HyTIR – an airborne hyperspectral imaging research platform in the LWIR wavelength range

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Abstract

Hyperspectral cameras play a crucial role in remote sensing across various applications. The sensors designed for the visible to near-infrared (VNIR) and short-wave infrared (SWIR) ranges are particularly valuable due to their ability to detect reflected light from measured objects and absorption characteristics of atmospheric radiation. These capabilities are essential for numerous environmental and agricultural monitoring applications. In addition to VNIR and SWIR sensors, imaging sensors that operate within the mid-wave and long-wave infrared ranges have been developed. These sensors focus on capturing radiation emitted by objects due to their inherent temperatures. Despite their potential, these infrared sensors have seen limited use primarily because of the higher costs associated with their deployment. Anhalt University of Applied Sciences is overcoming some of these limitations by incorporating an FTIR hyperspectral camera, specifically for the long-wave infrared (LWIR) range, into its repertoire of imaging sensors. This expansion is part of a project funded by the GRC to establish the HyTIR platform. The primary aim of this platform is to support Earth observation missions and to enhance measurement campaigns in agricultural and environmental science fields. The article outlines the distinctive features of the measurement system provided by the FTIR hyperspectral camera. It details how this system is flexibly combined with complementary sensors depending on the requirements of each campaign. The article also presents initial findings from test flights conducted using the system. The overarching goal of the HyTIR platform is to make its advanced capabilities available to the international scientific community. By doing so, it aims to contribute significantly to the fields of remote sensing as well as agricultural and environmental sciences, by enabling advanced Earth observation and data collection methodologies.

1. Introduction

The HyTIR platform represents an innovative approach in remote sensing by integrating Fourier-transform infrared (FTIR) spectroscopy with hyperspectral imaging. This technology is aimed at spatially mapping and monitoring various biotic and abiotic parameters of land surfaces, from small fields to larger mixed landscapes. The core of this platform involves the collection of infrared spectra from aircraft, which allows for the monitoring of these parameters over diverse environments.

Key to this approach is the use of the Telops Hyper-Cam Airborne Mini (Hyper-Cam), which is instrumental in capturing thermal infrared (TIR) data from the environment. This is complemented by other established hyperspectral sensors such as the Phase One camera and the HySpex VNIR 1600 imager. Together, these devices enable comprehensive spectral data collection across different regions of the electromagnetic spectrum:

> The visible to near-infrared (VNIR) range is covered by both the Phase One camera and the HySpex VNIR 1600 imager.
>
> The short-wave infrared (SWIR) range is covered by a HySpex SWIR 384 imager.
>
> The thermal infrared (TIR) is specifically covered by the Hyper-Cam.

This combination of sensors allows for extensive and unprecedented multi-sensor observation campaigns, giving researchers the ability to conduct environmental remote sensing with a level of detail and accuracy not previously possible. By integrating these data sources, HyTIR provides a powerful tool for understanding land surface parameters and processes over large areas, potentially leading to new insights in environmental science.

2. Telops Hypercam Airborne Mini

2.1 Telops Hyper-Cam Airborne Mini

The core of the HyTIR platform is the Hyper-Cam Airborne mini hyperspectral camera from Telops, a Canadian company. This camera system was specifically designed for use in airborne measurement applications. The measurement head of the system features a stabilized platform from Somac, an inertial measurement unit, and a GNSS receiver. The measurement head is connected to and controlled by a data acquisition unit. The complete system is controlled by a mobile computer connected to the measurement head, which is operated by a sensor operator during flight. The power supply is provided by the aircraft's onboard power system.

The system acceptance and initial testing were completed in May 2024 at Telops' headquarters in Quebec.

The Hyper-Cam covers the wavelength range of $\boldsymbol{\lambda} = \mathbf{7.4 - 11.8}$ $\mathbf{\mu m}$ (corresponding to wave numbers of $\tilde{\boldsymbol{\nu}} = \mathbf{848 - 1351\ cm^{-1}}$) with adjustable spectral resolution of $\boldsymbol{\Delta\tilde{\nu}} = \mathbf{0.5 - 64\ cm^{-1}}$.

Hence, the entire TIR spectrum is sampled by $\sim\mathbf{10\text{-}1000}$ channels while the achievable maximum spectral resolution in flight depends on the minimum aircraft speed.

The maximum optical field of view is $\mathbf{13.7°} \times \mathbf{11.0°}$ (without amplification by fore optics). The angular resolution per pixel is $\mathbf{750\ \mu rad} \approx \mathbf{0.04°} \approx \mathbf{2.58\ arcmin}$, which enables a spatial resolution on ground in the sub-meter range for flight altitudes below 5,000 feet. The detector system is cooled to $\approx \mathbf{75\ K}$ thus providing a noise equivalent spectral radiance (NESR) below $\mathbf{35\ nW\ (cm2\ sr\ cm^{-1})}/$. So, the detector thermal noise is remarkably suppressed, and the signal- to-noise ratio is high over the entire wavelength range.

Table 1 summarizes essential properties of the Hyper-Cam, which are relevant for integration and application. Details and an evaluation of the camera properties, e.g. the verification of Noise Equivalent Spectral Radiance, can be found in (Turcotte et al., 2023).

Specifications	
Spectral Range	7,400 – 12,800 nm
Field of view	13.5° x 10.9°
Measurement head size	28 x 35 x 38 cm
Data acquisition unit size	23 x 21 x 18 cm
Total weight of components	~24 kg
Power consumption	<260 W

Table 1. Selected specifications of Telops Hyper-Cam.

Sophisticated planning, operation, and post-processing of observation missions are done by the delivered software Reveal IR Suite (see Section 2.3). The software suite is supported by a data base of chemical spectral signatures used to correct the TIR data for molecular extinction and thermal emission from the atmosphere. Moreover, a viewer for scanning hyperspectral data cubes pixel by pixel facilitates investigations of spectral or interferogram contents. The Hyper-Cam has been utilized in recent scientific remote-sensing campaigns of the environment (Schlerf et al. 2012, Buddenbaum et al. 2015, Gerhards et al. 2016, Rock et al. 2016, Kim et al. 2018). It should be noted that all this remote sensing has been conducted ground-based only and at distances far below $\sim\mathbf{102\ m}$.

2.2 Research Aircrafts

Following delivery in summer 2024, the technical integration into research aircraft is currently in progress. This involves mechanical and electrical integration, as well as establishing flight procedures for future campaigns. The integration of all key components into the measurement head provides high flexibility in the selection of measurement aircraft. Figure 1 depicts the CAD model of a custom-made adapter plate, already manufactured for the installation of the system in the cabin of a Diamond DA-62.

Integration into different research aircraft requires the design of another adapter plate or a modification of the existing plate.

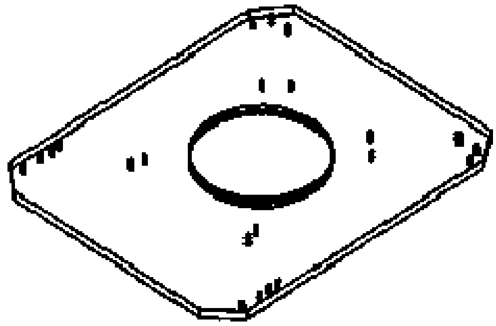

Figure 1. Design of the DA-62 adapter plate.

2.3 Required interfaces

Installation of the system into a research aircraft requires mounting the sensor head and the data acquisition and control box with four screws each. Only the connection to the power supply and an externally mounted GNSS antenna on the aircraft are required in addition. Additional adapter plates for aircraft of local and international partners are in preparation. Installation into a DA-62 special mission aircraft is shown in Figures 2 and 3 depict parts of the sensor, while Figure 4 shows the installed data acquisition and control box.

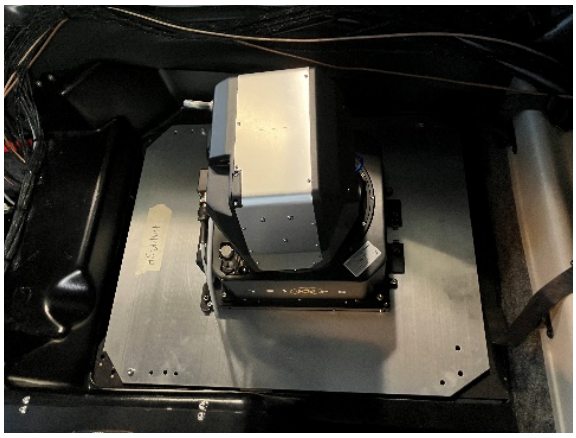

Figure 2. DA-62 adapter plate mounted into aircraft

Figure 3. Hyperspectral FTIR sensor in combination with integrated RGB viewfinder camera.

2.4 Software Tools

Telops provides a number of software tools for preparation of airborne FTIR imaging campaigns, operation of the sensor during the measurements and data processing after the flight. Table 2 lists the necessary processing steps and the implementation of the step into specialized software tools.

Phase	Step	Software Tool
Preflight	Mission planning	Reveal Planner
	Ground check	Reveal Airborne
Flight	Sensor operation	Reveal Airborne
	Online detection of gas emissions	Gas detection module
Postflight	Data cube inspection	Reveal Processor
	Generation of georeferenced orthomosaic	Reveal Mapper
	GCP optimization	Reveal Mapper
	Post processing	Reveal Processor
	Radiometric calibration	Reveal Processor
	Orthomosaic based on most precisely georeferenced data cube	Reveal Processor
	Atmospheric correction	FLAASH IR
	Temperature emissivity separation	FLAASH IR

Table 2. Processing steps and corresponding software tool within the Telops Reveal software suite.

Figure 4. Data acquisition unit and control unit of the FTIR sensor

3. Survey Planning

The section provides details and results about the mission planning phase of a test flight. Using the software Reveal Planner different scenarios have been prepared. In a second step, they undergo evaluation by a scoring system, which has been implemented as a spread sheet. The parameters of the selected scenario are exported and then used by the flight control software of the aircraft as well as for sensor operation by the software Reveal Airborne.

3.1 Mission Planning Software

Mission planning consists of three steps. First, the region of interest has to be provided. Second, it is imported into Reveal Planner. Third, survey is planned by definition of crucial parameters like flight direction, ground speed, ground sampling distance (GSD), spectral resolution, across-track-overlap. Reveal Planner includes evaluation of the planned flight and predicts the quality of the interferogram given estimated ground speed and resulting measurement time. Figure 5 shows the user interface of Reveal Planner and the necessary steps during survey planning.
Together with the planned GSD, the estimated noise-equivalent spectral radiance (NESR) provides a quality measure to compare scenarios with different flight heights, flight directions and speeds

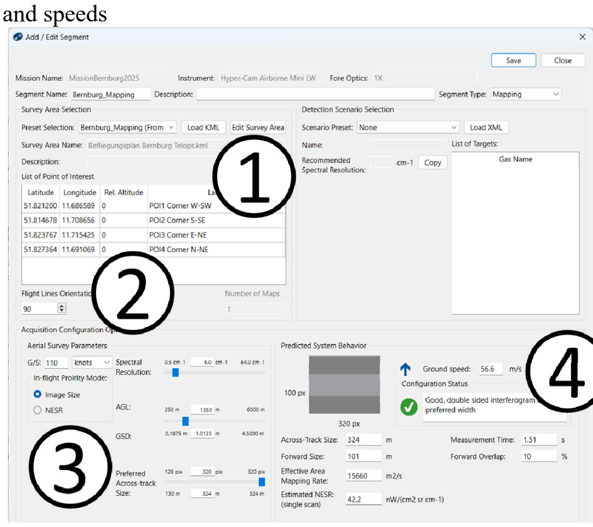

Figure 5. Interface of the mission planning software Reveal Planner. (1) Survey area is imported and listed, (2) flight direction is defined, (3) general survey parameters are defined, and (4) planned parameters are evaluated with respect to data quality constraints.

3.2 Test site

Initial tests with the Hyper-Cam are being conducted at Bernburg, a site where Anhalt University of Applied Sciences manages several field trials and sensor networks. This setting is ideal for testing the Hyper-Cam because it provides a rich source of reference data that can be used to validate and calibrate the airborne FTIR measurements. The availability of comprehensive reference data is crucial for ensuring the accuracy and reliability of the remote sensing data collected during these tests.

The field trials and sensor networks at Bernburg allow for controlled testing environments where various biotic and abiotic parameters can be monitored and measured alongside the hyperspectral data collected by the Hyper-Cam. Figure 6 shows the location and coordinates of the trial site. By conducting these tests, researchers can refine the methodologies used for data collection and analysis, understand the capabilities and limitations of the Hyper-Cam, and enhance the integration of the FTIR hyperspectral camera into the broader HyTIR platform.

These efforts contribute to the overall goal of developing a robust system for Earth observation that can benefit agricultural and environmental sciences by providing accurate and detailed spatial data. The tests at Bernburg represent an important step in ensuring that the HyTIR platform fulfills its intended role in supporting the international scientific community.

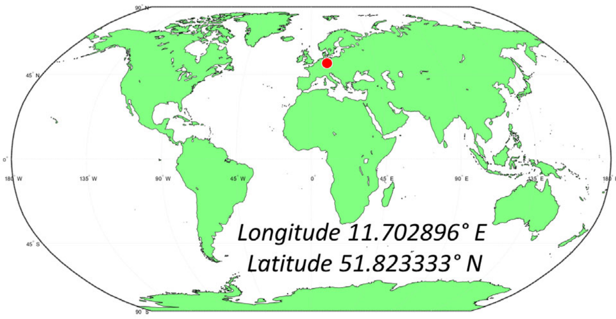

Figure 6. Location and coordinates of the test site at Bernburg, Germany.

Bernburg and the field trials of Anhalt University of Applied Sciences are situated in an area characterized by relatively low precipitation due to the rain shadow effect of the Harz Mountains. The predominant soil type in this region is loess chernozem, which is known for its fertility and suitability for agricultural activities.

Over the long-term average from 1991 to 2020, the region receives an annual precipitation of approximately 516 mm, highlighting its comparatively dry conditions. During the same period, the average temperature was 10.1 degrees Celsius, indicative of a temperate climate.

These specific climatic and geological conditions make the area around Bernburg an interesting site for environmental research and agricultural studies, particularly in terms of adapting agricultural practices to dry conditions. This setting provides an ideal platform for testing remote sensing technologies like the Hyper-Cam, as the data collected can provide valuable insights into the impacts of climatic and soil conditions on agricultural systems.

Figure 7 illustrates the area of interest designated for the test flight, along with the derived rectangular survey area. This particular region encompasses multiple field trials related to ongoing research projects.

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Figure 7. The survey area (blue rectangle) contains the area of interest (AOI, white polygon).

These trials include those conducted by Anhalt University's Agriphotovoltaic Research Center, which explores the integration of solar power and agriculture. Additionally, the area covers parts of the AgriRestore project, which investigates the impacts of landscape elements such as wildflower strips and hedges on the environment. Furthermore, it includes a field trial of the TRANSFORM project, which focuses on soil moisture and irrigation practices.

3.3 Parameters for mission planning

Using Reveal Planner, eight potential scenarios for mapping of the survey area have been defined. They differ with respect to flight speed, altitude above ground level (AGL) and direction of flight. Choices depend on the minimum speed of available aircraft, available budget with respect to flight duration and potential wind directions. Scenarios presented in Table 3 are selected with respect to a Diamond DA-62 aircraft.

Scenario	Speed [knots]	Altitude [m]	Direction
1	100	1000	N ←→ S
2	100	1000	E ←→ W
3	100	1500	N ←→ S
4	100	1500	E ←→ W
5	120	1000	N ←→ S
6	120	1000	E ←→ W
7	120	1500	N ←→ S
8	120	1500	E ←→ W

Table 3. Different scenarios of flight speed, altitude and flight direction for mapping of Bernburg survey site.

Next. the scenarios are ranked based upon the following criteria:

a. Ground sampling distance (GSD, the smaller the better)

b. Spectral resolution (the smaller the better)

c. Flight direction (N to S is preferable as main wind direction is W to E thus flight speed can be kept relatively constant)

d. Number of flight lines (the smaller the better)

e. Estimated Noise Equivalent Signal Ratio (NESR, determines weakest detectable spectral radiance, the smaller the better)

The choice of criteria reflects the trade-off between imaging quality (criteria a, b, e) and operational constraints (criteria c, d). In the table the lowest penalty value receives the highest rank. Therefore, scenario 6 is selected for the test flight.

#	GSD	Spec. Res.	Fl. dir.	Fl. lines	NESR	Penalty value	Rank
	[m]	[1/cm]			[nW/(cm² sr cm-1)]		
1	0.75	4.9	N ←→ S	11	57.6	84.25	4
2	0.75	4.9	E ←→ W	7	57.6	70.25	3
3	1.125	3.2	N ←→ S	7	70.9	92.23	8
4	1.125	3.2	E ←→ W	5	70.9	80.23	7
5	0.75	6.0	N ←→ S	11	52.0	79.75	2
6	0.75	6.0	E ←→ W	7	52.0	65.75	1
7	1.125	3.9	N ←→ S	7	64.1	86.13	6
8	1.125	3.9	E ←→ W	5	64.1	74.13	5

Table 4. Final selection of scenario based on weighted ranking of the different criteria.

Figure 8 shows the comparison between the lowest rank and the best rank scenario. Spatial resolution and NESR of scenario 6 outperform the other variants, while spectral resolution is lower.

Figure 8. Visualization of scenarios No. 3 and No. 6 (see Table 4).

4. Summary

The integration of the Hyper-Cam Airborne Mini into aircraft has reached operational status, and initial test flights have been successfully conducted. For future FTIR imaging campaigns, mission planning is already available, and research partners can designate areas of interest by providing KML or Shape files, which assist in evaluating the parameters and duration of the measurement flights.

It's important to note that total flight times and associated costs can vary significantly due to factors such as the choice of aircraft provider and the distance between the airport and the measurement site. To ensure the accuracy of data collected during flights, it is recommended to provide ground truth data as a reference, which may necessitate combining flights with terrestrial data acquisition efforts.

The Bernburg campus of Anhalt University serves as an excellent test site for such activities because of the array of ground-based sensors and reference data available from ongoing agricultural and environmental field trials. This infrastructure provides a robust foundation for validating airborne data.

Currently, the online gas detection software module has not been acquired. This module would further enhance the capabilities of the HyTIR research platform. Acquiring it depends on the specific requirements of future projects and the availability of project funding. Its integration would be a logical step in expanding the HyTIR platform's capabilities, particularly in enhancing the depth and breadth of environmental observations.

Declaration of generative AI in scientific writing

During the preparation of this work the authors used ChatGPT 4.0 in order to improve readability and language. After using this service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication

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