Real-time Distribution of an Airborne Situational Picture into Command and Control Systems

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Abstract: The Modular Aerial Camera System (MACS) has been developed, built and operated for more than a decade at the Institute of Optical Sensor Systems, German Aerospace Center (DLR, Berlin). It is a highly flexible system which is adapted to a wide range of carrier systems like Unmanned Aerial Systems (UAS), helicopters or piloted aircrafts. It is used for a variety of applications like mapping of environmental changes, 3D-reconstruction and urban mapping. One of the main goals of the system is to provide fast and reliable georeferenced information and situational awareness for civil security applications.

In this paper we present the most recent developments of MACS, enabling the integration of georeferenced image mosaics in real-time into command and control (C2) systems, GIS-software and mobile devices for first responders. The use of satellite communication systems allows the worldwide use of MACS even in destroyed environments without telecommunication services. The georeferenced image mosaics are disseminated to end users worldwide via web-map services. The developments are illustrated along several use cases including forest-fire and flooding.

The transfer of selected scientific developments and technologies to operational use and integration into C2 systems is done with commercial partners as part of the Helmholtz Innovation Lab OPTSAL. The workflow has successfully been certified to be integrated into a Web Map Service standard protocol, so the MACS-data can be shared in GIS systems worldwide. For disaster relief situations we demonstrated a workflow for integration and distribution of our live-map to all teams via the United Nations (UN) International Search And Rescue Advisory Group (INSARAG) coordination management system. Further developments include the use of onboard-classification to extract relevant information and reduce the amount of data to be transferred.

1 Introduction

This article presents an operational workflow to produce an airborne situational picture and distribute it to a C2 system in real-time (RT). We give an overview about motivation (section 1), existing workflows and solutions with focus on search-and-rescue (SaR) and civil-security applications and their limitations (section 2). Then we outline our workflow and the technical prerequisites (section 3) and finally we illustrate the process along the example of situational pictures for first responders (section 4) and summarize the findings (section 5).

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1.1 Motivation

In times of climate change and increasing frequencies of weather extremes causing floods and forest fires even in northern and central Europe, the need for fast airborne situational pictures has emerged for coordinating emergency response more effectively. The successful management of major emergencies requires reliable and up-to-date information. A prominent example for such a situation was the flash flooding in the Ahr Valley (Germany) after heavy rainfall in July 2021. DLR was able to provide several large-scale operational pictures of affected regions within shortest time (DLR-OP 2021; WIELAND et al. 2022) to support the relief and rescue measures.
The Institute of Optical Sensor Systems (OS) at the German Aerospace Center (DLR) in Berlin is working to operationalize a novel technology for civil security applications to enable airborne situational pictures in real-time for first responders. DLR-OS is involved in an international SaR activity which is coordinated by the United Nations INSARAG working group. In cooperation with the non-profit aid organization International Search and Rescue Germany (I.S.A.R Germany) (DLR 2016) a first prototype of a MACS camera system was developed and tested to quickly retrieve airborne situational pictures by using fast flying drones (HEIN et al 2019). The further development of the prototype was done within the research projects Live-Lage (DLR 2018; BERGER et al. 2018) and INGENIOUS (INGENIOUS 2023).
Furthermore, DLR-OS operates the Helmholtz Innovation Lab OPTSAL (Optical Technologies for Situational Awareness) (OPTSAL 2023) with the goal to operationalize its camera technology and workflows together with industry partners, public authorities and end-users. In this context a close cooperation with EuroCommand has been established. The main product of EuroCommand is the C2 system CommandX (EUROCOMMAND 2022), which is broadly used by public authorities. Another cooperation was established with the drone supplier Quantum-Systems, which provides Vertical Take-Off and Landing (VTOL) drones (QUANTUM-SYSTEMS 2023) as carrier for MACS camera systems. Operational testing is being carried out in cooperation with the Duisburg Fire Department (FEUERWEHR DUISBURG, 2022).

1.2 Remote sensing situational pictures

Remote sensing based situational pictures are provided on different scales. On large scale satellite data are used. Optical satellites provide geocoded image maps and can be interpreted e.g. to provide flooded areas or forest fires when the view is not restricted by clouds, fog or smoke. Radar can be used in all weather conditions, yet the field of applications is restricted, a typical use case is e.g. flooding. The DLR Center for Satellite based Crisis Information (DLR-ZKI) in Oberpfaffenhofen (Germany) provides satellite based rapid situational image maps in cooperation with the Federal Office for Civil Protection (BBK) as part of the European wide Copernicus Emergency Management Service (CEMS). CEMS is operated 24/7 by a network of designated authorities, the National Focus points (COPERNICUS 2023a). Part of this is the Rapid Mapping service (COPERNICUS 2023b), which offers four standard products, a pre-event reference product and three post-event products: delineation, grading and first estimate. Typically, the products are provided within several hours to several days after the CEMS is activated. An overview over the service and typical activation times is given in (WANIA et al. 2021).

Airborne data has so far been limited in use in the CEMS, one example was the EMSR177 in 2016 covering an earthquake area in Central Italy one day after the event. Still the time from data acquisition to delivery has so far been considerably long. The airborne EMS will be extended by a manned aerial service operated by CGR/Eurosense and an unmanned aerial service operated by FairFleet. A 4-year framework contract has been awarded to these companies (EU 2022). The service will be provided where satellite images are not available or where the satellite's resolution is not sufficient.

Preparing fast-response airborne situational pictures has been a focus of DLR for several years. DLR has produced airborne image mosaics from manned aerial carriers e.g. for the Luebtheen forest fire 2019 (BUCHER et al. 2020) and the Ahr valley flash flooding (WIELAND et al. 2022, CRISIS PREVENTION 2021) within a few hours after data acquisition.

Drone based situational pictures have become widely available in the last years. Many public safety authorities and organizations (German acronym: BOS) operate specialized drone-teams (BOS DROHNENEINHEITEN DEUTSCHLAND, 2022). So far mainly live video streams are used to help the operational command to evaluate the situation. For drone based real-time mapping applications a small number of software solutions exist, e.g. DroneDeploy (DRONEDEPLOY 2022) and DJI Terra (DJI 2023), further details see section 2.

1.3 Real-time situational pictures in C2 systems

C2 systems are used to provide a common situational picture to local authorities in case of an emergency situation and to distribute the information to the first responders. Maps and base layers stored on a server or locally can be displayed and shared with all instances connected to a Geographic Information System (GIS) or C2 system. In dynamically changing situations layers can be updated and added. In many cases this is done interactively by the first responders on mobile devices coordinated by the operational command. To add or update base layers and aerial imagery data sets the technical and geographic specifications and interfaces have to be met. So far, most C2 systems do not have the capabilities to generate aerial imagery base layers themselves within the software in real-time. Therefor pre-processed georeferenced data from third-party sources or software must be loaded, often as geo-tiffs. This adds a time-offset for map generation in third party tools and data transfer, which adds up to at least a couple of minutes after acquisition for small image maps, which are mostly drone based. Usually it takes hours to days for large areas until the data are processed and available.

2 Real-time data processing and distribution into C2 systems

Real-time situational pictures from airborne imagery data rely on a) synchronous acquisition of image, position and attitude data, b) georectification and optimization of every image, c) continuous transmission of optimized image part to the ground, and d) transfer of the resulting image mosaic into a C2 system within a very short time. The georectification and image optimization process can be conducted in a separate software or in the C2 system itself, but it is preferable to do this instantaneously after image acquisition. To enable the real-time capability a transfer of the aerial image data is mandatory. This can be done by using several appropriate radio links (i.e. WiFi, LTE, SatCom, StarLink, etc.). No matter what types of radio links are used the bandwidth is always a limiting factor and has to be considered. These four steps are shortly described in the following sections.

2.1 Acquisition of airborne image, position and attitude data

Georectification of airborne imagery data can be done in different ways. Most efficient and widespread is a parametric georectification based on the exact GNSS time, position (X, Y, Z) and attitude (Omega, Phi and Kappa) recorded while the image is taken. These parameters (exterior orientation) can be measured by using an appropriate GNSS aided Inertial Navigation System (INS). The exact synchronization between GNSS/INS system and the camera system needs to be ensured and all data must be stored in an appropriate manner. To gain good results the offset between GNSS antenna and IMU should be given as well as the offset between camera system and IMU. The internal geometry of the camera system (interior orientation) should be known as well to avoid lens distortions. The frame rate and the exposure time of the camera system can be a limiting factor in relation to the flight speed and altitude above ground. While high quality imaging is widespread for many UAV camera systems, quality of positional and attitude data can be limited or data even be not available for some of the smaller and cheaper systems. Access to all mentioned parameters is often restricted and leads to bad results in the georectification process.

2.2 Direct Georeferencing / Georectification

A small number of software solutions are available for drone based real-time mapping applications. DroneDeploy offers a live mapping feature with a reduced resolution by a factor of 5 (KASSIGKEIT 2021). It is so far of limited use for many public authorities due to data privacy conflicts as the data can only be transferred in the cloud. DJI Terra provides a near real-time feature with some observed latency (KASSIGKEIT 2021), which is allegedly caused by limited bandwidth of the UAS radio link. For none of these software solutions a live map export into C2 systems is provided. PIX4Dreact (Pix4D 2023) is a rapid mapping software which provides maps after landing. A delay of several minutes is present because of transfer of the raw data to a computing unit (i.e. laptop or work station) and the photogrammetric processing of the imagery on the ground. The computing speed of Pix4Dreact can be optimized by using modern graphics processing units (GPU). Pix4Dreact can handle input data of a variety of drones and camera types. The resulting map can be exported as GeoTiff.

A different way to geocode imagery is to use reference data and align the newly acquired data by selecting identical features or ground control points in both data sets. This is a time consuming offline-workflow, the results often are of limited quality, especially when strong local relief hampers the use of parametric models. Image and phase correlation have also been used to co-register image data to a base-map. An example for such a co-registration workflow for airborne and satellite data is COSI-COR (LEPRINCE et al. 2007).

Deep learning and AI have emerged as powerful tools for image co-registration. The software Edgybees (EDGYBEES 2023) rapidly co-registers satellite scenes in real-time to a reference map or fine-tunes and stabilizes coarsely geocoded video-livestreams e.g. from drones with limited orientation accuracy using a reference scene. Vice-versa reference data (vectors) can be reprojected into the video-stream. This has already been applied in use cases with emergency responders (SWEET 2021).

Alternatively, a representation of an aerial image to a spatial grid can be calculated in consideration of a digital elevation model (DEM) and the mentioned interior and exterior orientation parameters. The earth's surface was measured by NASA with the Space Shuttle Radar Topography Mission (SRTM). The resulting DEM (SRTM 30) covers the whole earth and is available as open data set. Latest DEM data sets are available by TanDEM-X mission which is managed by DLR. TanDEM-X 90 is available as open data set.

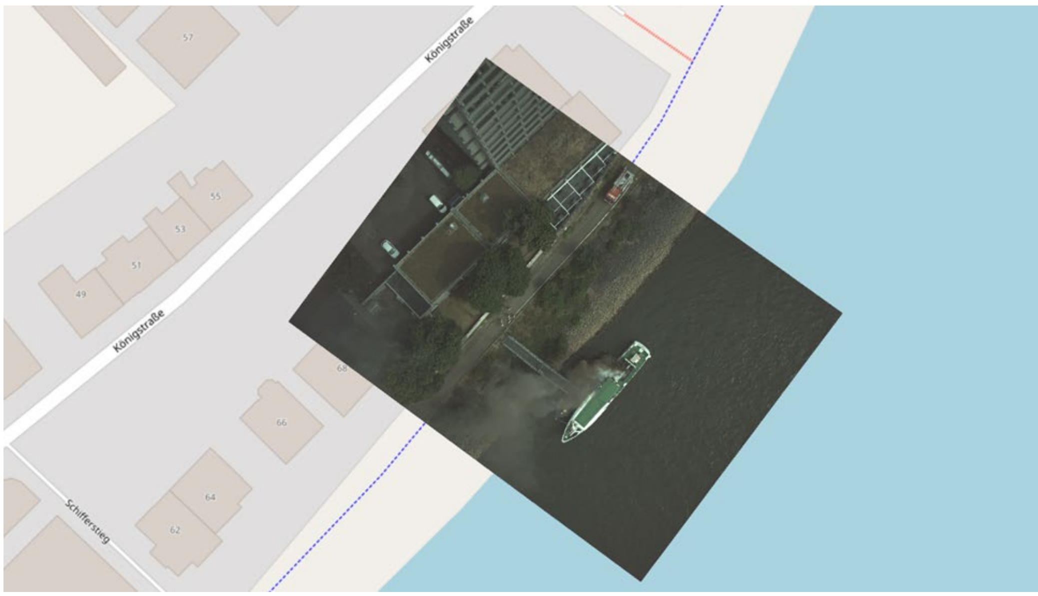

Fig. 1: Georectified aerial image of MACS using the SRTM digital elevation model

2.3 Transmission to the ground

The transfer of image and meta data from a drone to the ground is a restricting factor due to limited bandwidth, range and achievable data transmission rates during flight. Several radio transmission technologies are available like wireless local networks, telecom networks and satellite communication. The choice of the appropriate technology depends on the availability of the service and the technical requirements like size, weight, power, price, frequency range, bandwidth, data transfer rate and achievable range. No matter which technology is used, range and achievable data rate can strongly vary. To counteract these limitations the amount of data to be transferred should be minimized e.g. by reducing image size and image resolution. Furthermore, the data can be compressed. To avoid data loss buffering of data should be implemented as well.

2.4 Transfer of a georectified image data into a C2 system

Modern C2 systems have a GIS feature to manage, analyze and visualize geographic data. Most common is the import of GeoTiff files and/or using a Web Map Service (WMS).

It is recommended that the georeferencing and processing of the aerial image data is done outside of the C2 system to guarantee a fast import and quick visualization. This can be done by using individual or tiled files or by providing a WMS. Pre-processed files can be provided via USB stick, hard disk or FTP server. A WMS needs additional infrastructure and maintenance yet it is recommended for real-time mapping applications despite the need for access to the internet and extra costs for maintenance and infrastructure.

3 Real-time situational picture by DLR

DLR has developed a suite of camera systems, the Modular Airborne Camera System MACS (LEHMANN et al. 2011; DLR 2023a) and software solutions (DLR 2023b) to operate these systems. In the last years the focus has moved to reducing the size of the systems (camera, computing stack, storage media) while maintaining and improving image quality and onboard processing capabilities. Another focus was to improve the real-time capabilities and diversify the options for data communication.

The general MACS camera concept has been described in (BRAUCHLE 2015). It combines a modular selection of calibrated cameras of variable spectral and geometric properties with high end GNSS/INS for accurate position and attitude data. A computing stack handles the onboard camera operation. A description of a marine airborne real-time situational picture acquired from a motorglider is given in BRAUCHLE et al. (2018). A description of an UAS mapping system including hard- and software is presented by HEIN et al. (2017). The processing was improved by using TAC (Terrain Aware Image Clipping) for direct georeferencing (HEIN 2018), which crops the images only retaining a small overlap with the neighboring images, thereby reducing the data to be downlinked up to a factor of 10 when high overlap e.g. 90% is recorded. The remaining clipped images are further compressed using a 12bit JPEG compression algorithm, which leads to a reduction of down to <1% of the original image size. This allows to retain the full geometric and radiometric resolution even with lower transfer rates. The whole workflow including the ground processing is described in detail in HEIN (2019).

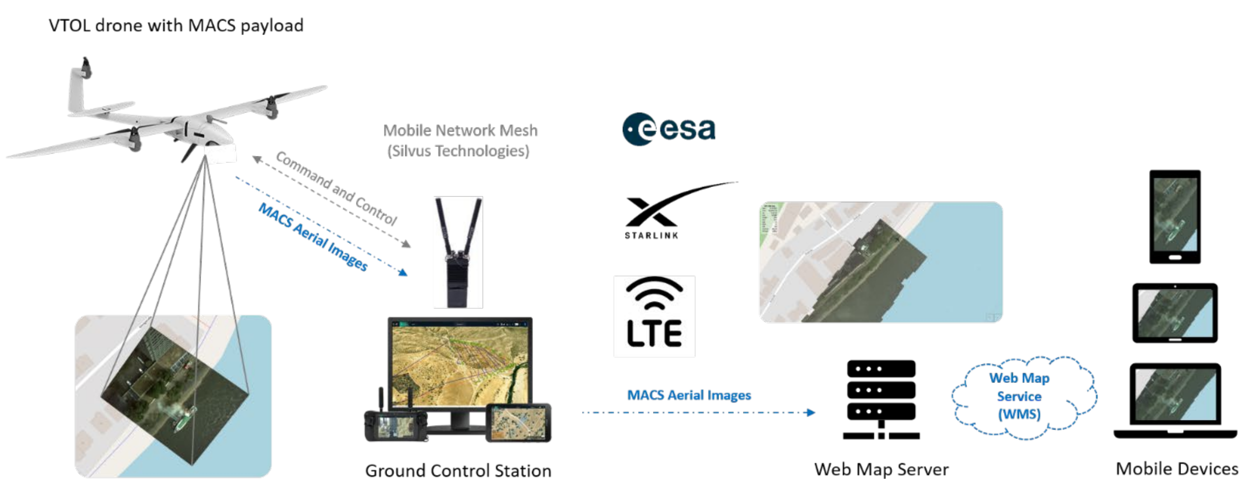

Fig. 2: Overview of the real-time mapping workflow with MACS and VTOL drone (Source: DLR)

The real-time mapping feature is available with the latest MACS development for the VTOL drone Vector by the German manufacturer Quantum Systems (QUANTUM SYSTEMS, 2022). As a result compressed georeferenced aerial image snippets are continuously received on the ground with one or several distributed receivers. Incoming snippets are added to a live image mosaic which is continuously updated using the MACS RT-Viewer software (DLR, 2023b). The operator can navigate through the live map, select zoom stages and regions of interest. The histogram can be interactively stretched and adjusted to the operator's needs. The software is able to export regions of interest as GeoTiff file. This allows sharing of data even if no telecommunication service is available. If a service is available (e.g. LTE, StarLink or IRIS²) the incoming aerial image snippets can be forwarded from the ground station to an appropriate Web Map Server. The resulting WMS can be consumed worldwide via GIS or C2 systems. This allows an easy integration of the live map even on mobile devices. The first prototype was tested and evaluated in 2021 by DLR in cooperation with several partners and institutions. The implementation of an appropriate WMS feature is still ongoing.

Fig. 3: VTOL drone Vector with latest MACS payload (left) and notebook with radio link module (right) to receive and visualize the situational picture (Source: DLR)

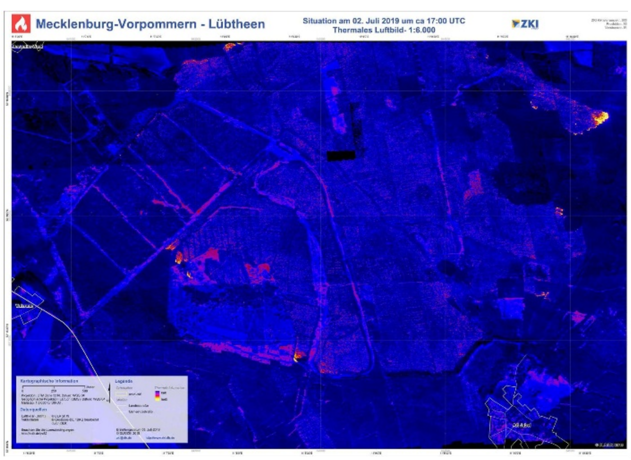

Fig. 4: Luebtheen forest fire situational map.

Fig. 5: Ahr Valley situational map.

4 Case studies

DLR has supported German authorities in several emergencies with situational pictures in the last years. In case of the Luebtheen forest fire (BUCHER 2019) or the Ahr Valley flash flood (2021) the image maps were taken on short notice within several hours with a manned airplane. The data were

not downlinked in real-time. It was transferred after landing via hard disk to DLR, processed and uploaded to the situational command via FTP server. Standardized image maps where processed by DLR ZKI (Fig. 4 and Fig. 5). Meanwhile a communication infrastructure has been established as further data communication link for MACS to distribute the live mapping result in real-time as Web Map Service.
In case of the experiments in the project LiveLage (DLR, 2022a) and the Grunewald forest fire (DLR, 2022b) the situational picture was live streamed via LTE in the C2 systems of the involved fire departments by using a WMS. In cooperation with I.S.A.R Germany the usage of StarLink was successfully tested. The three scenarios are described in the following sections.

4.1 Exercise with Duisburg fire department

The project Live-Lage started in 2018 as cooperation between Duisburg fire department, I.S.A.R Germany and DLR. The aim was to develop a new technology to rapidly generate a large-scale situational picture by using fast flying drones (BERGER et al., 2018). The latest prototype was tested in May 2022 during an exercise. The VTOL drone Vector was activated from the Duisburg fire department building to monitor a fire on a ship in the Duisburg harbor. Image data was captured and processed onboard of the drone with the latest MACS camera system. The georectified image snippets were transferred to the ground continuously using the drone's radio link. The data was synchronously visualized at several places on the ground and as well in the operational control center. The situational picture was constantly received to cover the changing situation. A short video documentation of the exercise can be found at the official website (STADT DUISBURG, 2022).

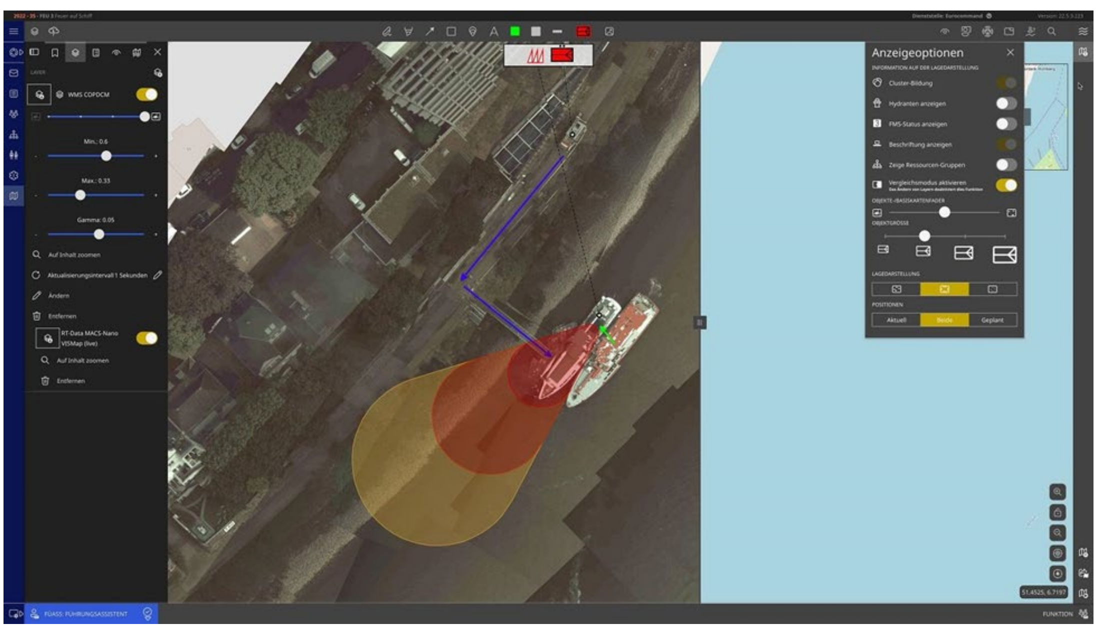

Fig. 6: RT-Situational picture at Duisburg Harbor in CommandX (image credit EuroCommand)

4.2 Forest Fire Berlin-Grunewald

On August 3 2022 a fire on a site for controlled detonations in Berlin-Grunewald started, which lead to uncontrolled detonations of ammunition. A security distance of 1000m was established, access to the fire was strongly reduced. Due to the fact that drones of the Berlin fire department had a relatively small action radius due to the limited reach of their remote controllers, DLR was asked to provide a RT-situational map with its MACS-Nano system and a Vector VTOL drone, well suited for quickly mapping large areas (Fig. 7). The drone was started from the blocked AVUS motorway. A predefined flightpath was programmed and autonomously covered Beyond Visual Line of Sight (BVLoS). The georeferenced and compressed image snippets were transferred to the ground (BROADCAST SOLUTIONS, 2022) and forwarded to a server of the Berlin fire department, from which the data could be accessed in the C2 software in the mobile situational center (Fig. 8) and the mobile devices of the active firefighters.

Fig. 7: MACS-Nano in Vector UAS (Quantum systems)

Fig. 8: Visualization of MACS-data in a C2 system, Berlin fire department

4.3 Exercise with I.S.A.R Germany

In areas with destroyed infrastructure in disaster relief missions mobile satellite communication can be the key for transferring the data to decision makers. In exercises with I.S.A.R Germany we have repeatedly tested live-mapping for first responders. In May 2022 we successfully demonstrated the creation of a RT-situational map captured from a drone during flight and the transfer of the map via WMS to the United Nations INSARAG C2 System and in situation rooms worldwide via the StarLink satellite network of the US space company SpaceX (DLR 2022g).

5 Conclusions and Results

Airborne real-time situational pictures require a consistently performant and resource efficient workflow to handle a large amount of data while retaining radiometric and geometric quality and resolution. Delays caused by data redundancy can be solved by intelligent on-board processing like terrain aware clipping (image cropping) and compression, the risk of bottlenecks caused by bad downlink connections can be reduced by buffering and the selection of the most suitable communication links. Specific software for tone mapping and a real-time compatible viewer enable an on-the-fly adjustment correction and conversion to 8-Bit, which can be directly output to a WMS. This service can be provided using standard internet communication (LTE or StarLink) and it can be accessed synchronously worldwide via GIS, C2 software or simply a browser. This workflow was successfully employed in several real-world situations and exercises enabling access to a real-time situational picture to first responders. Work to further operationalize and distribute these capabilities are ongoing in the Helmholtz Innovation Lab OPTSAL together with industry and BOS end-users.

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