Regional Rapid Mapping for First Responders - Turkey 2023 Earthquake

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Abstract

In disaster scenarios, up-to-date information about the affected areas is of fundamental importance, especially for Search and Rescue (SaR) teams. Although the usual space-based optical remote sensing systems provide an overview, the ground resolution of several dozen centimeters per pixel does not reveal many important details. In addition, clouds can delay the recording of the affected area for days. The approach presented here intends to address these problems. SaR teams are enabled to independently map the terrain assigned to them immediately upon arrival. These rapid maps are made easily accessible to all organizations and teams involved in the operation without delay. For the 2023 earthquake mission in Turkey, a SaR team accredited by the United Nations (UN) was equipped with a specific aerial camera and a vertical take-off and landing fixed wing drone. This system is capable of recording almost 7 km^2 per hour at a ground resolution of 3 cm per pixel. The maps were made available worldwide within seconds via radio and internet connection during the flight using a web map service and visualized in the INSARAG ICMS dashboard. In addition to operational aspects, the process chain from the acquisition of the images to the publication of the rapid maps on various geographic information systems (GIS) is described. Additional benefits, the required infrastructure and the need to integrate this capability into the certified SaR teams are discussed.

1. Introduction

On 6^{th} February 2023 two earthquakes with a magnitude of 7.8 and 7.7 struck southern and central Turkey and northern and western Syria [USGS, 2023]. There was widespread damage and tens of thousands of fatalities. On 7^{th} February, a 3-month state of emergency in the most affected provinces was declared [Al Jazeera, 2023]. Following Turkey’s call for international help, more than 141,000 people from 94 countries joined the rescue effort. Germany participated with three SaR teams which were all certified by the UN organization International Search and Rescue Advisory Group - INSARAG. One of them, *ISAR Germany*, arrived the city of Kirikhan in the province of Hatay on 7^{th} February.

After the incident of devastating natural disasters, the first few days are crucial for managing emergencies. Frequently updated information is very important to enable a fast and efficient rescue chain [United Nations, 2018]. First aid responders like SaR teams, governmental agencies for public safety and humanitarian actors are dependent on any information available. This includes an estimation of affected human beings, infrastructure assessment and location of possible work sites [Wieland et al., 2023]. Beside information by locals and on-site authorities, one of the main information sources are remote sensing technologies which cover large areas. Optical remote sensing images can be provided by satellites [Copernicus, 2023], manned aircraft [Overwatch Imaging, 2023] and drones of different sizes [Daud et al., 2022] [Baykar, 2023]. The bird’s view of widely used space-borne optical imagery carries a lot of content and provides unsophisticated human-interpretable assessment. However, there are some limitations coming along with this technique. First, cloudy weather condition can prevent taking images for days wasting valuable time for coordination organizations and first responder teams. Second, the ground resolution per pixel (ground sampling distance, GSD) is typically in the range between 30 cm to 50 cm giving sufficient overview but much of relevant information cannot be resolved. A higher ground resolution less than 10 cm, better 5 cm would be required to identify potential work sites, count persons or select acceptable approach routes. Third, deployment of maps and associated data comes with a delay caused by orbit coverage and data processing. These products are provided via proprietary national and organizational services. However, SaR teams are

Figure 1. VTOL drone with aerial camera ready for survey flight

struggling for every hour to save survivors. Their field work usually begins 24 to 30 hours after the disaster occurred. The teams require prompt, easy to find and easy to access visualization of their assigned working region. These three issues are addressed in the present work. The approach includes the technical equipment development like a drone-based aerial camera. This system is capable to process images instantly to minimize the data rate. Subsequently the preprocessed images are visualized as georeferenced rapid map in the UN organization's *International Search and Rescue Advisory Group Coordination & Management System (INSARAG ICMS)* dashboard which all UN-certified SaR teams use in the field. In parallel the mosaics are instantly (while flying) made available as web map service (WMS) to be accessed by third party participants like authorities.

During the Turkey 2023 earthquake the end-to-end system was tested for the first time in an operational environment. It was shown, that regional scale rapid maps can be acquired within hours after the SaR team arrives in the affected area. The maps are showing a GSD of 3 cm. Images were made available worldwide within 10 seconds after acquisition which provides a new source of visual work site assessment. The sensing system and the processing chain are described in this paper including the image cropping method. The need for data transportation methods like cellular or sat-based radio links is discussed. Improved postprocessed true ortho mosaics (TOM) compared with the real time projected mosaics figures out that, if some time delay is acceptable, both quality levels should be deployed. Operational aspects like necessary remote sensing groups integration into the SaR teams are considered. The outlook gives ideas about automated classification and necessary steps to deploy the ability of rapid mapping to further international SaR teams.

2. Materials and Methods

2.1 Drone-based Aerial Camera System

To generate high-resolution photogrammetric maps, it is necessary to harmonize the sensor and the carrier system. As suitable take-off and landing runways cannot be expected in disaster areas, a vertical take-off and landing (VTOL) drone has operational advantages. To cover several square kilometers in the shortest possible time, a drone was selected that combines VTOL capability with fixed-wing flight characteristics, see figure 1. Fixed-wing aircraft fly faster and more energy-efficiently than quadro-/hexa-/octacopters and therefore achieve a significantly higher area performance. The battery-powered VTOL system used is flying at a speed of approx. 70 km/h with a practical flight time of approx. 75 min at an altitude of 200 m above ground level (AGL). Below cloud ceiling, the drone automatically flies over previously defined waypoints, so that parallel flight lines are generated. Along these lines, the built-in camera captures aerial images whose ground coverage overlaps longitudinally along the flight path and overlaps transversely through the laterally adjacent lines. If only a real-time mosaic (RT-map) is to be created (see chapter Rapid map deployment), the flight is planned with a transverse overlap of approx. 20% to ensure entire ground coverage even in case of extensive roll correction maneuvers. If post-processing of the raw images is to be carried out subsequently for the creation of a digital surface model (DSM), (see chapter Postprocessing for Map Quality Improvement), transverse image overlap of 60% is required and thus the flight is planned with a overlap of 70%, i.e. the parallel strips have a smaller distance to each other. In this case, the area performance drops to approx. 43% compared to the RT-map flight. Thus, a decision must be made before the flight as to whether more time is available for the higher overlap in order to be able to derive post-processed products later. The aerial camera is an in-house development. It is integrated into the drone so that its power supply, positioning and orientation solution and radio link are used, see figure 2. The sensor is a geometrically calibrated industrial camera providing electrical in- and outputs for correct time stamping. Using an embedded PC the image data is merged with the external orientation valid for each image. This means that each pixel is assigned to a geo-coordinate and an exact time of recording. The geo-coded imagery is stored in raw data files. Characteristic parameters of the camera system are compiled in table 1. The images are recorded with a trigger rate that generates approx. 90% longitudinal overlap. In this way, it is possible to create photogrammetric products such as digital elevation models (DEM) and true ortho mosaics (TOM) by subsequent processing of the raw images. As mentioned above, this requires sufficient transverse image overlap of approx. 60% minimum. In addition, the images can be processed step-by-step during the flight in such a way that the longitudinal overlap is minimized to almost 0%. For this purpose, a method called Terrain Aware Image Clipping (TAC) is used, which projects and crops the geo-referenced images onto an elevation model [Hein and Berger, 2018]. Every single TAC-image retains the full image width, the image height however is cropped to few hundred rows to seamlessly fit to both adjacent images. Together with the subsequent data compression using a modified 12-bit jpeg algorithm, the original raw data rate is reduced to approx. 0.3% [Hein et al., 2019]. In this way, the data stream is shrunk from 570 Mbit/s to approx. 1.7 Mbit/s at one image per second. The camera system continuously delivers the pre-processed TACs to the radio link, which maintains an IP-based connection to the ground station. Image data not delivered due to a broken or weak radio connection are buffered by the aerial camera and transferred to the server as soon as the radio connection is re-established.

Parameter	Value
Sensor resolution	7,920 x 6,004 (47.5 Mpix)
Pixel size	4.6 µm
Radiometric depth	12 bit
Optical spectrum	RGB
Weight	700 g
Frame rate max. continuously	2 fps
GSD at 200 m altitude AGL	3 cm
Swath width at 200 m AGL	190 m
Area performance at 70 km/h, 200 m AGL	6.9 km^2/h (20% x-track overlap), 3.0 km^2/h (70% x-track overlap)

Table 1. Aerial camera parameters

2.2 Rapid map deployment

During the flight, the image data stream is received at the ground station and displayed as an image mosaic with correct geographical relation. The map extent grows with time. Projected aerial images can be inspected for the first time. If Internet access is available at the ground station, each TAC-image is instantaneously forwarded to a web map server hosted at the DLR. It does not matter what type of Internet infrastructure is used, e.g. mobile or satellite-based. The continuously growing ortho-mosaic is made available as web map service (WMS)

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Figure 2. *MACS-nano* aerial camera (left) and integrated in VTOL fixed wing drone (right)

and can be used immediately by any authorized user via web browser or freely available GIS-apps. The map can be moved freely and zoomed up to full geometric resolution. Every newly transmitted image and every newly recorded area is added live to the WMS or updated when it is repeatedly recorded. The WMS includes the use of maps in the field on mobile devices such as smartphones and tablets, see figure 3. In addition, the recorded areas can be integrated into the INSARAG ICMS as described in the following chapter. Out of the RT-map, figure 4 shows the cutout of an geo-projected single image in full resolution. In this case, a blocked street is recognizable. To not be stuck with trucks in this dead end and loose valuable time, an alternative route to the work site should investigated before leaving the camp. The flow diagram to provide the RT-maps through the WMS is shown in figure 5.

2.3 ICMS dashboard visualization

In disaster situations under the leadership of UN, the INSARAG ICMS is used for registration, deployment planning and information of all SaR teams involved. This is a web-based tool. The ICMS is utilized by the teams en route and teams already on site. It is fed with their own data during the rescue operation. The central element of the dashboard is a GIS based on *ESRI ArcGIS*. The increased use of such a dashboard helps to manage disaster relief and share relevant data [ZKI, 2023] [Tomaszewski, 2020]. The geographical positions of relevant logistical points of interest are displayed on provided base maps and selectable layers. These include, for example, organizational units such as the Reception Departure Centre (RDC), the USAR Coordination Cell (UCC) and the On-Site Operations Coordination Centre (OSOCC). Additionally the localization and status of the individual SaR teams's working areas are included. Thus, ICMS is a situation map. Because the dashboard is used by all international rescue teams, it is widespread in the community and the access threshold is low. The GIS interface, including map visualization, makes it possible to integrate the self-created maps. New layers with high-resolution, up-to-date maps were added during the deployment, see figure 6. In this way, it is possible to provide the teams on the way and already on site with a new source of information and assessment.

2.4 Postprocessing for Map Quality Improvement

The process chain shown here derives its added value primarily from the topicality of the maps combined with the highest optical resolution. Seconds after an image is captured, it is available worldwide via WMS. However, the rapid availability leaves no room for improving the image quality by postprocessing the entire image composite. As a result, principle-

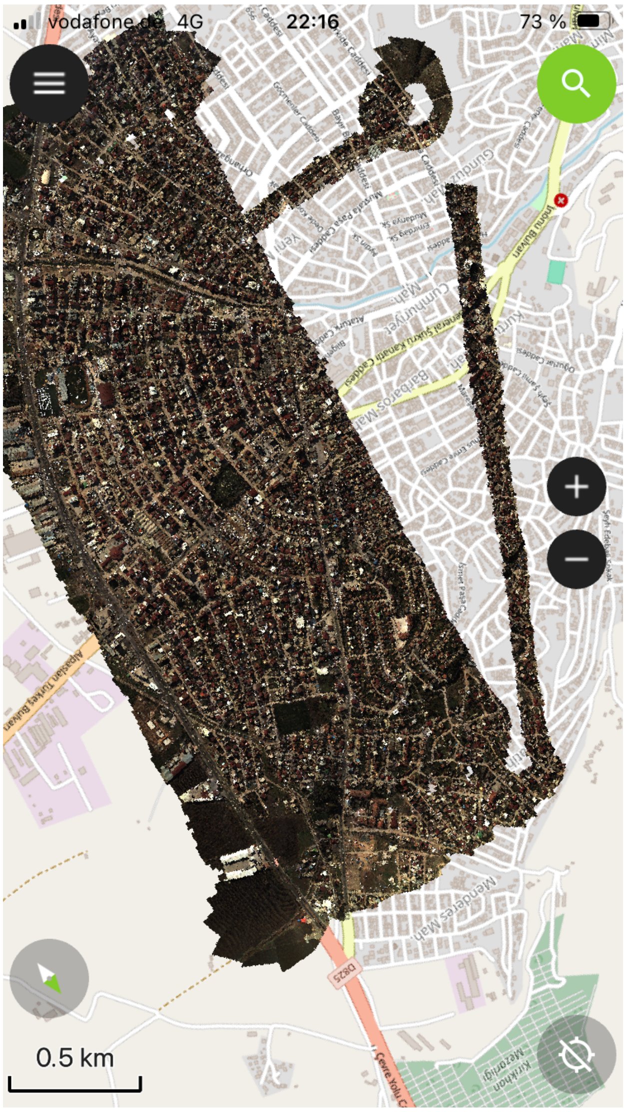

Figure 3. Interactive rapid map arising during the flight, smartphone app *QField* (base map ©*OpenStreetMap 2023)*

based errors such as offsets between image edges remain. These result from the measurement inaccuracy of the inertial-aided GNSS positioning system, but also from the perspective projection. Post-processing is required to eliminate these errors [Wiggenhagen and Steensen, 2021]. In order to derive digital surface models without edge offsets from the rapid ortho-mosaic, the raw images were processed in the team's base camp. This can be done either via a photogrammetric workflow or with the help of Structure for Motion-based (SfM) software, e.g. *Pix4D*, *Agisoft* or the *OpenDroneMap* project. Depending on the extent of the flight area and the hardware available, including copying and converting the images, the whole process can take well over a day. This makes high-performance computing technology in the field and an effective workflow all the more important. During the earthquake operation, it took around 24 hours to provide the DSM for a 3 km^2 area with a GSD of 3 cm per pixel on a gaming laptop. The DSM of the entire city of Kirikhan covers approx. 8 km^2 and has a size of approx. 8 GByte. This amount of data was transferred to the WMS server and made available as an updated data set for GIS visualizers such as ICMS, *QGIS* or the mobile device app *QField*.

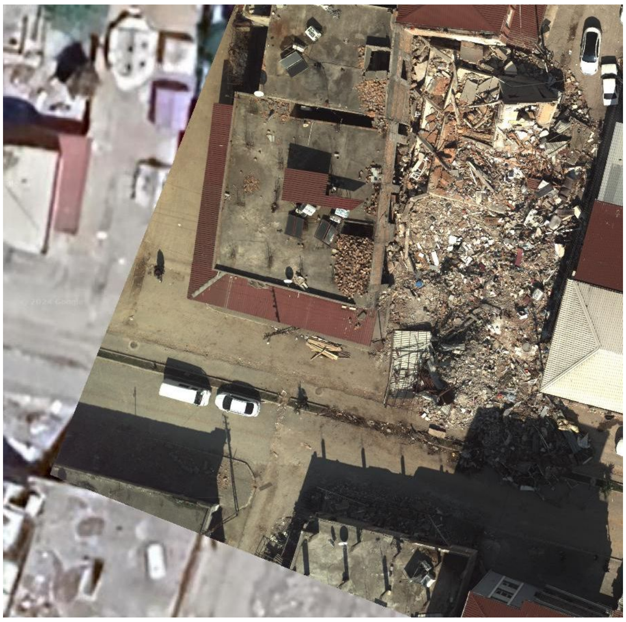

Figure 4. Projected single image showing an impassable route to a work site (cutout, base map ©*GoogleMaps 2023*)

3. Results & Conclusion

For the first time, a drone-based optical remote sensing system was demonstrated under real disaster conditions specifically for the fast, user-open provision of rapid maps. The tests were conducted in the city of Kirikhan as an example. With a ground resolution of approx. 3 cm per pixel, the aerial camera can cover areas up to approx. 7 km^2 per hour. This enables the system to acquire affected surfaces in a regional scale. Such high resolution maps provide an up-to-date and reliable basis for decision-making. The maps were made available in real-time to the on-site operational management of the ISAR Germany SaR team as well as to selected users worldwide. The time span from image acquisition to visualization depends largely on the radio transmission paths. Under optimal conditions, the image is added to the WMS within few seconds and is therefore available to the user. If the throughput rate between the camera system and the server is limited or interrupted, the time span is extended accordingly. If not possible at the fly crew ground station, an Internet connection should be available at the base camp. Thus, in addition to the teams on site the rapid map can be used worldwide.

Information relevant to operational planning was extracted, including crowds, route planning and worksite triage. The maps were made available for standard end-user GIS systems and in the INSARAG ICMS. Subsequently, the DSM post-processed in the field was made available as an additional layer to the real-time maps. It was shown that high-resolution, up-to-date ortho-maps have a relevant added value in disaster scenarios, especially for SaR teams. The technical systems must be designed in such a way that the target area can be overflown at short notice, that large-area image acquisition is achievable and furthermore quickest possible provision of maps is realized. Therefore Internet connection is necessary with adequate data rate. While a rapid map is completely sufficient for initial assessment, the photogrammetric maps like a DSM should be added in the course of the operation, as it is of higher quality particularly with respect to projection errors.

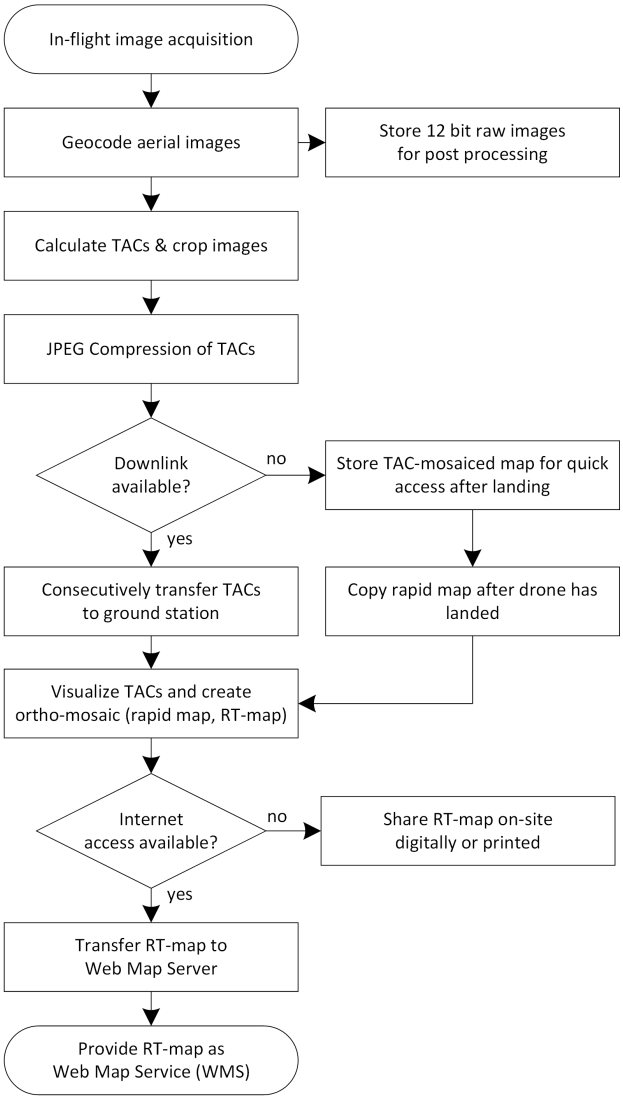

Figure 5. Rapid map generation flowchart

Due to the integration into INSARAG organizational and activation structures, it seems reasonable to establish a rapid mapping capability within this UN unit or its certified SaR teams. The demonstrated technology can be operated in an integrated manner within such a team. This should be accompanied by a regulation on the use of remote sensing drones in crisis areas. This applies in particular to flight authorization and integration into the respective airspace to ensure safe operation.

4. Outlook

Feedback of SaR teams and the community is taken up and considered in further development after the real-world operation. This includes accelerated post-processing in the field as well as AI-based classification in real-time to detect humans and estimate degrees of destruction. First tests on the Turkey dataset are impressively promising. Additional spectral channels such as thermal infrared will be introduced to make heat sources visible. The overarching goal is to enable SaR teams to acquire and upload the areas assigned to them and any adjacent areas themselves, and to integrate rapid mapping as a capability module of an INSARAG-certified SaR team.

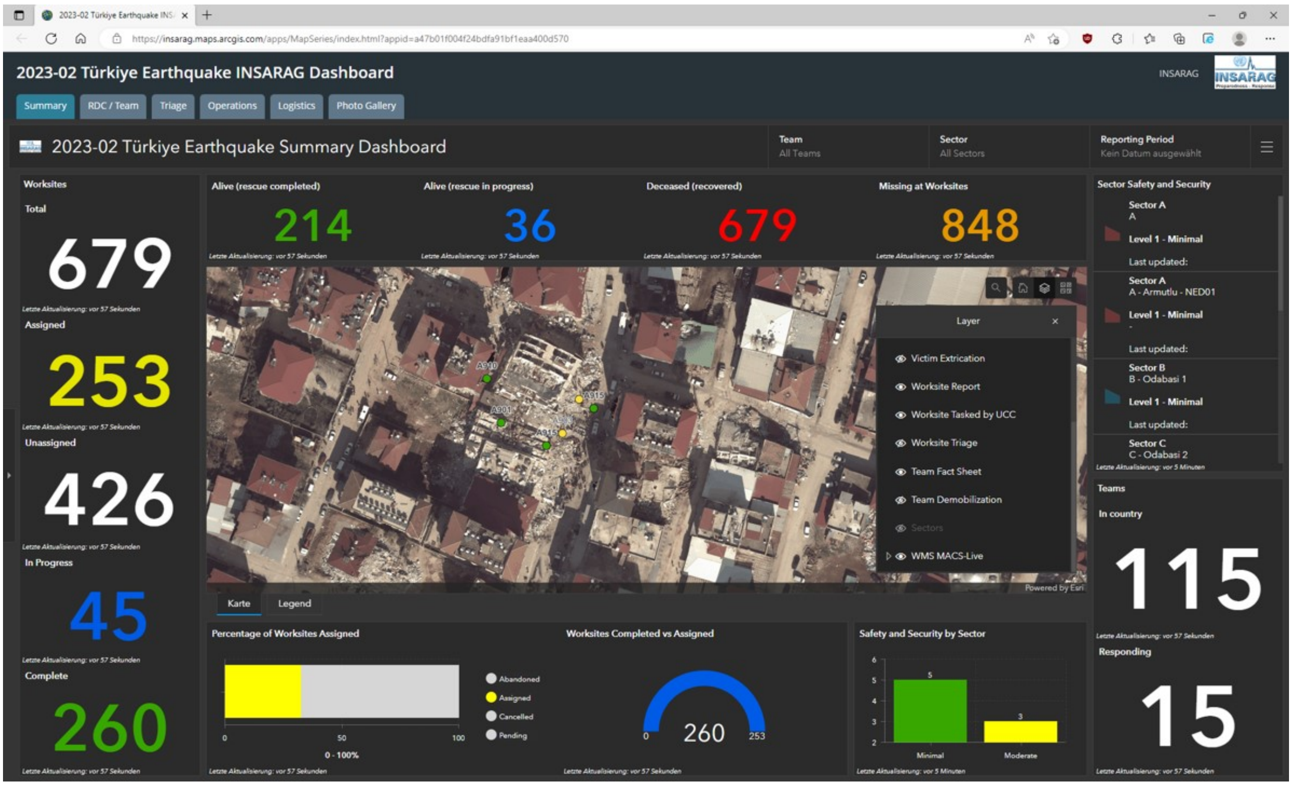

Figure 6. *MACS rapid map* layer in INSARAG Coordination Management System (ICMS)

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