Case study: Near real-time thermal mapping to support firefighting and crisis management

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Abstract: Hot and dry summers have led to an increase in forest fires both concerning numbers and intensity in north-eastern Germany in the last years. In the project FireSense the German Aerospace Center (DLR) has adapted its sensor system MACS (Modular Airborne Camera System) with a set of thermal mid- and long wave infrared (MWIR and LWIR) cameras to detect, monitor and quantify high temperature events (HTE) like forest fires. Ground-based, airborne and spaceborne measurements over fire-experiments are synchronized for cross-validation of the systems and to test the developed workflows.

In summer 2019 gas flaring tests were conducted in cooperation of DLR and the Federal Institute for Material Research and Testing (BAM), parallel several large forest fires in Brandenburg (Lieberose) and Mecklenburg-Vorpommern (Lübtheen) developed. In coordination with the crisis management group (local authorities, firefighters, armed forces, federal police) to get the permits MACS conducted 3 flights over the fires in altitudes between 6000 (sunny) down to 3500 ft (under clouds), Lübtheen was covered twice, on July 2 and July 4, when the fire was already under control. Synchronously firefighting helicopters operated close to ground, also delivering videos of the fires for visual interpretation.

To get both background temperatures for orientation and landscape features and also information about the fires within one data set, a broad calibration range for the LWIR camera was commanded. Using synchronized position- and orientation data of MACS with given calibration data and a Digital Terrain Model, direct geocoding and the processing of near real-time mosaics was possible using the DLR workflow even without post-processing. The accuracy was sufficient for planning purposes. Geo-tiff maps were delivered shortly after landing within less than three hours. The real-time capabilities of the system could not be used as the flights were conducted on very short notice and the radio link was not installed.

The thermal data were delivered as false color heat maps. They show the thermal anomalies very well, clearly discriminating burning area, recently burnt area and unaffected forest. In the RGB data the ground fires are rarely visible as they are covered by and almost did not affect the closely standing crowns. The spread of the fires can be seen in the overlapping regions of adjacent flight lines.

Data exchange and use of the data proved to be difficult due to limited data rates and IT infrastructure in the command and situation center in the field, sometimes taking more time than the acquisition and processing. This reduces the practical benefit for the data in the field. For future planned experiments for real-time mapping of forest fires this will be one of the main points to improve the latency of the data transfer to the control center ideally by using a live data link and to optimize the coordination with the control center. Further activities will be coordinated by the Helmholtz Innovation Lab OPTSAL (Optische Technologien für Situationserfassung im Sicherheitsbereich), which was started at DLR in 2020. In OPTSAL hard- and software solutions are developed and activities concerning situational awareness for safety and security are coordinated with industry and authorities.

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1 Introduction

Forest fire activity is a continuous threat worldwide. This is to some extend attributed to the climate change, cumulating in the extreme forest fire season in Australia in the summer 2019-2020. In Brandenburg (North-Eastern Germany) the summer 2018 has been a record year concerning number of fires and the size of burnt area (LANDESKOMPETENZZENTRUM FORST EBERSWALDE 2019); this tendency has continued in 2019.
In order to detect and observe fire from space, the German Aerospace Center (DLR) developed and launched two small satellites (TET-1, BIROS) in the context of the FireBIRD (Fire Bispectral InfraRed Detector) earth observation mission (REILE et al. 2013). The mission aims to significantly improve detection, mapping and analysis of high temperature events (HTE) compared to currently existing sensor systems. One main application of FireBIRD is the detection and monitoring of forest fires. (BORG et al. 2017). On a local to regional scale the modular airborne camera system MACS (LEHMANN et al. 2011) is used for 2D and 3D-mapping and monitoring purposes on a variety of different carriers in different spectral ranges, focusing on security and research application. Examples are the projects 'EMSEC' for maritime real-time (RT) monitoring (BRAUCHLE et al. 2018), 'ACHILLES', with the first responders ISAR (International Search and Rescue) Germany and 'Live-Lage', with the Duisburg fire department, all using airborne carriers like planes or UAVs for rapid mapping applications (HEIN et al. 2017). In the ZIM project FireSense ground based, airborne and spaceborne sensors are coordinated to synchronously record fires for cross-validation of the different systems and to evaluate and improve the benefit of different sensors for fire detection and monitoring. In the course of this project the observation of gas flaring tests at BAM could be coordinated with overflights of several contemporary forest fires located in north-eastern Germany to test DLR`s rapid mapping technology under emergency conditions for forest fires. This paper gives an overview of these activities as a case study. A detailed overview over wildfire remote sensing is not goal of this paper, a comprehensive review is given by ALLISON et al. (2016).

2 Experiment Description

In June 2019 several experiments were planned and carried out at the BAM to closely evaluate the properties of gas flares using ground based and remote sensing data for the FireSense project. In the same time period several forest fires in north-eastern Germany emerged, including the largest ever recorded fire in Mecklenburg-Vorpommern in Lübtheen. In order to obtain both high temperatures and background land surface temperatures to quantify the gas-flaring tests, a MACS-system with a set of three aligned thermal cameras and a RGB sensor (MACS-Micro) for a true color image were installed into the research airplane of the Free University Berlin. Several flights were conducted with this instrumentation to measure gas flare tests at the BAM and to test the workflow for multi-temporal forest fire monitoring. Details concerning the gas flare experiment, focusing on quantifying radiometry, flame temperatures and their relation to the gas flow can be found in SOSZYNSKA et al. (this volume), the overflights of the forest fires are covered below, focusing on security related aspects.

2.1 Camera System and Carrier

Four cameras were aligned and synchronously operated in an experimental setup to observe both HTEs and background temperatures in high detail (see Fig. 1). The cameras used during aerial survey have following characteristics:

Tab. 1: Overview sensors in the MACS-camera system.

	MWIT_High_T	**LWIR_Low_T**	**LWIR_FullRange_T**	**MACS-Micro Truecolor**
Camera type	Infratec Imager IR 8300	Infratec ImageIR 8800	Infratec VarioCam HD	Industrial High Speed Camera
Sensor type	Actively cooled photon detector InSb	Actively cooled photon detector MCT	Uncooled microbolometer focal plane array	CCD
Wavelength	3.4–4.2 µm	8–12 µm	7.5–14 µm	RGB
Pixel size	15 µm	15 µm	17 µm	7.4 µm
Image size [pix]	640×512	640×512	1024×768	4864×3232
Working range used	200 to 500 and 300 to 800 °C	-20 to 20, 0 to 60° and 20 to 100° C	0 to 500 and 250 to 1200 °C	Not applicable

As a major goal of the forest fire flights was to create a near real-time map of the fires, we restricted the near real-time processing on two systems, the RGB MACS-Micro and the LWIR VarioCam HD, which offers a wide calibration range (0 – 500°C used) and sufficient radiometric resolution to cover both background and high temperatures. The cameras were mounted in an experimental setup in a Cessna 207 (Fig. 2) on a stabilized platform (Fig. 1).

Fig. 1: Operation of 4-head camera system on stabilizing platform

Fig. 2: Cessna 207, FU Berlin, cloudy weather

2.2 Flight Operation

Due to the fire the airspace over the forest fires was blocked. To receive the flight permits the overflight was coordinated with the local operation teams consisting of representatives of the federal police, local authorities, firefighters and armed forces and air traffic control (Deutsche Flugsicherung, DFS). Weather conditions for Lübtheen were cloudy with strong winds, therefore the flight altitude was lowered to fly under the clouds. Due to the low flight altitude the flight plan was adjusted, which resulted in a fairly high spatial resolution but reduced coverage per hour. A lower limit for the flight altitude was given due to the operation of the firefighting helicopters, which were simultaneously operating. This excluded the operation of UAVs, which could have been an alternative for smaller areas. For the Lübtheen flight on 2019/07/02 parts of the fire could not be covered due to clouds below the lower flight limit. There were also helicopters of the federal police operating with thermal- and visual video systems (Fig. 3). These are used for visual inspection of the fires, but don't deploy geocoded image maps for offline planning purposes, which are especially helpful to delineate and track small features.

Tab. 1: Overview of forest fires covered with the MACS-camera system.

Target	Lieberose	Lübtheen_1	Lübtheen_2
Date	2019/06/28	2019/07/02	2019/07/04
Local Time	11:30 – 11:45	16:45 – 17:30	14:00 – 14:45
Altitude	6000 ft	4000 ft	3500 ft
Weather	sunny	cloudy	cloudy
Number Flight-	2 (small area flown as	7 (norther part not com-	9

2.3 Forest Fires

Two forest fires were covered: Lieberose (Brandenburg) and Lübtheen (Mecklenburg-Vorpommern), both on former army training areas with limited access due to unexploded ammunition, restricting ground-based firefighting to cleared areas. Due to the larger extent and the multi-temporal coverage the paper concentrates on the data of Lübtheen. The Lübtheen fire started on 2019/06/30, it has been the largest forest fire recorded in history in Mecklenburg-Vorpommern. Local firefighters, Federal Agency for Technical Relief (THW), federal police and armed forces cooperated to fight the fire, coordinated by the district authority. In the main phase 3000 people were activated. The fire affected about 1300 ha and forced the evacuation of three villages. DLR coordinated its activities directly with armed forces and federal police, data distribution was managed through the district authorities.

Fig.3: Oblique view of the Lübtheen fire seen from a federal police helicopter. Data are recorded as side-by-side videos, georeferenced maps are not provided

Fig.4: First overflight Lübtheen forest fire 2019/07/02

3 Data Processing and distribution

The data was stored on hard disks during the flight. A real-time radio transmission interface is available and can be operated on planes, UAVs or any other carrier; it was not installed as the flight was initially planned as regular post-processing overflight of the BAM test site only. Data processing started after delivery of the hard disks at DLR in Berlin with a delay of about 90 minutes caused by the flight back to Berlin and the data transfer by car.

For a georeferenced rapid mapping product the parameters for the interior (calibration) and exterior orientation are needed. Calibration data for all sensors are automatically selected in the processing chain from a data-base, exterior position and orientation are measured and stored in the MACS image headers. Therefore an initial rapid mapping product can be generated right after receiving the imagery using the workflow described in HEIN & BERGER (2018). Using drag-and-drop the images are projected on a coarse DTM using an adaptive projection. Systematic offsets due to misalignments and rotations can be interactively adjusted; remaining offsets are mainly caused by the missing post-processing of orientation data and the lack of an aero-triangulation, which is also part of the workflow but was not performed to save time (about 2 hours for this data set). As the image acquisition was continued from the BAM test overflight, which was operated in a different acquisition mode, the thermal data needed one conversion step to apply the rapid mapping tool-chain. Overall the process for the generation of image mosaics from the raw data including the production of color coded maps and export to geo-tiff took about 2.5 hours. If all cameras are operated in the rapid mapping mode, faster response times below one hour are possible, with radio data link real-time fire maps can be realized. In the following figures examples for different data products are given:

Fig. 5: Rapid mapping of the first overflight Lübtheen, MACS-Micro RGB, as seen directly after drag-and-drop import into the workflow. Cloudy images in the center (small hole) were removed. High overlap of images of about 80%, black lines outlining the center parts of the images taken for the mosaic. Smoke covers parts of the area

4 Results

The prototypic multi-sensor camera system designed to map hot temperature events was successfully applied for tests over forest fires. The offer by DLR to map the forest fires was quickly approved by the local authorities in charge. Coordination and management of the three flights worked well on very short notice.
Within less than three hours after landing GeoTiff map products could be delivered consisting of RGB mosaics (30 / 25 cm resolution) and false color IR data (1 m / 30 cm resolution) showing the affected areas. The data were delivered via ftp-service and to a cloud-server. The operational use of the data on-site was limited mainly due to time/manpower and local IT restrictions. As the data was acquired and delivered on short notice, the IT infrastructure was not well prepared for such data.
In the maps of the thermal imagery the main hotspots as well as many – certainly not all – small glowing nests and the burnt area can easily be identified. In RGB data the burning and burnt areas are almost indiscernible from undisturbed forest as the fire was restricted to ground vegetation and not immediately affecting the crowns which hide most of the fire activity (see Fig. 6). On the other hand RGB data gives explanations to effects like the localization of firefighting infrastructure or precautionary measures which cannot be resolved in thermal data (see Fig. 7).

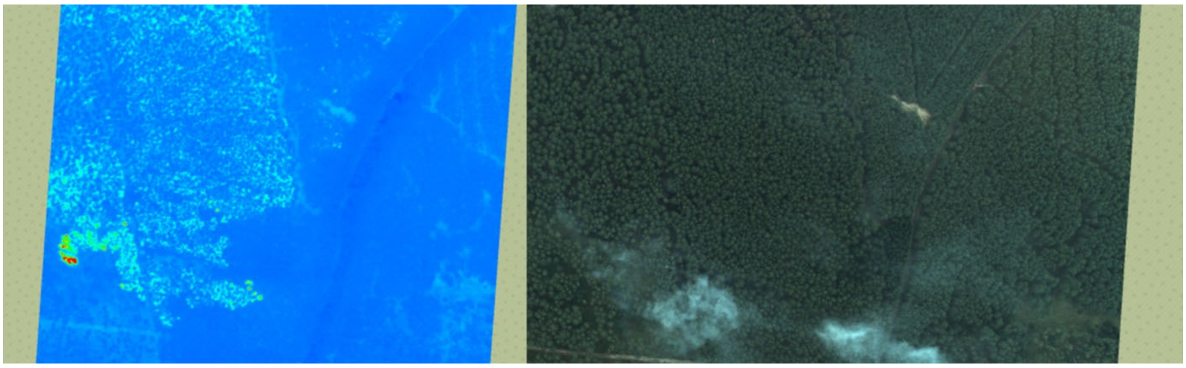

Fig. 6: Individual thermal (false color, left) and RGB images, map-projected: Thermal images nicely show burning and burnt areas, which do not show up in the RGB

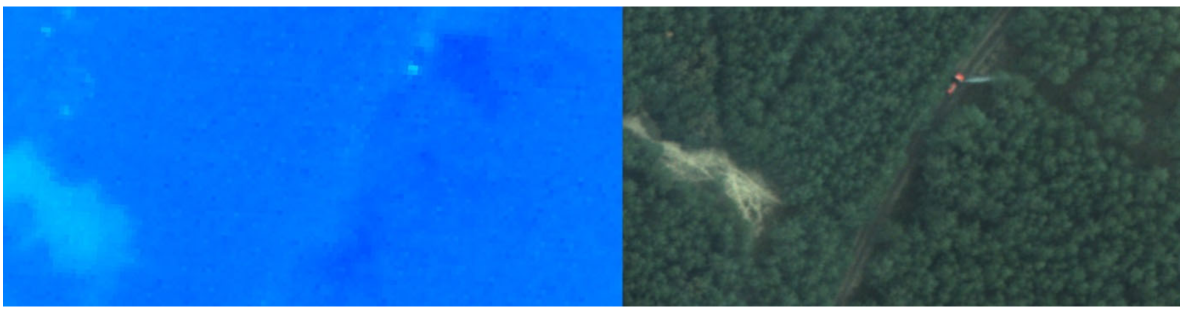

Fig. 7: Zoom into Fig. 6: Colder areas (dark blue) can be nicely explained using in the high resolution RGB image, they are caused by watering the adjacent forest by fire trucks

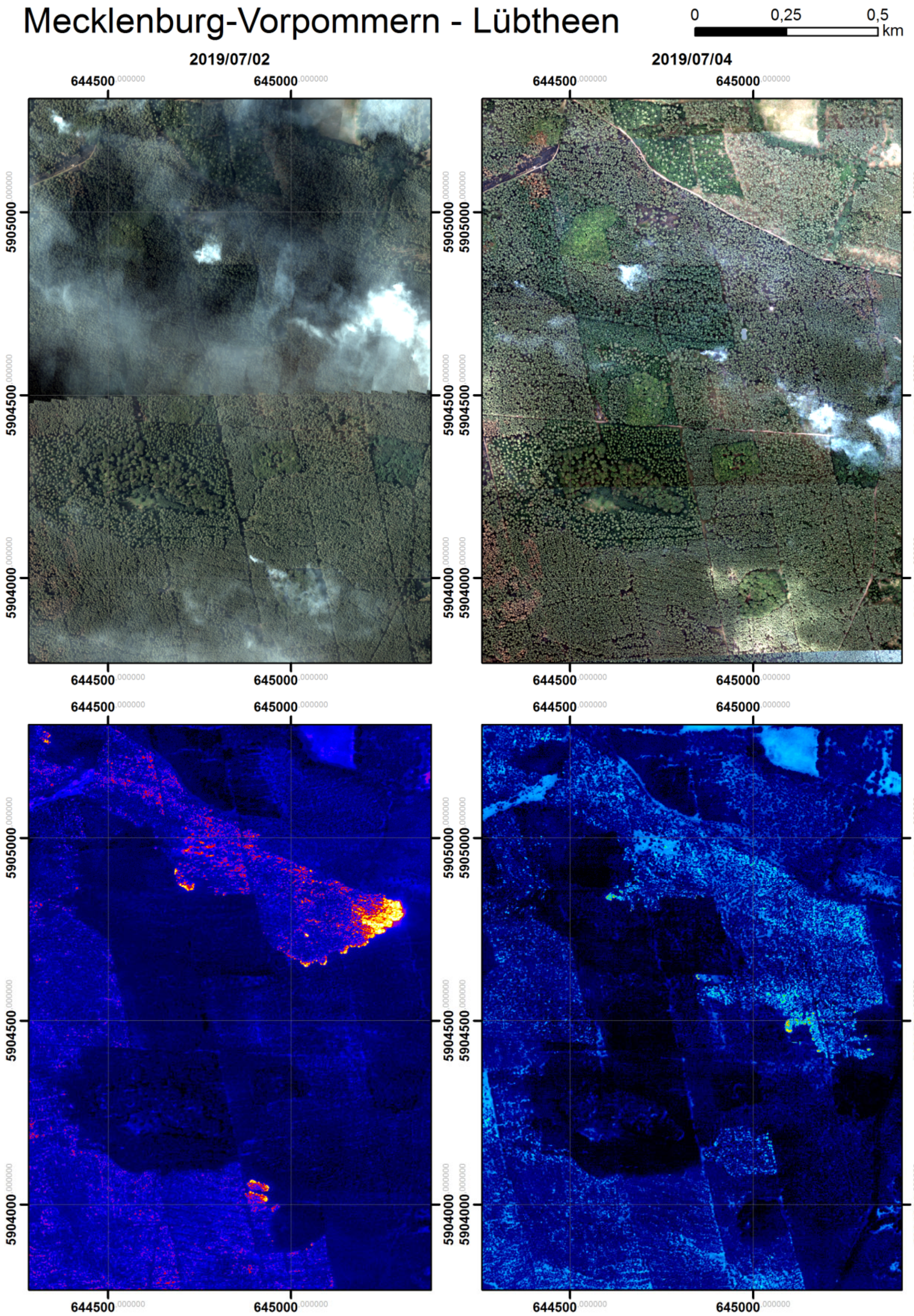

Fig. 8: Single projected thermal (false color, left) and RGB images, zoom: Cool areas (dark blue) caused by spraying the forest nicely show up in the geometrically high resolution RGB image

In the multi-temporal comparison (see Fig. 8) the spread of the fire and the burnt area can be documented. On July 4th the fire was under control, only very small active fires remaining. But exactly the monitoring of these small glow nests over a large area is a task which could be ideally suited for thermal infrared remote sensing systems.
The observed temperatures in the thermal imagery are considerably lower than measurements on the ground. This is caused by many factors, including atmosphere and size-of-source effects. Details on these effects are in the focus of the gas-flaring experiments at BAM (see SOSZYNSKA et al., this volume). For the on-site planning of fire-fighting measures the qualitative false-color maps resulted to be an efficient base for interactive interpretation in geo-information systems.

5 Discussion

The results of the overflights of the forest fires are encouraging. Essential information about size and location of burning areas can be provided within few hours. For the near future a real-time monitoring experiment using radio transmission of images to a ground station situated close to the command and situation center seams feasible, the technology is existing. Such an experiment needs to be well prepared especially concerning the interfaces to the planning software in the control center. Starting 2020 the Helmholtz Innovation Lab OPTSAL (Optische Technologien für Situationserfassung im Sicherheitsbereich) was started, which develops hard- and software and coordinates activities concerning situational awareness especially for safety and security with industry and authorities. There is a strong need for operational systems in this field so that the reaction on the growing number of forest fires worldwide can be improved and accelerated.

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