Concept and integration of an on-line quasi-operational airborne hyperspectral remote sensing system

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ABSTRACT

Modern mission characteristics require the use of advanced imaging sensors in reconnaissance. In particular, high spatial and high spectral resolution imaging provides promising data for many tasks such as classification and detecting objects of military relevance, such as camouflaged units or improvised explosive devices (IEDs). Especially in asymmetric warfare with highly mobile forces, intelligence, surveillance and reconnaissance (ISR) needs to be available close to real-time. This demands the use of unmanned aerial vehicles (UAVs) in combination with downlink capability.

The system described in this contribution is integrated in a wing pod for ease of installation and calibration. It is designed for the real-time acquisition and analysis of hyperspectral data. The main component is a Specim AISA Eagle II hyperspectral sensor, covering the visible and near-infrared (VNIR) spectral range with a spectral resolution up to 1.2 nm and 1024 pixel across track, leading to a ground sampling distance below 1 m at typical altitudes. The push broom characteristic of the hyperspectral sensor demands an inertial navigation system (INS) for rectification and georeferencing of the image data. Additional sensors are a high resolution RGB (HR-RGB) frame camera and a thermal imaging camera. For on-line application, the data is preselected, compressed and transmitted to the ground control station (GCS) by an existing system in a second wing pod. The final result after data processing in the GCS is a hyperspectral orthorectified GeoTIFF, which is filed in the ERDAS APOLLO geographical information system. APOLLO allows remote access to the data and offers web-based analysis tools.

The system is quasi-operational and was successfully tested in May 2013 in Bremerhaven, Germany.

Keywords: remote sensing, aerial reconnaissance, real time hyperspectral, MALE, online georeferencing, multi sensor wing pod

1. INTRODUCTION

The field of ISR has increasingly demanding requirements of aerial reconnaissance. Examples are mission planing, perimeter security, vehicle re-identification and littoral surveillance. State-of-the art solutions use hyperspectral (HS), RGB, infrared (IR) or light detection and ranging (LiDAR) sensors to handle these tasks[1].[2] Many of these challenging problems demand the combined use of different sensors. To fully utilize these, the development of data fusion algorithms is essential. In particular for route clearance or the detection of camouflaged objects, hyperspectral sensors are a promising support of conventional sensors. A wide range of systems benefit from earlier access to the gathered information. Existing approaches use airborne real-time georeferencing,[3] but are limited to analysis inside the plane. Our approach incorporates data transmission to a GCS in order to allow a wider range of real-time or near real-time analysis tools.

In order to evaluate and demonstrate the benefit of hyperspectral sensors in combination with state-of-the-art sensors, the Fraunhofer IOSB developed a multisensor platform in cooperation with the German companies OHB System AG and Geosystems GmbH.

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Demands placed on the system:

• Quasi-operational in military trials	• Real-time capability
• Data cataloging for easy access and sharing	• Intuitive data analysis software

To meet these requirements, the "Condor-I" motor glider was chosen as flight platform. OHB System AG already operates such a system and developed a high data rate radio communication system and a fully functional ground control station.[4] Geosystems provides the ERDAS-Apollo geodata server[5] which allows storing, cataloging and displaying of huge amounts of geodata. This basis allows not only to record but also to transfer, process, store and analyze aerial intelligence data close to real time. With this system we are able to apply algorithms developed at Fraunhofer IOSB for the analysis of hyperspectral data as well as for fusion of multisensory data. Another important research topic with potential for future development is on-board data processing and compression.

Chapter 2 presents the system design, starting with an overview about the overall system, the multisensor platform with the different sensors and a short overview of the GCS. In chapter 3 the data flow of recording, transmitting through the downlink and preprocessing into the geodata server is described. Finally in chapter 4 we present some first results collected during system demonstration in Bremerhaven in May 2013 and further uses of the acquired data.

2. SYSTEM DESIGN

This chapter gives an overview of system requirements, the choice of hardware is motivated and the two main components, the multisensor platform and the ground control station, are described.

2.1 Overview

Reconnaissance encompasses many different tasks.[6] The use of UAV[7] for these can be very beneficial. The idea behind this project was to create one complete system containing all single components needed for aerial reconnaissance, see Figure 1. In this section we will present the system demands and our solutions.

Demands

Operational	**Analytical**	**Cooperational**
• Worldwide deployable	• Real-time georeferencing	• Remote access (web service)
• Mobile	• Image mosaic mapping	• Data cataloging
• **Compact System**	• Intuitive evaluation	• Interoperability
• High spectral and spatial resolution	• On-line analysis in GCS	
• Quasi operational		
• Quick availability to operations (especially HS)		

Solution

The improved Stemme S10 motor glider "Condor-I" is an ideal choice for the flight system, as it is flexible, has a good range up to 1000 km, is cheap in maintenance and can carry two external load carriers (wing pods) with a payload of up to 60 kg each. Using external load carriers provides a lot of benefits in comparison to the integration into an aircraft. The mechanical integration is simpler and, more importantly, one flight platform can carry different setups and therefore the system can be easily adapted to different mission tasks (e. g. HS/IR-Turret). Combining all sensors into a wing pod also reduces the difficulties regarding calibration. Especially the boresight calibration, necessary for correct georeferencing, is much more stable compared to integreating each sensor seperately into the aircraft.

In the setup described in this paper, one wing pod carries the data link system aerial reconnaissance data system (ARDS), which is capable of handling the necessary data bandwidth with its downlink data rate of 83 Mbit/s over a distance of up to 250 km. The other wing pod carries three main acquisition sensors (HS, HR-RGB, IR-Video), an INS and a high performance data aquisition unit (DAQ) to record and preprocess all incoming sensor data. It reduces the data stream from 480 Mbit/s to 60 Mbit/s to meet the limits of the downlink

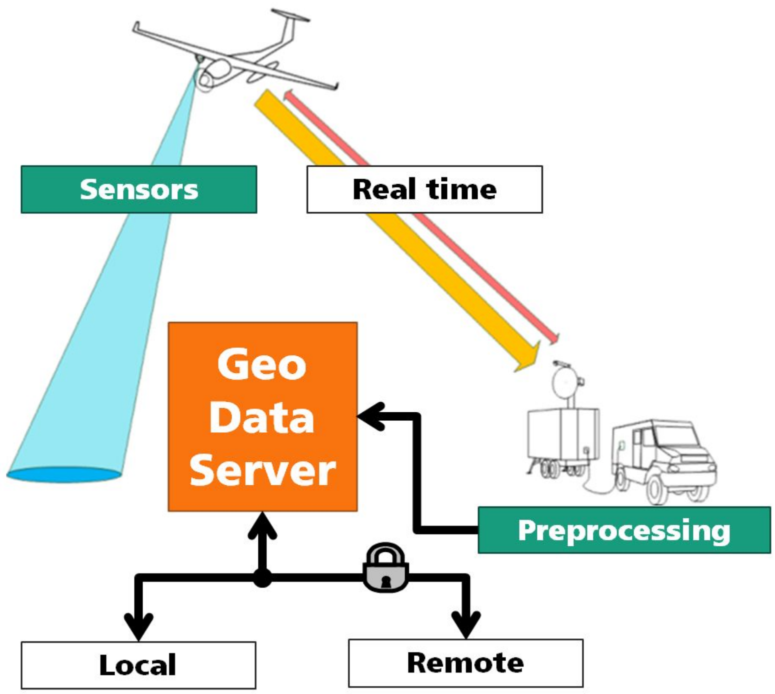

Figure 1. System overview of the three main components. The wing pod as the multisensor platform, the ground station which provides the preprocessed data and the geodata server. The captured data is accessible by local and remote clients in near real time.

rate. At the same time, an unaltered copy of the data is saved for offline processing after the flight. The data is then transferred to the ARDS wing pod and transmitted to the GCS. Here, the HS- and HR-RGB images are preprocessed, georeferenced and stored in the ERDAS-Apollo geodata server. Through the provided web-ATR methods, not only a data analyst inside the GCS, but other interested parties have global access to the acquired data. This provides the possibility to have the highly trained data analyst at a safe location instead of out in the field, potentially with simultaneous access to multiple sources.

Conclusion

Integration of all sensors into a single wing pod enables a quick operational readiness, since tedious and complex equipping of an aircraft with all sensors is replaced by just mounting the pod under the wing. Additionally, integration ensures **simpler calibration**. By transmitting the data to the GCS and cataloging it into a geodata server, the system enables **near real-time remote access**. Furthermore, **multiple analysts share simultaneous access** to the data instead of a single operator in the aircraft. Use of existing components allows a quick integration into existing applications and processes, the system is therefore **quasi-operational**.

2.2 Multisensor platform

As stated previously, equipping a plane using wing pods offers several advantages. On the downside, all components have to fit into the limited available space. As a direct result, selection and physical configuration of the components is essential. The presented system contains four sensors and a recording computer, each component will be described in the following. Arrangement of all other components has to defer to the HS, visible (VIS) and IR sensors, since they have to be placed on the bottom of the pod to enable data acquisition. Fig. 2 depicts the chosen configuration. In order to achieve the desired placement, the pod has custom designed mounts for its components. Special care was necessary to ensure correct wiring of the components connected by fiber optic cables. A fiber optic downwelling irradiance sensor (FODIS) is used to capture the sun-spectrum, for which a fiber optic cable leads from the HS-sensor to the rear of the wing pod.

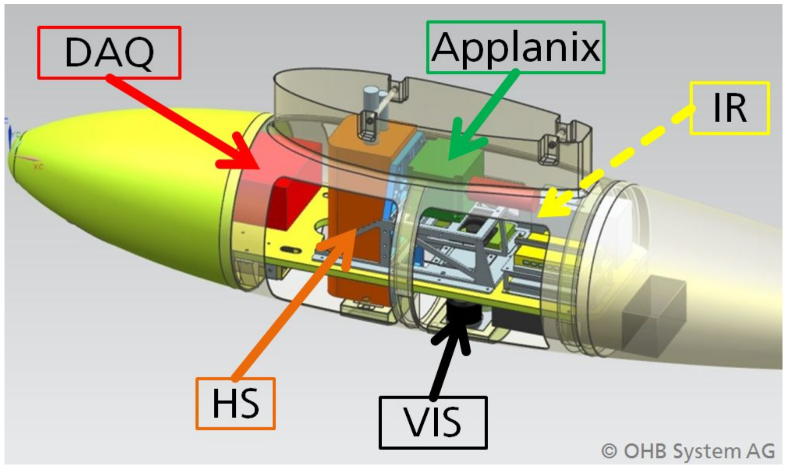

Figure 2. Schematic layout of the multisensor wing pod. The HS, VIS, and IR (on rear side) sensors are on the bottom, in order to enable a nadir view. The Applanix and DAQ are on top. Not shown is the FODIS element.

HS (Eagle) The AisaEagle from Specim[8] was chosen as a hyperspectral sensor because it has a high spectral (488 channels) and spatial (1024 pixel across track) resolution. It can capture light in the VNIR range (400 - 970 nm). It has a 38° field of view (FOV). Furthermore the Fraunhofer IOSB has experience with this sensor and it is field tested in our group.

VIS (SVCam) The visible spectrum is captured with the SVCam from SVS-Vistek. It has a resolution of 4,872 by 3,248 pixel. It can capture up to 4 frames per second. We use a 1.4/50 lens because it gives the camera approximately the same FOV as the hyperspectral sensor. Additionally, the sensor has already proven itself in some of our previous setups. Furthermore, its compact form factor allows easier integration.

IR (IR-TCM 640) The used infrared sensor is a bolometer from Jenoptik which operates in the long-wavelength infrared (LWIR) region of the electromagnetic spectrum. It has a resolution of 640 by 480 pixel. It can capture up to 5 frames per second. This choice is partially based on its ability to capture video, which will be used in future work.

IMU (Applanix) The POS/AV 510 with the IMU-46 from Applanix has a clock frequency of up to 250 Hz. It measures the speed with an accuracy of approximately 0.005 m/s and the roll, pitch and heading with circa 0.005°. The drift is less than 0.5° per hour. As with the hyperspectral sensor, this choice is also based on previous good experience with the sensor.

DAQ (custom made) In order to acquire and process data from all sensors simultaneously, a custom DAQ was constructed*. It is small, light and energy efficient enough to fit into the pod, yet has the capabilities to record data from all sensors in the pod. With this setup, custom software can be used to record data from the sensors and perform preprocessing on-board. All acquired data is stored internally, so that everything can be processed after the flight - independently of communication status during flight and also data that was intentionally not sent to the GCS. The three possible processing levels are:

- Online on-board (limited by processing and storage capabilities of DAQ)
- Online via downlink (processing, storage and analysis capabilites of GCS)
- Offline (precise post processing, not limited to data sent via downlink)

The different levels do not exclude each other. Data can be transmitted to the GCS as much as the downlink permits, while all data is recorded for further post processing in any case.

*i7 CPU, mini-ITX board, 3.5GiB RAM and a 32 bit OS (some sensor interfaces are not yet 64 bit compatible)

2.3 Ground Control Station

The GCS is already operational and used by OHB.[9] It is based on a regular van in order to achieve mobility, as shown in figure 4. Parts of the equipment inside the van allow monitoring the flight status and other vital information from the ground via aircraft telemetry. This information is presented to the operators as shown in figure 4(b). Data is received using a trailer mounted anntena with a reach of up to 200 km. The trailer (figure 3) can be attached to the GCS van for transportation. Using the computers in the GCS, operators can actively screen VIS data in near real time and analyze it on site. One application is to identify targets in need of further inspection by the aircraft.

Figure 3. The antenna of the GCS is mounted on a trailer and can be transported by the GCS vehicle without requiring a second vehicle.

(a) Outside (b) Inside

Figure 4. The GCS provided by OHB System AG is fitted into a standard sized van. It is very mobile and can be moved without special permit. It is equipped with four work stations and a rack for the geodata server (not pictured).

3. DATA FLOW AND PROCESSING

This chapter presents the software components of the system. Section 3.1 explains how the data of the different sensors is acquired and transmitted to the GCS. Section 3.2 describes how the data is handled after its arrival at the GCS.

3.1 Data Aquisition and Transfer

Data flow inside the wing pod is shown in figure 5. The HS sensor uses the trigger concept implemented by its manufacturer Specim: every full GPS second, the Applanix INS sends GPS time and navigational data to the HS sensor. In addition to that, the HS sensor determines the offset between the full second timestamp and each capture, which results in an individual timestamp for each frame. Given stable GPS data, all timestamps therefore have a maximum deviation of a second. Navigation data is sent to the DAQ which generates navigation files to be further processed by the GCS. The VIS camera works in a similar fashion: for each capture, the camera sends a trigger signal to the Applanix, which in turn is relayed to the DAQ as part of the navigational data stream. As with the HS timestamp data, these are sent to the GCS in the form of navigation files for further processing.

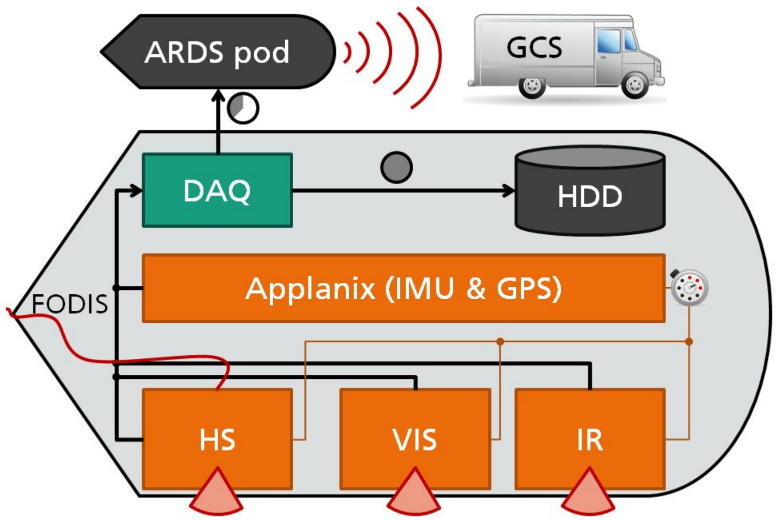

Figure 5. Multisensor wing pod. The three sensors (HS, VIS, IR) are placed on the bottom to enable nadir sight. The HS sensor has an exra FODIS element to capture the direct sunlight. The Applanix acts as the masterclock and triggers the sensors. The DAQ records the full sensor data onto a harddisk and only transfers a reduced version to the ARDS-pod from where it is transmitted to the GCS.

Combined, the three acquisition sensors (HS, VIS and IR) deliver data at a rate in excess of 50 MByte/s. Navigation data and timestamps have a negligible impact. HS data is recorded at 60 Hz with 127 spectral channels at 12 bit resolution. VIS data is captured at 1 Hz with a resolution of 4,872 by 3,248 pixels and a depth of 12 bit. While the raw data is stored for post-processing, only a reduced data stream is transmitted to the GCS: HS and navigation data are aggregated into data packets and sent once every second. The HS data itself is reduced from 12 bit to 8 bit and bands are combined using eightfold binning. Of the VIS data, one image is sent every 4 seconds.

3.2 Data processing

The analysis software is based on an existing processing chain of the Fraunhofer IOSB for the processing of hyperspectral pushbroom sensor data. Special attention was directed towards enabling real time and on-board processing. The GCS offers interfaces to integrate individual software into the data processing stream. The IOSB software was adapted accordingly and now runs inside the GCS. There it analyzes the received data for losses during transmission. After de-mosaicing the VIS data into color images, these are processed along with the HS data and cataloged in the geodata server as shown in figure 6.

After receiving a packet of hyperspectral and navigation data, the preprocessing computer immediately begins working on the packet. Since a packet contains a second's worth of acquired data, it is at this point delayed by at least 1 s compared to the original acquisition time. The raw HS data is transformed with a simple radiometric correction, followed by direct georeferencing: for each hyperspectral scanline, position and orientation information is derived by synchronizing to the navigation data via interpolation and transformation. If the offset, in the form

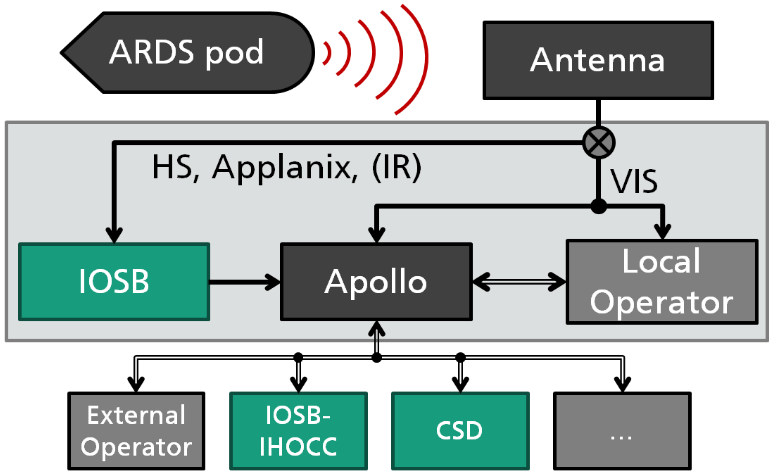

Figure 6. Data flow in the GCS. Transmissions from the ARDS pod are received by the antenna. The VIS data is then processed by Geosystems GmbH and presented to the local operator. The HS and navigation data (applanix) is processed by the Fraunhofer IOSB (see Figure 8) and stored into the geodata server (Apollo). Currently, IR data is only stored, not processed. The local operator as well as multiple external services can interact with the server through the web interface. All acquired data is available in near real time.

of relative position and orientation, between the INS and HS sensor (boresight) are known, these can be taken into account. Boresight offsets have to be compensated visually, either in advance or in flight, before reaching the target area. Sufficiently precise georeferencing is only attainable with good boresight correction. Rectification works without boresight correction. Leverarms are calibrated by measuring physical sensor configuration.

Since the inner orientation of the HS sensor is known, recorded data can be transformed back to object space, or Earth's surface. This is achieved by determining orientation information of each individual pixel (roll, pitch, yaw and Euler matrices) and intersecting an elevation model with a highly efficient raytracer (see figure 7) developed at Fraunhofer IOSB. The resulting pointcloud is rastered using a nearest neighbor interpolation and saved in the GeoTIFF format, augmented with metadata. Each 1 s interval results in a georeferenced hyperspectral image that is transmitted to the Apollo geodata server. There, a process integrates the image and relevant metadata into the catalog. An overview of the data processing flow is shown in figure 8. If parts of the transmission are lost in the downlink, these are presented in the image as black areas.

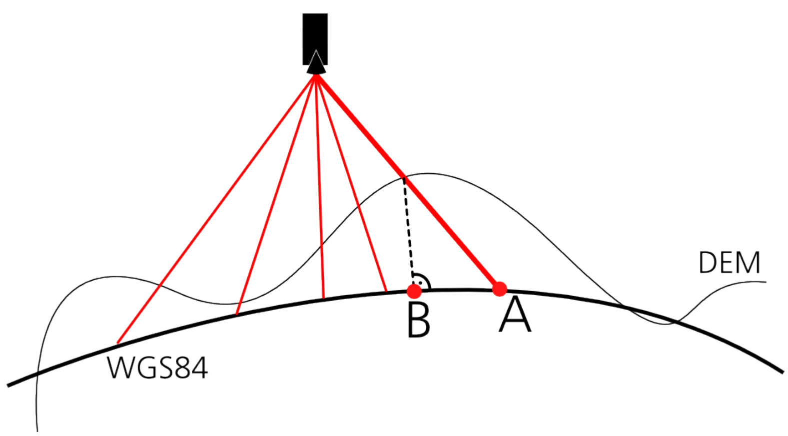

Figure 7. To account for local deviations from the reference ellipsoid WGS84 a DEM is used. The calculated geo coordinate A has a greater approximation error than the coordinate B which was calculated by orthogonal projection of the intersection with the DEM. The compensated error is greater at the edges of the FOV of the nadir looking sensor.

At typical flight elevation and speed, a hyperspectral system can be expected to deliver 60 lines of data.

Real-time georeferencing is possible, since the processing of 60 lines takes significantly less than 1 second. Earlier real-time capable hyperspectral target detection algorithms exist,[1] but the presented method does not rely on compute unified device architecture (CUDA).

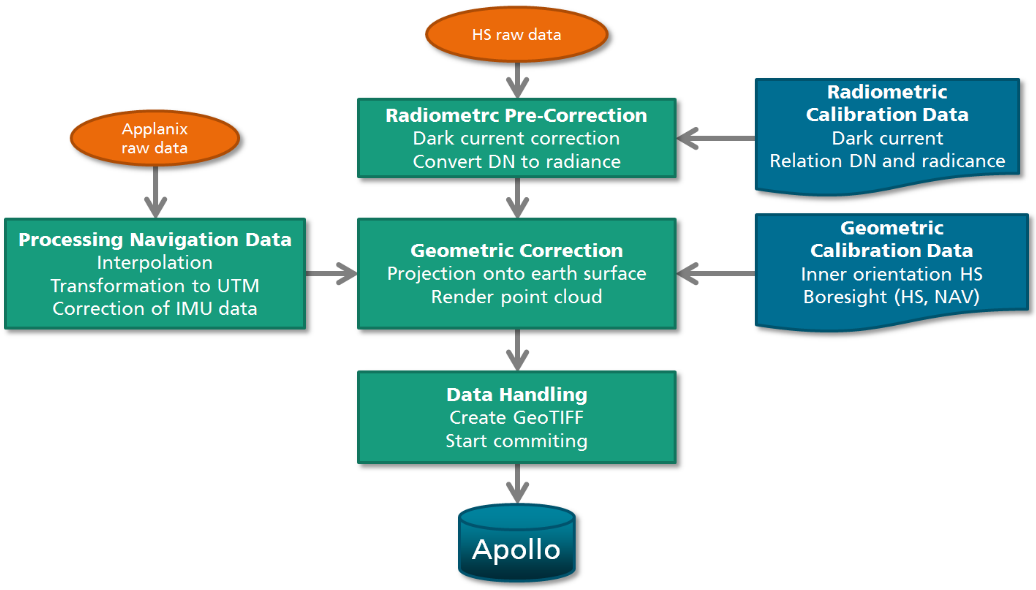

Figure 8. Data processing by Fraunhofer IOSB. Calibration data from the two boxes on the right are acquired pre flight. After correcting the HS data it is combined with the navigation data for georeferencing. In the last step, processed data is cataloged into the geodata server (in this case Apollo).

4. APPLICATION

The system presented in this paper was successfully demonstrated, as described in the next section. Data usage with different analysis software and algorithms is described in section 4.2. Section 4.3 gives an outlook on future developments.

4.1 Flight Demonstration

During a demonstration flight above Bremerhaven, Germany, in May 2013, the system (as shown in figure 9) was evaluated. Different test objects were placed and acquired, ranging from camouflage nets and cars in parking lots to larger objects such as dikes. The system's real-time capabilities were successfully demonstrated, the previously described acquisition and processing steps were performed correctly. Using the combined sensors and further analysis options of the ground control station, vegetation anomalies were successfully detected.

Figure 9. Condor-I shortly after take off during the presentation on 24th and 26th of May 2013 in Bremerhaven, Germany.

4.2 Analysis Software

Different analysis algorithms were successfully applied to the acquired data. Interaction with the geodata server through the defined interfaces also worked as intended.

Applications Several applications benefit from the described systems. One is an interactive and intuitively usable classification tool for HS data, IOSB-IHOCC (figure 10). Another use is road tracking.[10] This is especially useful as a preprocessing tool in cases where the focus lies on outer edges and boundaries of the road. In these cases, such as convoy protection and counter IED related efforts, it is often not feasible to process the entire image stream. Successful road detection allows lengthier and more complex algorithms to focus on the relevant areas. A combination of HS and LiDAR data is the basis for analysis especially intuitive to humans, since it combines geometry with radiometry. One method using Bayesian Networks shows how digital terrain models can be derived automatically from HS and LiDAR data.[11] All supervised classification tasks rely on ground truth data, which can be difficult or costly to gather. Especially if human analysts are involved, active learning can be used to alleviate some of the need for more ground truth data and help reduce the training costs.[12]

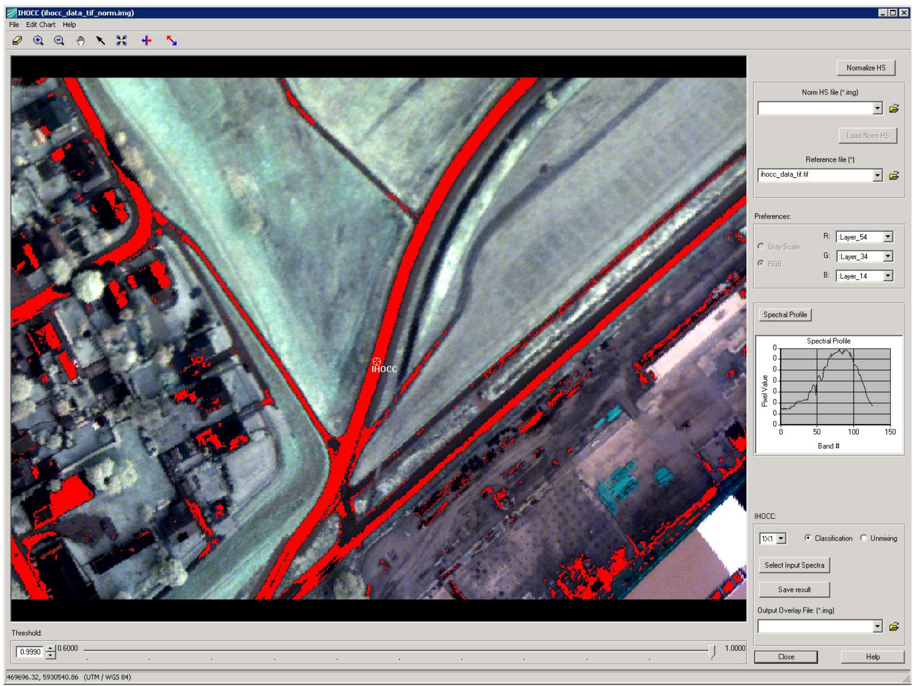

Figure 10. User interface of the IOSB-IHOCC. The user can select a source region and the algorithm highlights all other pixels which are similar in respect to the given parameters.

Interfaces Interfaces and protocols of the Open Geospatial Consortium (OGC) were implemented to ensure maximum interoperability regarding cataloging and communication of geodata. In addition, all data can be viewed and processed using the Web-ATR framework of Fraunhofer IOSB.

4.3 Outlook

An immediate improvement of perceived data quality and quantity at the GCS could be achieved by improving data compression. One option is to strip data and details not necessary at the GCS. Another is to perform more on-board processing. Ideally, the GCS could control sensors and specify which on-board processing to prioritize. This would be helpful to ensure mission critical data is received even with limited transmission capabilities. An interface for coalition shared data (CSD) to increase interoperability with allied parties is in development. Integrating a LiDAR sensor into the system would increase usefulness by adding geometric measurements. This sensor was not added to the wing pod due to limited available space. Of all integrated sensors, IR data is used during processing neither by the DAQ nor by the GCS. It lends itself to improving classification results and

Figure 11. View of a map with an overlay of georeferenced hyperspectral data (color infrared).

will be integrated into the processing algorithms in the near future. The GCS has enough resources to facilitate further and improved processing. One example is automatic re-identification of targets. Coupled with ground based control of the wing pod sensors, this could enable automatic tracking of and therefore effective focusing on targets.

REFERENCES

1. T. Skauli, T. V. Haavardsholm, I. Ksen, G. Arisholm, A. Kavara, T. O. Opsahl, and A. Skaugen, "An airborne real-time hyperspectral target detection system," in *Defense, Security, and Sensing*, *SPIE Proceedings*, pp. 76950A76950A–6, SPIE, 2010.
2. E. Puckrin, C. S. Turcotte, M.-A. Gagnon, J. Bastedo, V. Farley, and M. Chamberland, "Airborne infrared hyperspectral imager for intelligence, surveillance, and reconnaissance applications," in *Security + Defence*, *SPIE Proceedings*, pp. 836004836004–10, SPIE, 2012.
3. T. O. Opsahl, T. V. Haavardsholm, and I. Winjum, "Real-time georeferencing for an airborne hyperspectral imaging system," in *Defense, Security, and Sensing*, *SPIE Proceedings*, pp. 80480S80480S–6, SPIE, 2011.
4. OHB System AG, "artist impressions of the condor/ards system," 07.08.2013. https://www.ohb-system.de/play-video/movie/2.html.
5. Intergraph, "Erdas apollo," 07.08.2013. http://geospatial.intergraph.com/products/ERDASAPOLLO/Details.aspx.
6. USArmy, "Fm 3-90-2: Reconnaissance, security, and tactical enabling tasks: Volume 2," 2013.
7. USArmy, "Fmi 3-04.155: Army unmanned aircraft system operations," 2006.
8. Specim, "Aisaeaglehyperspectral sensor: Datasheet," 09.08.2013. http://www.specim.fi/files/pdf/aisa/datasheets/AisaEAGLE_datasheet_ver2-2012.pdf.
9. OHB System AG, "Ards - aerial reconnaissance datasystem," 07.08.2013. https://www.ohb-system.de/ards.html.
10. H. Schilling, W. Gross, and W. Middelmann, "Self-adaptive road tracking in hyperspectral data for c-ied," in *Optical Engineering + Applications*, *SPIE Proceedings*, pp. 85150S85150S–8, SPIE, 2012.
11. D. Perpeet, W. Gross, and W. Middelmann, "Automatic generation of digital terrain models from lidar and hyperspectral data using bayesian networks," in *Remote Sensing*, *SPIE Proceedings*, pp. 85370W85370W–7, SPIE, 2012.
12. S. Wuttke, H. Schilling, and W. Middelmann, "Reduction of training costs using active classification in fused hyperspectral and lidar data," in *Image and Signal Processing for Remote Sensing XVIII*, **8537**, pp. 85370M85370M–9, 2012.