all data related to the embankments integrated in one IT system.

Unmanned aerial vehicles (UAV) collect low-altitude images and are used in order to address many issues related to photogrammetric spatial data acquisition (Colomina and Molina, 2014). They are also used to provide maps in crisis situations (Choi and Lee, 2011; Boccardo et al., 2015). The development of the navigation sensors used to measure the position of the mobile platform during the flight also increases the possibilities of using direct georeferencing and resignation from the control points (GCP) while conducting photogrammetric studies, which requires a high workload in the field (Mian et al., 2015). The use of this type of sensors and solutions therefore seems particularly important in crisis situations.

In recent years, a lot of attention has been paid to research considering possibility of using the new generation of GNSS/INS sensors during the acquisition of photogrammetric data, including for corridor facilities (Mian et al., 2016). The conducted research focuses on aerotriangulation using a minimum number of GCPs or excluding their participation in bundle adjustment. The impact exerted on the exterior orientation parameters by factors, such as camera calibration, GCP distribution, coverage between photos or even postprocessing of the GNSS/INS observations using PPK technology (Stöcker et al., 2017) is also investigated. However, such developed methods related to the photogrammetric workflow require additional time for the post-processing of data and orientation of images. Although the use of GNSS/INS observation can significantly shorten the photogrammetric processing time (Mian et al., 2015), a processing period of 30 minutes is still unacceptable from the perspective of emergency applications, when spatial information is required immediately.

The developed IT system must meet the high requirements of providing data for the management of the crisis mission, but also for levee monitoring in a preventive configuration not only by means of photographs but also by employing a LiDAR system (Bakuła et al., 2016; 2017). In this type of remote sensing technology, the GNSS/INS system plays a key role (Pilarska et al., 2016). In the case of an interventional configuration, the expected map layer has to fulfil two key features: (1) it must be characterised by high resolution and (2) it should provide data as soon as possible after landing the

https://doi.org/10.5194/isprs-archives-XLII-3-W4-563-2018

platform. Therefore, the conducted experiments primarily focused on data processing using only direct georeferencing with GNSS/INS observations, with their rapid georeferencing, projective transformation leading to the orthomosaic creation. This paper therefore provides justification for such adecision, as well as an introduction to the interventional configuration of the SAFEDAM system.

2. INTERVENTIONAL MODE OF SAFEDAM

The distinguishing feature of the SAFEDAM system is represented by its ability to work in two configurations: preventive and interventional. The preventive configuration makes it possible, among others, to assess the condition of the embankments and the state of emergency using aerial and satellites remote sensing data processed to orthophotomaps and the digital terrain model (DTM) (Bakuła et al., 2018). Optical and particularly radar satellite data from Sentinel are used for the purpose of water body identification (Pluto-Kossakowska et al., 2017; Weintrit et al., 2017). Aerial data from geodetic repositories are used to preselect areas for the high resolution inventory using the UAV platform equipped with an ultralight LiDAR system and photogrammetric camera. Moreover, the system indicates areas that require direct verification in the field and successively transfers information on the threat collected from the public using the geoparticipation application.

The interventional configuration is designed to work already at the time of flooding. Its mission is to support the crisis management and fire services in managing the protection of the levees. On-site services have an image transmitted from an unmanned platform and data from the system's databaseat their disposal, which facilitates the efficient identification and protection of areas that have been classified as areas of increased riskduring the preventive activities. The system in interventional mode also enables the communication of on-site emergency services to the crisis staff by retaining current information related to the area of activities in the application. Table 1 presents the characteristics and functionality of the interventional mode of the IT system.

When working in the field during a crisis action, the key aspect is time. Because of this fact, the tools offered to the relevant services have to deliver actual information as quickly as possible, preferably in real time. Very often, in order to deliver a large amount of data in a short time, the quality or resolution have to be downgraded. It was a reason why in the SAFEDAM system, the methodology for transmitting data to devices in the interventional mode was limited from many various data from different technologies (LiDAR, photogrammetry, etc.) to video streaming from the UAV platform and uploading nadir photos from the drone just after the platform is landed.

The interventional platform developed in a project as a recommended and example UAV platform is a six-engine version of the multi-rotor Hawk Month (Figure 1). It is equipped with observing head providing in-fly video streaming in an optical spectrum or thermal infrared spectrum to emergency services and firefighters in a field. Additionally, a Sony a6000 camera records the nadir optical images that are acquired during the mission and transmitted to the information system after landing the platform. They are used in order to produce a basic layer for planning missions and risk management. After the rescue operation, the collected photos are processed in a photogrammetric workflow resulting in the orthophotomap. During the rescue operation, many of the photos with their location and angles interpolated from the trajectory are georeferenced.

Type	mobile application
Access	login, appropriate permissions
Available data	access to data from the action area uploaded to the mobile device before the action, or access to the SAFEDAM database in the case of Internet connectivity
Basic functions	zooming, centering, displaying coordinates of the mouse cursor, dynamic scale of the map, searching for data in the database, the ability to turn off the visibility of layers, setting the transparency of layers, measurements of area, length and height, the ability to draw on the map, screen shot to graphic form, export of shapefiles with markings from the action, export of shapefiles with evaluation of leeves, sharing links to WMS layers visible in the system
Dedicated functions	displaying oriented photos from the UAV after landing, live video streaming from UAV (optical or thermal infrared), displaying hazard and risk maps referring to levee failure and overflow, advanced tools for drawing and placing information on the course of action, high-resolution large-area preview of areas based on satellite data (ordered on demand), positioning the mobile device on the map, simulation of flood water by changing the height of water level, creating reports and documentation in accordance with accepted standards,
Result	current information about the situation in the field

Table 1.Interventional mode characteristic

Figure 1. The Hawk Moth platform by MSP Poland with observing head recommended in interventional configuration of SAFEDAM project (source: MSP promotional materials)

Due to the time-consuming processing of data into the form orthophotomap, in the interventional mode, it was decided to write an algorithm that would display the images right after the flight. This allows relevant services to preview the current situation from the area immediately after landing the drone. Pictures are downloaded from the SD card from the drone to the laptop, are recorded on USB for further distribution in the field. It is a solution that makes transferring photos from the Internet connection independent (Figure 2) which can be eventually possible during an action.

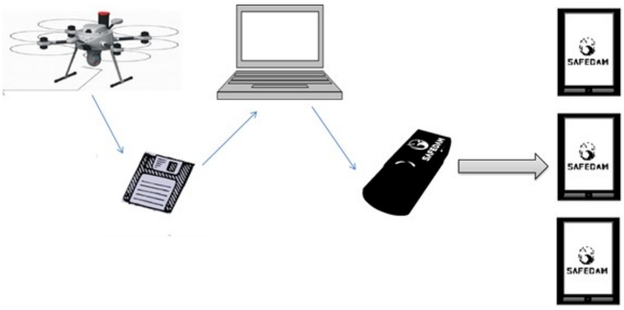

Figure 2. Diagram of acquired imageries distribution in the field

3. EXPERIMENT

In this chapter, the import and orientation of the images collected from the multi-rotor platform are described. The justification for selecting direct georeferencing and projection transformation on the reference surface of the DTM in order to obtain orthomosaics with lower localisation accuracy but in a short time is also provided. The developed algorithm takes into account the elements of exterior and interior orientation of the camera as well as the digital terrain model.

3.1 Experiment description

As part of the experiment, it was decided to examine the horizontal accuracy of the photos imported to the system. As mentioned in the introduction, it was decided to use direct georeferencing on the basis of the data from the navigation system placed on the GNSS/INS platform. The accuracy without any processing of APX15 by Trimble used in the platform is 1.5 m horizontally and 3.0 m vertically. The error in the angle measurements is 0.04° for the roll and pitch and 0.30° for the heading. The height of the flight mission was 40 m, which was selected to cover the whole embankment width. Ultimately, the height above the ground in flight mission is selected for the TIR or RGB observation head.

As part of the experiment, photos which were not eliminated due to overlap, were imported to the system. The analysis was also related to further additional parameters defining the location of the camera included in the algorithm, such as taking into account the angles of rotation or the digital terrain model instead of the average height of the area recorded image.

The horizontal accuracy was estimated based on the measurements of the vector error in relation to the orthophotomap with a spatial resolution (GSD) of 10 cm created from the same data in the photogrammetric workflow, which took into account the initial elements of exterior observations and tie points extraction and bundle adjustment, dense image matching and orthorectification. The orthophotomap was generated in Agisoft Photoscan and the measurement including the evaluation of the images' horizontal accuracywas performed in ARCGIS by Esri. The measurement of the horizontal errors was subject to the manual measurement of the visible details on the mosaic of photographs and the orthophotomap generated from the photographs. The characteristic points were detailed visible on both orthophotomap and image mosaic.

In the experiment, 88 photos were submitted from one of the test areas of the system (Annopol city). The initial exterior orientation was interpolated from the trajectories recorded by the GNSS/INS sensor and recorded with an accuracy of 1m for linear elements and 0.1° for angular elements. In the file with the trajectory, information about the camera such as image resolution, image size and focal length was also given.

3.2 Algorithm of image import and orientation

The developed algorithm first selects the images in order to limit the quantity of the resource. It has been assumed that images that overlap more than 50% are rejected. In order not to limit the range of the terrain being imaged, all extreme photos are used in the algorithm.

The result of image orientation according to method described below can be seen in Figure 3. General correctness is visible through the continuity of the technical road located on the levee crown and the continuity of land use and land cover corresponding between the UAV-based mosaic of photos and the orthophotomap.

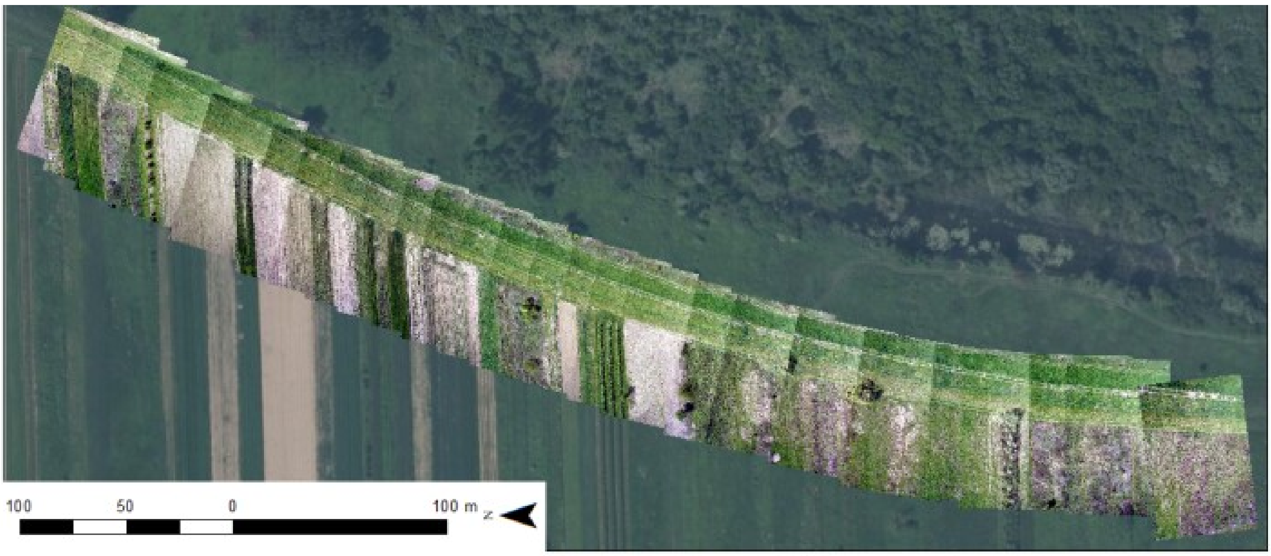

Figure 3. Example of images taken with UAV platform oriented and imported to SAFEDAM IT system

The algorithm uses the information available immediately after landing the UAV platform, and thus the trajectory of the flight directly from the device. In order to correctly adjust the photos, the digital terrain model of the area is used. For each photo:

1) The position of the camera is converted to the corresponding coordinate system,
2) The terrain elevation data from the available DTM are obtained,
3) The relative height of the drone (above ground level - AGL)
4) Based on the height, the angle of the drone, the size of the image and the focal length of the camera, the pixel size, coordinates of the centre and the individual vertices of the image are calculated.

In the first tested variant, for all the corner points of an image the image footprint is calculated using the Alpha Shape algorithm (Edelsbrunner et al., 1983). Images whose corners are on the calculated edge are selected for saving. For the remaining images it is checked whether the image has already been selected and if the overlapping area is bigger than 50%. If not. the image is selected for saving. In the second variant the angular elements of the exterior orientation were ignored to test its influence. In the third approach the average height for image footprint was used in image projection and in the fourth option respectively to the second angular elements were ignored from the third approach.

A mosaic of images created in this way is an indispensable basic layer for quick response during a threat. The mosaic is the background for the measurements of the distance or height from the water surface to the crown of the levee (by interpolation in the indicated places from the DTM). It also gives the opportunity to use it as background in order to create the documentation about action. After the rescue operation. all image data are transferred to specialists preparing the photogrammetric product: an orthophotomap. This product is very important for the preventive configuration effect because it delivers information at a high water level.

4. RESULTS

In Table 2. the results of 4 variants of the experiment were presented with their description in comparison to time of orthorectification in photogrammetric post-processing. The table contains processing time without exporting, total time and horizontal accuracy. The results prove that direct georeference and projective transformation using the DTM can provide results accepted in crisis management reaching about 1.5 m. The importance of exterior orientation has been proved while projection for average height brought slightly better results than interpolating height for all image corners. The supplied orthomosaic can be a basic layer for end-users with a proper accuracy and the visual effect in Figure 3 also confirms it.

Figure 4 presents the layout of the SAFEDAM IT system in the interventional configuration. In this picture, the table of contents divided into 4 parts can be seen on left-hand side. Each part of the table of contents is reserved for a different type of data (orthophotomaps, DTMs, raster data, vector data). At the top of the software window, the following tools can be selected: drawing tools, static simulation of the growing water level, In this picture, part of the library is also developed by the members of the crisis management team.

5. CONCLUSIONS

Thanks to the approach used, the images from the platform are available in the near real time on the screen of the interventional mode of the SAFEDAM system and are an extremely valuable and informative source of data. The system also integrates tools, which support the management of the action and prepares a site documentation. In this particular case, an accurate photogrammetric processing of the data turns out to be many times longer and direct georeference provide sufficient results. It is possible to obtain results about 1-2 metres using direct georeference using available GNSS/INS sensors without any postprocessing. Algorithm that brought the best results was applied used initial information from DTM to find average height of terrain covered by image.

Variant	The original number of photos	Number of selected photos	Processing time [s]	Total time of processing and exporting [s]	Horizontal Accuracy [m]
Perspective transformation on surface defined by height of corners from DTM	88	66	19.2	38.6	1.73
Perspective transformation on surface defined by height of corners from DTM without angular elements of exterior orientation included	88	86	15.4	37.9	7.16
Perspective transformation on surface of average distance (AGL) for the whole area (angular elements included)	88	75	15.9	36.1	1.29
Perspective transformation on surface of average distance (AGL) for the whole area and without angular elements of exterior orientation included	88	86	15.6	38.3	7.04
Orthorectification (bundle adjustment. tie points extraction. dense image matching. orthorectification)	88	88	2280.0	2300.0	-

Table 2. Table of the image processing parameter variants for the sample area with time of computing and horizontal accuracy of the image mosaic.

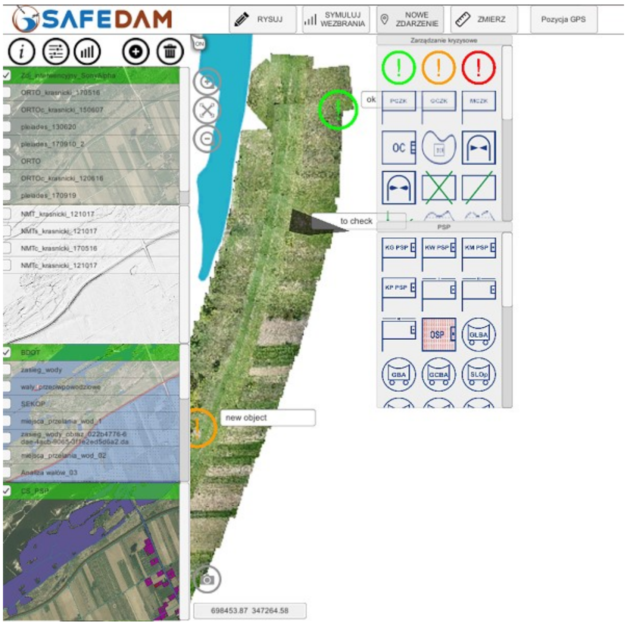

Figure 4. Layout of the SAFEDAM IT system in the interventional configuration: visible table of content divided into four types of data (left-hand side) and symbols of elements related to action that can be placed in a system

The goal of the SAFEDAM project is to develop a monitoring system of levees using an unmanned measuring platform UAV as well as aerial and satellite imaging. The measuring platform is equipped with a laser scanner and high-resolution optical sensors. The monitoring system is based on the latest photogrammetric and remote sensing technologies. The collected spatial data are stored in the IT system. A comprehensive set of tools and algorithms enables the automatic analysis of both 2D and 3D data and their visualisation for hydrological services and crisis management specialists.

The created IT system contains a number of data about levees collected during the prevention. Their combination gives the management services the possibility of supervising the rescue operation and the use of additional data collected during the flood i.e. UAV images and video recordings. These data in the presented system allow for efficient documentation of the course of the action as well as their subsequent analysis. The presented system is an example of the implementation of modern remote sensing and geoinformatic technologies in flood risk management

ACKNOWLEDGEMENTS

Project "Advanced technologies in the prevention of flood hazard (SAFEDAM)" is financed by National Centre for Research and Development in Defense. Security Programme [grant number DOB-BIO7/06/01/2015].

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