Airborne multi-sensor management support system for emergency teams in natural disasters

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ABSTRACT

This paper describes the development of a multi-functional airborne management support system within the frame of the Austrian national safety and security research programme. The objective was to assist crisis management tasks of emergency teams and armed forces in disaster management by providing multi spectral, near real-time airborne image data products. As time, flexibility and reliability as well as objective information are crucial aspects in emergency management, the used components are tailored to meet these requirements. This article includes the individual system components as well as their performance using examples from lab tests and real-life deployments. Based on this, the impact of existing command and control processes as well as the benefits for time critical decision making processes are described based on expertise of the involved end users. In addition, it gives an outlook on future perspectives.

Keywords

Multi sensor imaging, airborne sensing, near real-time geo-processing, decision support, natural disaster management

INTRODUCTION

Within crisis management at natural disasters, the key for effective decision support and the potential to support time critical decision processes is the ability to provide a common operational picture consisting of rapid available, up-to-date geo-data and related data analysis results (Almer, 2013). The airborne multi-functional management support system developed under the integrated Austrian safety and security research programme is designed to assist emergency management staff members in the management of natural disasters (floods, forest fires, etc.) and the armed forces in preparations and the deployment on site. The system can be integrated into different airborne platforms and can thus also be used for other applications of airborne surveillance like international environmental monitoring assignments. Solutions and concepts for airborne mapping and precise data processing already exist (e.g. Petrie, 2011) but they lack the possibility to deliver data products in near real time. To meet the needs for rapidly available ortho-rectified airborne data in the deployment area new methods and developments were required to ensure fast and cost-efficient usage (Almer et al. 2007; Schnabel, 2013). The research project used results and experiences from previous projects and focused on the development of a more flexible integrated concept taking into account both, technological aspects and extended requirements of the public stakeholders and industrial partners. The research project was carried out in close cooperation with the Austrian Defence Ministry and the civil protection departments from the regional governments of Styria and Lower Austria. This allowed the focused detailed definition of real world problems and needs into the frame of the requirement definition phase. One important objective within the project was to develop a modular and easily transportable multi-sensor platform for efficient integration into various aircraft types like the Pilatus Porter PC-6 Austrian Army (AA), the DA 42 MPP (Diamond Aircraft Industries) and various Cessna models. A further key objective was to realise a fast scenario oriented processing workflow and an end user focused management solution. Therefore, the resulting system called ARGUS (Airborne Real-Time Ground Units Support) provides high-performance data processing and the definition of different processing chains tailored to user requirements. Thereby, near real-time data processing enables an efficient support of time-critical decision-making processes in disaster management. The management solution allows a coordinated data acquisition, control over the performed geo-data processing modules, data archiving and distribution to other existing systems.

The system requirements can be summarised as follows:

- Development of a flexible integrated solution, from airborne data acquisition, on board as well as on ground data processing through to data management and data distribution.
- Using a multi-sensor approach for flexible integration of optical and thermal sensors combined with accurate GPS (Global Positioning System) and IMU (inertial measurement unit) solutions for a wider field of applications.
- Deployment on different platforms to achieve a flexible usage and low mission costs.
- Geo-referencing accuracy in accordance with user requirements (<= 1 meters positional accuracy).
- Near real-time data processing and analysis (generation of radio-metrically calibrated ortho-photos, ortho-photo mosaics and value added products on a ground segment).
- A user friendly and scenario oriented data management and decision support module including interfaces to existing geo-oriented digital command and control systems.

SYSTEM COMPONENTS AND WORKFLOW ANALYSIS

To respond to the needs of rapid data acquisition and provision of accurate geo-products, the following key system components were developed:

- *Airborne segment:* Sensor set (RGB, near IR, thermal IR and GPS/IMU) for the acquisition of image data and an application for operator control and pilot guidance.
- *Data transfer solution:* Line-of-sight (LOS) connection for near real-time data transfer to the ground station over a distance of up to 50 km.
- *Ground modules:* Base station for reception and near real-time processing of image data, plus a visualisation and management solution.

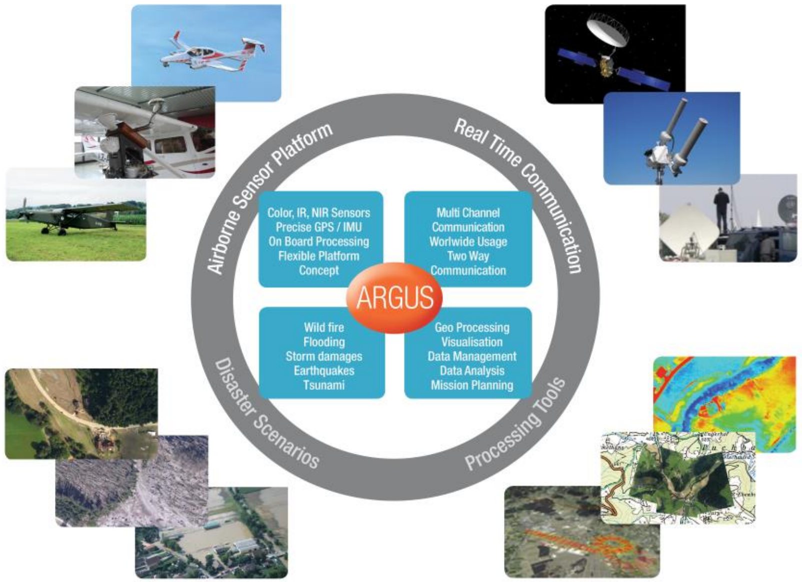

Figure 1. System concept

Airborne Segment:

The airborne segment including the multi sensor solution is able to acquire RGB colour image data as well as images in the near (NIR) and thermal (IR) infrared range. Thermal infrared is required in particular for locating temperature maxima, which is of essential importance for the monitoring of forest fires and floods. Furthermore, IR allows measuring temperature differences and so detecting drenching ground which is relevant in the field of flooding to prematurely detect potential crevasses. The near infrared image sensor on the other hand is used for environmental monitoring missions like the analysis in agriculture domains and forestry. All components were integrated into a single case (see Figure 2) to be able to install it on the prepared plane within 20 minutes and therefore it can already be used in the air after a very short period of time. Apart from this solution, different camera systems (e.g. Hinz et al. 2000; Leberl et al. 2003; Kremer J., 2010 or Leica ADS80) for precise airborne mapping exist but these do not aim on and also do not allow near real time availability of the images due to the amount of data and therefore are not appropriate in the field of fast support in crisis situations. Next to this, for most customers the cost factor as well as the need of flexibility of the sensor platform related to carrier platforms are important issues (Almer et al. 2011).

Figure 2. Components of the airborne segment at a Pilatus Porter PC6 AA

The sub chapters describe the components included in the airborne segment as well as their purpose.

Cameras

- The used RGB camera was a Prosilica GE 4900C RGB with a resolution of 4872x3248 pixels (16MPx) and could flexibly be switched to the higher resolution version with 29MPx (Prosilica GT6600C). The 50mm lens provides a ground resolution of 15cm at a standard flying height of 1000m above ground level (AGL) and a swath width of 720m.
- A Prosilica GC2450 with 2448x2050 pixels (5MPx) was used for the near infrared (NIR) range. It provides the same coverage (720m@1000m AGL) at a resolution of 30 cm per pixel.
- As described, thermal sensors (IR) are an important data source for special applications such as forest fires, dam monitoring, etc. Therefore, an InfraTec VarioCAM hr head 600 with a resolution of 640x480 pixels (0.3MPx) was also integrated into the platform. A panning mirror is used to ensure that it covers the same area as the optical camera, resulting in a ground resolution of 50cm per pixel. Thereby, 8 IR images are taken within the cycle time of one RGB image.

GPS/IMU

To allow a near real-time ortho-rectification, an indirect geo-referencing approach is employed by using high-precision IMU and GPS values. The inertial system is fixed to the reference system of the sensor platform to measure rotations about all 3 Cartesian axes. The control PC records the GPS position and attitude as well as the orientation data from the sensor platform simultaneously with the image acquisition. As IMUs exhibit drift errors that tend to increase with time, the IMU positioning data are supported by GPS to enhance overall accuracy to positional errors in the sub-decimetre range. Also special flight manoeuvres can be used to recalibrate the IMU from time to time to keep up the needed accuracy. Within this project, a Novatel GPS (L1/L2) receiver and an iMAR IMU-FSAS IMU was used for near real-time applications.

On-board control and processing modules

The on-board computing devices are used to fulfil the following tasks:

- Direct control of the different sensors (cameras, GPS, IMU), image capture and subsequent synchronisation between image and metadata and data storage.
- Data compression depending on the available data link bandwidth and subsequent data transfer.
- Optional on-board data processing capabilities to generate ortho-images, previews or value added products for flexibility and mission depending usage.

The components are fanless embedded box PCs style (ARK 3440 i7 from Advantech) including a fast and reliable SSD store to meet the requirements for using standard hardware within planes.

Transfer segment

Depending on the mission, a broadband data link is needed to connect the airborne segment to the ground segment and to transmit the taken images in real-time. Therefore, a bi-directional line-of-sight IP link with a bandwidth of 8Mbps and a range up to 50km was established. The goal was achieved by using an auto tracking antenna, following the plane and so enabling the maximum distance. Supporting different frequency bands allows using this solution also in an international context.

Figure 3. Tracking antenna

Ground segment and data processing

Ground-based data processing is carried out using different software modules, which were developed and consequently improved by the authors and their colleagues over the past two decades and also used as modules in commercial geo-spatial software products. One software package was designed for the processing of a wide range of remote sensing image data and covers the fundamental requirements of photogrammetric processing lines. Its modular concept enables problem- and client-specific generation and implementation of dedicated processing chains which makes it perfectly usable for the tasks within this system. An efficient processing control system enables image processing on a single system or on distributed systems including a geo-oriented priority system and data warehouse solution. This is of special significance for near real-time image ortho-rectification, which is performed in less than 5 seconds where several images can be processed simultaneously. The processing chains developed support different modes and accuracies, including near real-time ‘indirect geo-referencing’, ‘enhanced mapping’ and ‘precision mapping’. The system also features methods for automated mosaicking from several ortho-photos to provide a comprehensive overview of extensive areas (rivers etc.), thus substantially facilitating subsequent data processing steps. Also workflows for hot spot detection and thematic mask generations allow providing valuable benefits and an enhanced support of decision making processes in the field of crisis management. This is also valid for analysis for damage assessment actions, e.g. in the case of floods or forest fires (e.g. Raggam et al. 2006).

Geocoding accuracy

In natural disaster scenarios where situations and associated spatial changes evolve rapidly, the time factor is more important than absolute geometric accuracy. An absolute positional accuracy better than three meters is absolutely acceptable for real-time ortho-rectification for the involved relief forces and commanders. With an eye on the speed factor, indirect geo-referencing appeared to be a good approach but results mainly depend on the accuracy of the position and orientation sensors. (Gutjahr et al., 2010). Indirect geo-referencing involves combining the measured GPS and IMU data with the image data without subsequent post-processing. In principal, there are different approaches and quality levels of geo-referencing possible. This includes the mentioned indirect geo-referencing, enhanced mapping and precision mapping. Enhanced mapping includes automatically found tie points as well as an optional post processing of GPS/IMU data. This increases the geo-referencing accuracy at the expense of processing time. Precision mapping uses ground control points to enhance the absolute positional accuracy of the resulting data product. Table 1 shows the accuracies achieved by the system for the different processing modes based on the used sensors. The accuracy changes linearly with the flying height above ground level (AGL).

Geo-referencing level	**Flying height AGL**	**Positional accuracy**
Indirect geo-referencing	1000m	~ 1m
Enhanced mapping	1000m	~ 0.5m
Precision mapping	1000m	~ 0.15m

Table 1. Geo-position accuracy of differet processing aproaches

Visualisation and management module

After the automatic ortho-rectification of the gathered images, the results are available for visualisation and further on-demand processing (e.g. mosaicking, generation of hot spot maps, etc.). The management interface developed for this purpose offers the following features:

- Data acquisition planning and real-time mission control.
- Situation monitoring based on images of the areas affected.
- Temporal/spatial search functions.
- Visualisation of image data from the different sensors.
- Visualisation of different unit positions (plane as well as field staff).
- Selection of image products for further value adding processing
- Creation of mosaics from collected ortho-images.
- Hot-spot analysis based on thermal data.
- Data distribution to external systems (e.g. Intelli (Ruatti) R.4C).
- Comparison of historical and current images for assessing changes.
- Text based communication with the operator on board.

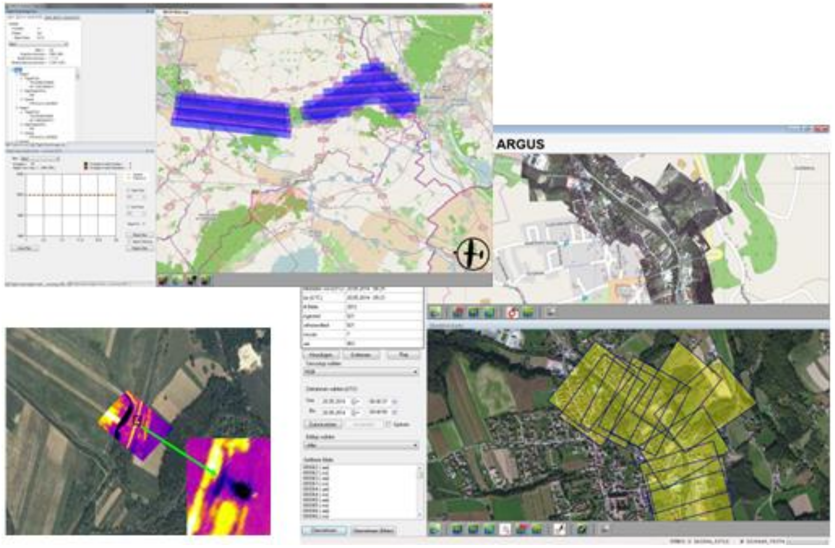

Figure 4. Visualisation and data management module

External interfaces

The generated information products are available in standardized data formats to allow an easy exchange with other, existing geo-information systems (e.g. local/regional GIS systems, geo-information systems for disaster management, etc.) ARGUS provides the possibility to distribute results offline via standard file transfer as well as online via ftp or OGC standard compliant interfaces. This means that planning staff experts always have access to current relevant data on site and are able to use their existing command and control system. In addition results can be displayed using a web based geo-view including basic data from Open Street Maps (OSM) or Goggle Maps / Bing Maps and are available on different platforms – web, desktop, mobile devices.

REAL-LIFE DEPLOYMENT

Apart from development and demonstration purposes, the system was deployed during the Danube (Austria) flooding in June 2013. The sensor platform was integrated into a Pilatus Porter PC-6 of the Defence Ministry, which serves as supporter on demand of the local governments and action forces in case of natural disaster situations. The ground station was located at the joint operation centre of the Province of Lower Austria in Tulln and provided results for the support of decision making processes of the command staff. Furthermore, ARGUS was deployed at a civil protection exercise in Styria in 2014 to include the aspects of a multi-sensor airborne support system into the training. Figure 5 and Figure 6 show (optical and NIR) images of Zwentendorf as well as a comparison of the optical and thermal sensor at forest fire scenarios.

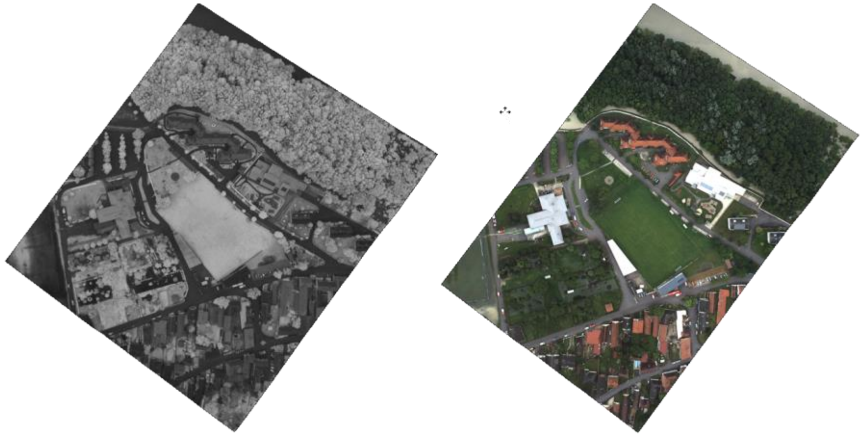

Figure 5. NIR (left) and optical (right) images (4 June 2013) of Zwentendorf

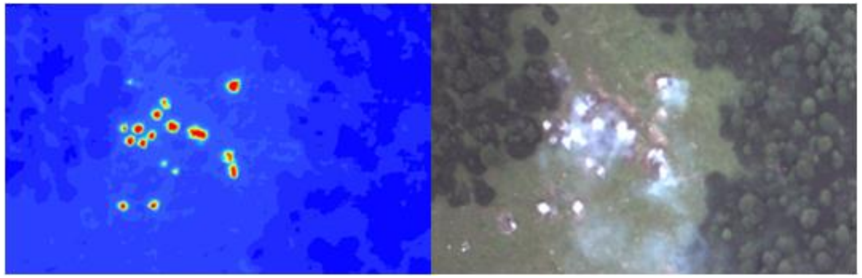

Figure 6. NIR (left) and optical (right) images of a forest fire situation

A typical mission scenario for ARGUS consists of the three main steps.

1.) Assignment from the command staff of the public authorities in charge (including the definition of target areas and expected results).
2.) Data acquisition planning and airborne execution, processing tasks, selection of results and distribution.
3.) Provision of the results to support decision making processes of the contracting entity.

CONCLUSIONS AND OUTLOOK

The experience gained from the deployment of the system during the Danube flooding in 2013 has shown that the airborne imaging system meets the major requirements of rapid support for decision making processes for disaster control staff. The information content of the image data supplied by the sensors is sufficient for most disaster management scenarios. The modular concept and flexible design enable easy adjustment to different quality requirements which could be higher image quality, adapted sensory or different processing chains. The camera systems can be fitted with different lenses and can thus be adapted to specific scenarios and applications. The system can also be readily adapted to different platforms, which is an essential aspect for international missions.
The tests and demonstrations carried out in the project focused primarily on forest fire and flood scenarios. The tests clearly demonstrated that the imaging system developed can quickly provide high-quality imagery for efficient disaster management. In a next step, the system is to be integrated into a permanent operational disaster management service on a national level in a close cooperation between the Ministry of Defence, the Ministry of Interior and the regional governments. In future, it is intended to extend the management capabilities with the aim to give an enhanced support in firefighting actions within forest fire scenarios. This includes the coordination of multiple planes, different hierarchies as well as an extended interaction with task force members in the field.

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