UNIVERSITY OF AGRICULTURAL SCIENCES, DHARWAD

COMPENDIUM OF INTERNATIONAL WORKSHOP on

HEAT WAVES: FORESTRY AND AGRICULTURE UNDER PRESSURE: A REMOTE SENSING PERSPECTIVE (RS-HEAT2023)

(19 - 21 OCTOBER 2023)

EDITORS

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O11 : A gyrocopter based multi-sensor remote sensing solution for research and learning fundamentals in remote sensing of the environment

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Abstract : This article presents an aircraft-based remote sensing platform for academic education in the area of remote sensing, photogrammetry, geoinformatics and environmental sciences established at the Anhalt University of Applied Sciences in Germany. Sensor specific operational aspectsof imagine spectrometers, thermal sensors and RGB camera are presented and discussed due to teaching and learning objectives relevant for airborne remote sensing-based research and applications at different levels of knowledge and expertise. Aspects of flight campaign project management and teaching case studies are summarized for remote sensing and photogrammetry. Presented work comprises didactic contents in the area of i) remote sensing sensor operation, ii) data understanding and processing and iii) knowledge gain about remote sensing and photogrammetry for students. Furthermore, a discussion is provided on risks and chances by facilitating remote sensing as key method within future academic curriculum to increase transfer of fundamental research outcomes into proper and urgent environmental applications.

Key words: airborneremote sensing; gyrocopter; spectrometer; thermal remote sensing, environmental observations

Introduction

There is a growing demand on competences and expertise in remote sensing (RS) for environmental research and applications (Wagemann *et al.* 2022, Maggioni *et.al.,* 2020. and Gerner and Pause, 2020). International satellite-based earth observation (EO) programs i.e., NASA's Landsat missions and Europeans Copernicus program provide extensive resources (i.e., data, software) for research, applications and academic education. Strong benefits of EO data for education are its frequent data availability, ready to use processed image data and software or cloud-based analysis chains (i.e., SNAP, CODE-DE). Such EO data is ideal teaching and learning material to study algorithms for data analysis i.e., in the field of land use classification and land use change detection, time series analysis and deep learning for any purpose and in combination with further data. An academic training unit which is not addressed with EO data is the data acquisition itself, including fundamentals and scientifically based aspects to collect high quality imagine RS data in terms of geometry and spectral characteristics.

Fundamental knowledge, competence and expertise in RS data collection is essential to understand and plan EO missions and to realize airborne RS campaigns for local and regional scale research and applications. Due to increasing request in RS data for monitoring impacts of climate change and ecosystem restoration, airborne campaigns play a key role in environmental monitoring campaigns at local and regional scale and within hotspots of extreme events (i.e., urban heat islands, droughts and floods) and measures (i.e., forest restoration). For instance, currently German's public authorities provide spatial high resolution digital image data acquired by aircrafts in biennial intervals. From the technical and logistical point of view it is a realistic scenario to enhance future airborne campaigns by implementing further RS sensors and provide new thematic information i.e., to support climate adaption of landscapes, urban areas and monitor impacts of ecosystem restoration measures.

Thereby, knowledge gain is required in i) RS data analysis and ii) to facilitate multi-sensor airborne RS campaigns. Thus, the paper presents a concept of teaching and learning RS established since 2014 at Anhalt University of Applied Science in Germany

Airborne Multi-Sensor Remote Sensing Platform

To facilitate an own airborne RSplatform a gyrocopter was purchased in 2014 by the institute of geoinformation and land surveying at Anhalt University of Applied Sciences. The implementation of the gyrocopter is driven by three main objectives:

i) To provide a flexible solution for proof-of-principle and proof-of-concept studies for RS sensor innovations.
ii) To enable studies on multi-sensor RS observation campaigns and collected data sets.
iii) To provide an advanced teaching and learning environment for under-graduate and graduate students and PHD students.

Since 2014, various solutions for imaging multi-sensor RS were implemented and studied within student research projects, industrial cooperation and PHD studies (Richter *et.al.,* 2021, Lin *et.al.,* 2020 and Bannehr *et.al.,* 2015). In the following relevant information for the gyrocopter and airborne remote sensing sensors are provided.

Gyrocopter Cavalon D-MHSA

A gyrocopter is an ultralight aircraft that provides several technical and commercial advantages to realize airborne RS campaigns relevant for hosting by academic institutions with focus on higher education and research. In (Lin *et.al.,* 2020) a comprehensive description of technical properties and flight parameters was published right after purchase in 2014. Therefore, only key parameters with relevance for airborne experiments summarized here:

- Slow *flight speed* possible (30 – 160 km/h), which allows experiments on signal integration to increase spatial resolution and signal-to-noise ratio (SNR), *i.e.* relevant for thermal infrared (TIR) observations.
- Short *landing strips* sufficient (around 50m) which provides flexibility on the selection of airports.
- *Take-off-weight* of 500kg and 311kg tare allows 189kg payload for pilot, sensors and mounting rack.
- *Climbing time* takes some time depending on atmospheric conditions (85 – 100 km/h). This has to be considered in flight planning and is a compromise between area coverage and available flight time.
- Beside maximum *fuel* availability (100 l tank for super unleaded, consumption 15 – 20 l/h) *flight time* mainly depends on take-off-weight and atmospheric conditions. Concerning pilot health, a maximum of 3 hours flight time is reasonable and should not be extended.
- *Flight properties* are quite stable by way of comparison with further small aircrafts.
- Gyrocopter *dimensions* (width 1.8 m, length 4.7 m) require only small space in aircraft hangar and are comparatively convenient.

Considering above listed properties and own experiences, it may be inferred that a gyrocopter provides excellent properties to efficiently study remote sensing equipment and collect data over small (10 to 100km^2) test sites. Due to limitations in cruising and climbing speed comprehensive airborne campaigns are no main field of operation. Annual cost including insurances, technical services and hangar are approximately 20K EUR.

Figure 1: Gyrocopter D-MHSA hosted by Anhalt University of Applied Sciences and applied for research and teaching remote sensing of the environment within the institute of geoinformation and landsurveying.a) presenting

the gyrocopter in 2023,b) presenting the multi-sensor rack during flight preparation, c) presenting the pilot seat and operational units during flight and data acquisition.

Remote sensing sensors

Through industrial cooperation and fundings by German Research Foundation (DFG) various commercial RS sensors could be purchased since 2014. Furthermore, two sensor innovations are a result of industrial cooperation (see co-authors 2 and 3) and are available as prototypes. All sensors are summarized in table 1.

Table 1. Overview of i) available commercial RS sensors and ii) in-house developed RS sensors implemented at D-MHSA airborne platform for photogrammetry and RS at Anhalt University of Applied Sciences. Key technical parameters and examples for field of application are specified.

sensor name/ source	technical parameters	area of teaching, research and application
Commercial available airborne sensors		
Phase One iXM 100MP RGB camera	44 x 33 frame sensor	Photogrammetry Basics in digital image acquisition 3D object modelling Flight planning Frame sensor aspects
HySpex VNIR 1600 NorskElektroOptik/ NEO, Norway	400 – 1000 nm	Basics and advanced knowledge in imagine spectroscopy, line sensor properties, environmental and land use studies, vegetation, soil and urban material classification, indicators and monitoring, handling high dimensional data cubes
HySpex SWIR 384 NorskElektroOptik/ NEO, Norway	1000 – 2500 nm	
FLIRA655sc Thermal	640 x 480 frame sensor, 7.5 -14 µm spectral rage	Land surface and material temperature and emissivity studies, urban heat indicators, building energy loss, forest and any vegetation vitality and impact on thermal pattern, lake and river water quality assessment,
In-house developed airborne sensors (prototypes)		
AOS-Tx8/ Bannehr *et.al.,* 2015	TIR/ RGB oblique sensor system, 4 x RGB frame cameras, 4 x thermal cameras	airborne-based 3D RGB and TIR data, *i.e.* for assessment of vertical thermal properties within urban areas or vegetation structures
MUMS-6	5 channel multi-spectral frame camera system, 1 x panchromatic camera,	airborne-based multi-spectral data and fast indicator supply, 3D photogrammetric object reconstruction and 3D multi-spectral surface models

Objectives For Learning Remote Sensing For Environmenatl Research and Application

In the following we provide some examples on the didactic implementation of the gyrocopter-based multi-sensor system with specific operational relevance for airborne research experiments and application. Figure 2 to 6 provide examples from own activities representing standard scenarios (Figure 2 and 3) for campaign management and teaching. Figure 4 is a result of a PHD thesis, which provides research on the application of imagine hyperspectral data to quantify water quality and detect pollution i.e., caused by industry (Ulrich, *et.al.,* 2020). As at Anhalt University of Applied Sciences much research is related to sustainable land management and landscape resilience, RS data is widely implemented in numerous research and monitoring projects (i.e., Figure 5). As aerial oblique sensor systems are promising future methods to provide 3D thematic object data an example is given in figure 6. Here, further research for its application in urban areas, forests and arable land are scheduled and are supported by student projects in graduate courses and final thesis. MUMS-6 sensor (see table 1) prototype is under further development within an in-house PHD student project and indicator retrieval to assess forest health is a key objective in sensor specifications and processing chain.

Table 2: Examples of teaching content and learning objectives with specific application of D-MHSA gyrocopter and multi-sensor platform within under-graduate and graduate courses at Anhalt University of Applied Sciences/ institute of geoinformation and land surveying.

teaching objectives/ content	**learning objectives**
campaign planning and flight management i.e., figure 2 and 3	
Parameters for flight planning: sensor and aircraft specific, additional requirements i.e., time window, budget, permission, GNSS and IMU data processing and geometric corrections, lever arm and rack design	- The students understand the interdependencies of sensor characteristics and flight altitude, speed and time of observation. - The students are able to argue for various sensor combinations to exploit synergies and complementarities for environmental observation. - The students are able to handle flight management software and analyze provided experimental data.
informationbehindpixeli.e., figure 4 and 5	
Physical background of relevant RS electromagnetic spectra, Environmental and technical factors i.e., affecting signal-to-noise ratio, atmospheric influence and correction, methods for ground truth	- The students are able to interpret pixel values and spectral signatures of various sensors types i.e., as provided in table 1 and with different spatial and spectral quality. - The students are able to analyze in-house experimental data and EO data with different commercial and open-source software. - The students are aware of ground truthing aspects and methods to i.e., retrieve indicators and qualitative / quantitative information.
photogrammetric aspects i.e., figure 2 and 6	
Fundamentals of boresight calibration, ground control point requirements, digital elevation and surface model retrieval, 3D object reconstruction, RGB orthophoto and thermal orthophoto construction	The students are able to prepare flight planning and analyze experimental data for the retrieval of true orthophotos, 3D-object models and boresight calibration. The students understand various solutions to provide oblique images.

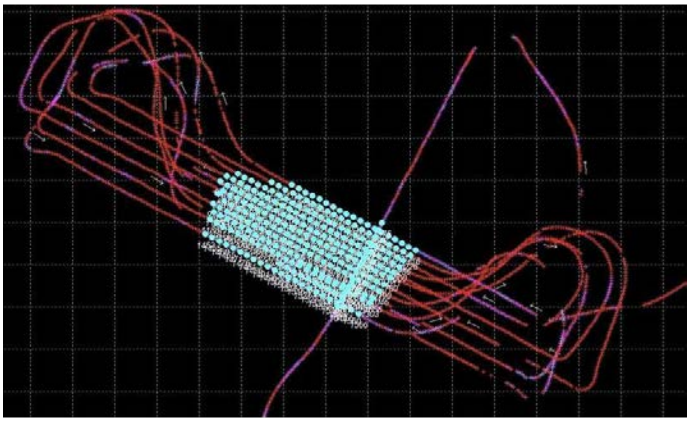

Figure 2: Flight strips (red/ magenta lines), curve pattern for D-MHSA gyrocopter and trigger points for PhaseOne RGB camera (blue dots).

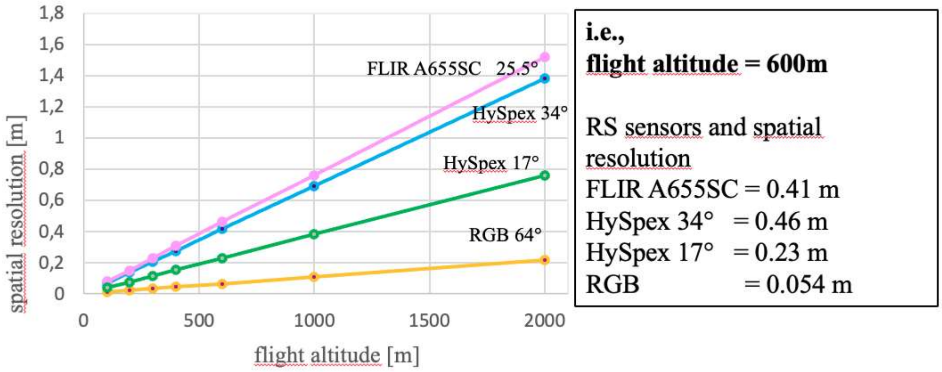

Figure 3: Aspects for flight planning concerning multi-sensor data acquisition during one flight. Diagram shows the dependency of flight altitude and possible spatial resolution for TIR data (magenta line), hyperspectral VNIR medium FOV (blue line), hyperspectral VNIR wide swath FOV (green line) and RGB aerial image (yellow line).

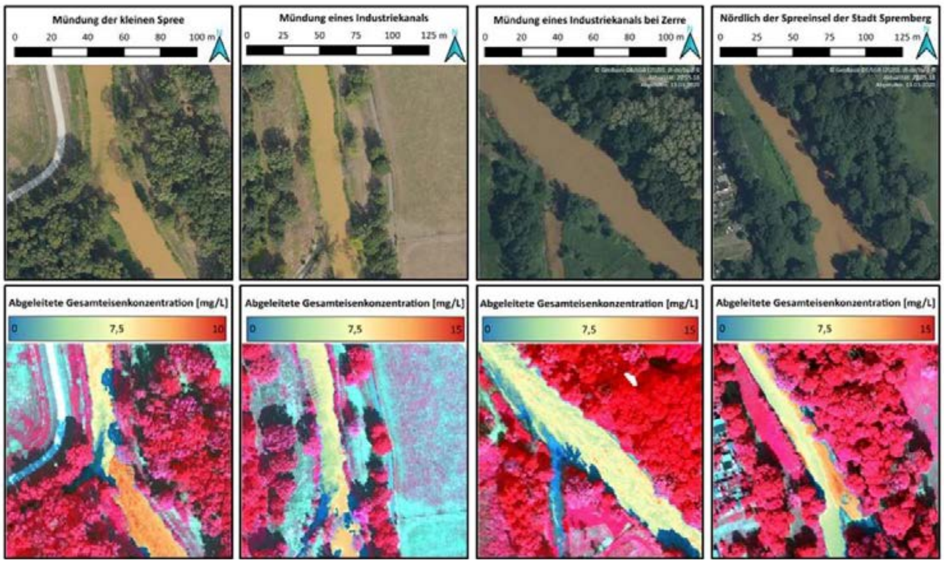

Figure 4: Monitoring of river water quality. The images represent different parts of a river. The color ramp represents iron concentration estimated using imagine hyperspectral data. Image source: PHD thesis (Ulrich, *et.al.,* 2020)

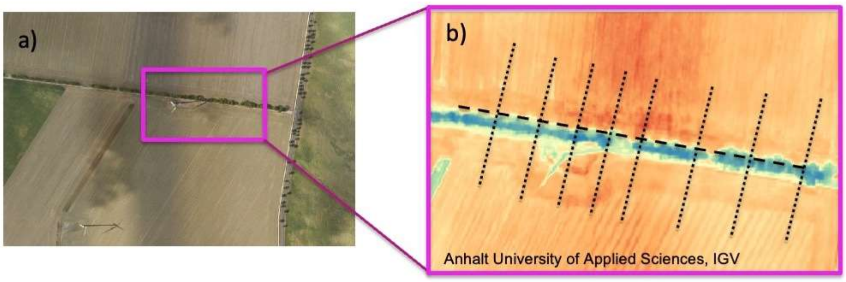

Figure 5: TIR pattern along hedge rows in arable area (left). The black dotted lines represent a future monitoring scheme for various biotic and abiotic parameters i.e., soil moisture, soil microbiome. RS data supports the development of in-situ monitoring design.

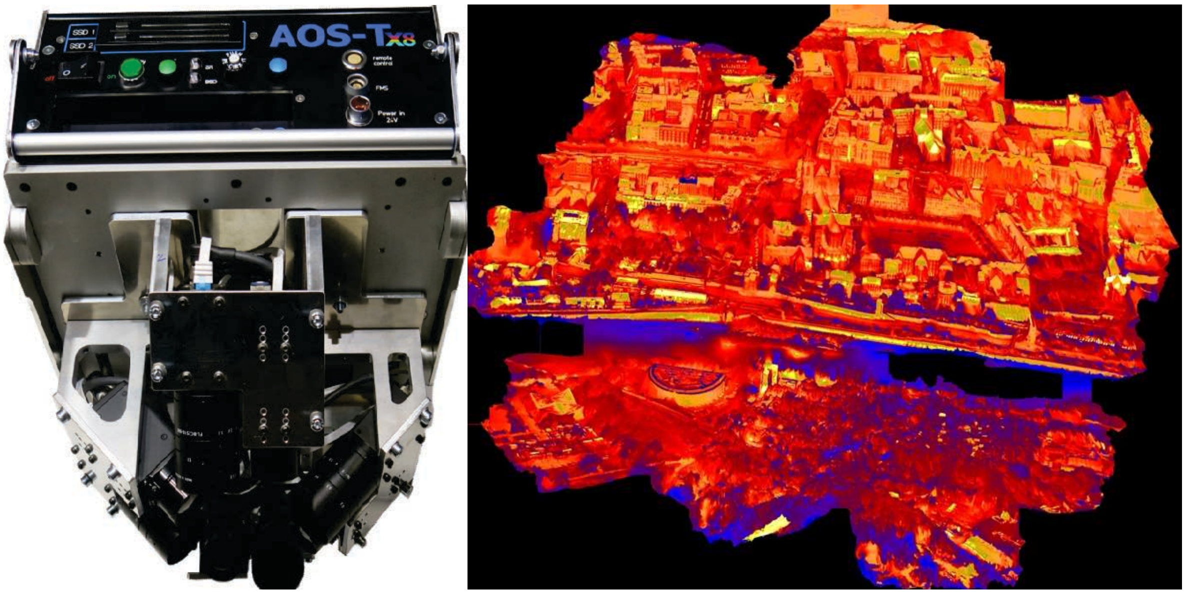

Figure 6: AOS-Tx8 prototype (left) and experimental 3D TIR image (right) from urban area collected during airborne campaign over Magdeburg/ Germany by D-MHSA gyrocopter 2017. Right image: blue areas are cooler (vegetated area) than red and yellow colors (buildings). Single building fronts are visible in the upper image section.

Conclusions

The availability of an own aircraft to facilitate RS teaching, learning and research is an excellent and rarely infrastructure at academic institutions. As summarized in previous chapters numerous possibilities and chances are linked to such infrastructure. However, the maintenance of such an airborne gyrocopter-based RS solution requires specific competences and motivation by all involved persons and the institution itself. As an experimental platform, almost all aspects are individual developments, which is a risk by loss of staff and many external technical changes require modification.

The request to contribute to interdisciplinary research with own flights is increasing and in many cases from the operational point difficult to manage mainly due to limitations in area coverage. Therefore, it is to emphasize the presented gyrocopter-basedRS solution is mainly for small campaigns and experimental scenarios that are in ideal circumstances close to the hosting airport.Otherwise, the gyrocopter could be transferred by car trailer to any airport.

Regarding the availability of different RS sensors,a LiDAR sensor would be an excellent extension. The combination of dense point clouds with already available spectral layers (TIR, VNIR, SWIR) would enable further research on the development and retrieval of environmental indicators i.e., representing phenology and crop condition or forest restoration level.In near future we will combine gyrocopter-based data with high spatial resolution UAV-based RS observations (i.e., LiDAR point clouds, arial images and 3D models) to study possible data innovations.

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