A LIGHT-WEIGHT HYPERSPECTRAL MAPPING SYSTEM FOR UNMANNED AERIAL VEHICLES – THE FIRST RESULTS

Juha Suomalainen[a], Niels Anders[b], Shahzad Iqbal[c], Jappe Franke[d], Philip Wenting[a], Harm Bartholomeus[a], Rolf Becker[c], and Lammert Kooistra[a]

[a] Laboratory of Geo-Information Science and Remote Sensing, Wageningen University, the Netherlands;
[b] Soil Physics and Land Management Group, Wageningen University, the Netherlands;
[c] Hochschule-Rhein-Waal, Germany;
[d] Alterra, the Netherlands

ABSTRACT

Research opportunities using UAV remote sensing techniques are limited by the payload of the platform. Therefore small UAV's are typically not suitable for hyperspectral imaging due to the weight of the mapping system. In this research, we are developing a light-weight hyperspectral mapping system (< 2 kg) suitable to be mounted on small UAVs. The system is able to produce georeferenced and georectified hyperspectral data cubes in 400-1000nm spectral range at 10-50cm resolution. The georeferenced reflectance factor spectra cubes are to be used in e.g. precision agriculture and soil erosion research. In this paper we describe prototype of the system, the processing chain, and present preliminary results

Index Terms**—** UAV, Hyperspectral, DSM, Orthoimage

1. INTRODUCTION

Small Unmanned Aerial Vehicles (UAVs) are becoming more and more an essential tool in local scale remote sensing. [1] The remotely piloted, semi-autonomous helicopters and fixed wing aircrafts are gaining popularity both in the research and commercial applications. Today, there are a number of commercial UAV solutions available, such as *Mavinchi Sirius I* and *GateWing X100*, that allow the user to perform aerial photography mapping using consumer cameras. There is also an increasing selection of available software to convert these aerial images to final data products such as orthomosaics and Digital Surface Models (DSMs). The UAV types most rapidly gaining popularity are small battery powered multicopters and fixed-wing aircrafts that can take-off and land outside official airfields. Typically such small UAVs can carry payloads between 0.5–2 kg.

For quantitative predictions of biochemical and biophysical vegetation parameters a hyperspectral camera system is most suitable [2], but unfortunately, the widely used lightweight hyperspectral pushbroom systems such as *Headwall Micro-Hyperspec*, *Resonon Pika II*, and *Specim AISA* products all fail to fit in such a strict payload limit.

Within the Interreg *Smart Inspectors* project, Wageningen University, Hochschule-Rhein-Waal, and Alterra started a co-operation to develop UAV remote sensing systems and apply them for different applications. One part of project is to develop a light-weight hyperspectral mapping system that would fit in the small UAV payload and would combine the capabilities of hyperspectral and photogrammetric remote sensing. In this paper, we describe the preliminary design, processing chain, and the first test results of the system.

2. THE HYPERSPECTRAL MAPPING SYSTEM

In 2012, Wageningen University and Alterra acquired an octocopter UAV – *Aerialtronics Altura AT8* (Figure 1a). The AT8 can carry payloads up to 2 kg with practical flight mission time of 5-8 minutes. Thus, also the maximum weight of the designed hyperspectral mapping system was set to 2 kg.

In general, a stand-alone pushbroom spectrometer system must consist of the following main components:

- a lens objective,
- a spectrograph,
- a camera,
- a frame grabber,
- a computer,
- a data storage device, and
- a GPS inertia navigation system (INS)

Figures 1a and 1b. Aerialtronics Altura AT8 octocopter and the hyperspectral mapping system. The system consists of a Panasonic Lumix GX1 camera, XSens MTi-G-700 INS, and a pushbroom spectrometer.

As the spectrograph we chose a 300-g *Specim ImSpector V10 2/3"*. Next, we combined the functionalities of the camera, the frame grabber, the computer, and a data storage device to a single unit: *PhotoFocus SM2-D1312* – an industrial camera with integrated Digital Signal Processor (DSP) based frame grabber and computer weighing only 600g. As the last main component, we selected the *XSens MTi-G-700* INS, weighing 150g including the GPS antenna. As the purpose of the system is to produce the DSM needed for orthorectification of hyperspectral data on one flight, we included a photogrammetric camera to the system – *Panasonic GX1* with wide angle (14mm pancake) objective (360g). With the 12-mm spectrometer objective, the necessary wiring, a small LiPo battery, and an aluminum frame, the total weight of the first prototype (Figure 1b) of the system became 1.9–2.0 kg. Even with the extra photogrammetric camera, the setup is still about 30% lighter than the other available commercial solutions.

In acquisition, the DSP computer will control and synchronize all operation. The DSP will record the spectral images acquired by the internal CMOS camera at the maximum frame rate allowed by the exposure time and the micro-SD card write speed. The DSP also triggers the photogrammetric camera at a regular intervals and records the INS serial port messages containing the position and orientation data. The INS output operation is synchronized to both the spectral and photogrammetric camera exposures using trigger pulse signals.

The major challenge in the installation on an UAV is the length of the spectrometer assembly. The spectrometer assembly is approximately 35 cm long, forcing it to be installed on front of the UAV instead of under it. This produces a challenge with the center of balance, which we solved by replacing the UAV flight battery on a boom on the opposite side.

At the time of the abstract submission, the final performance specifications are yet not validated. However the expected specifications are:

- spatial resolution of at least 220 distinct objects per line,
- spectral resolution 9 nm,
- spectral range from 400–1000 nm,
- spectrometer frame rate at least 30 lines per second,
- photogrammetric camera raw frame rate 0.7 fps

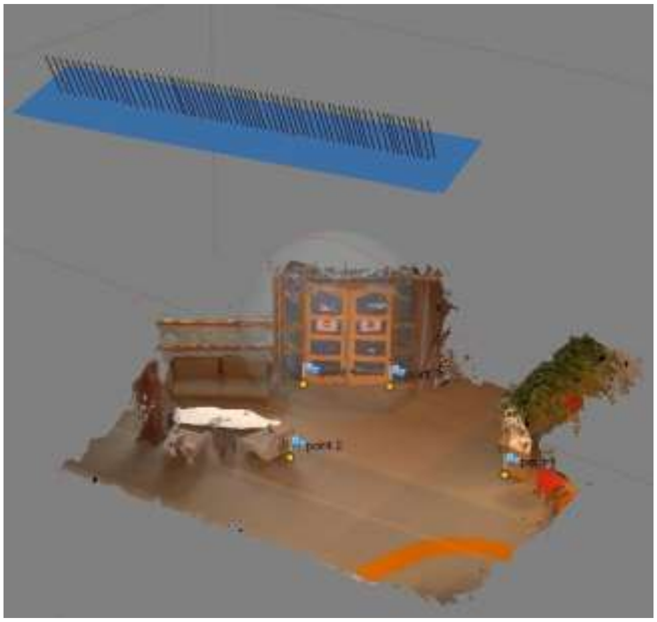
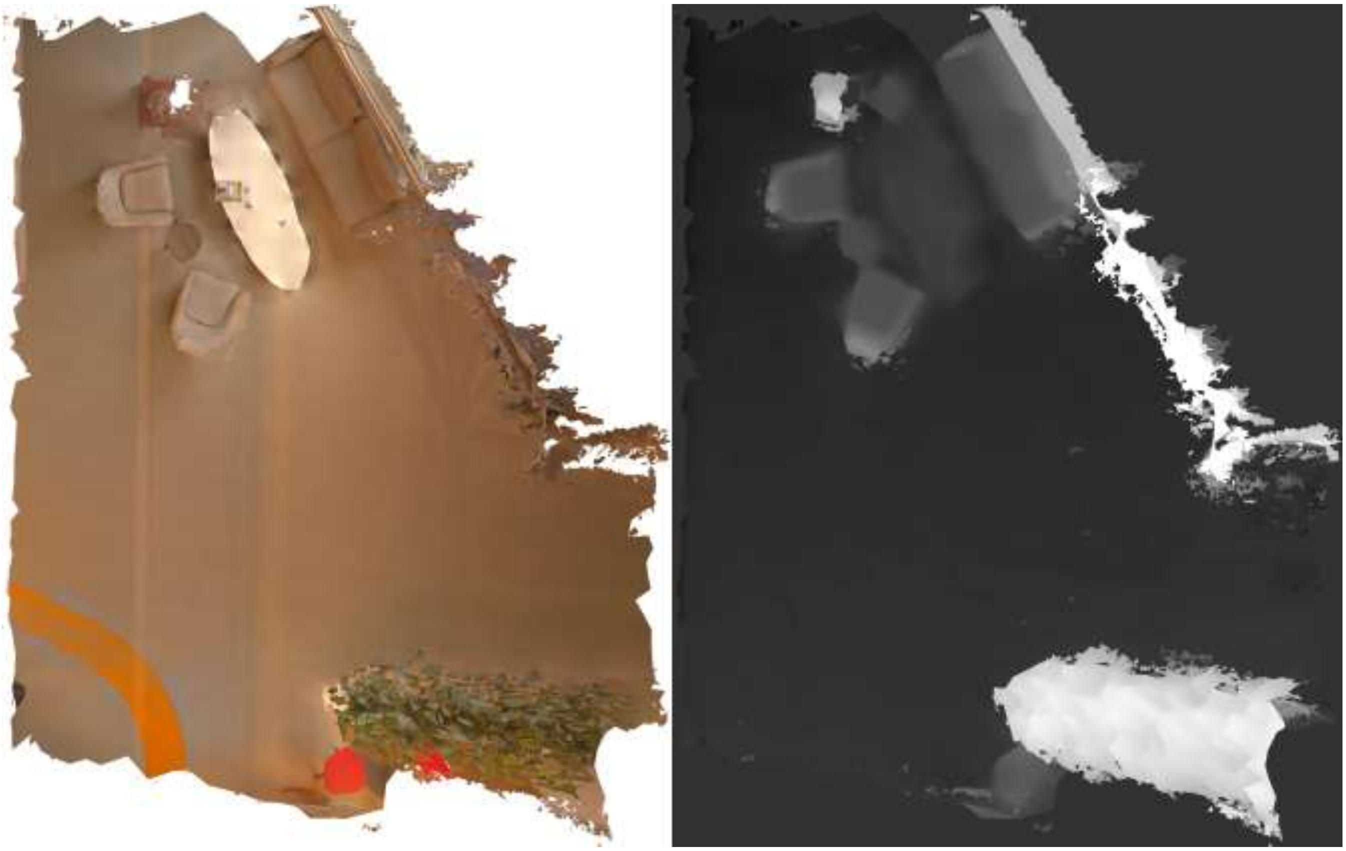


Figure 2. 3D model view (Agisoft PhotoScan Pro) of the indoor test area. The rectangles on top of the image mark the positions and orientations of the Panasonic GX1 images.



Figures 3a and 3b. An orthomosaic and a DSM created from the Panasonic GX1 images using photogrammetric methods (Agisoft PhotoScan Pro).

3. DATA PROCESSING CHAIN

A number of processing steps are required to convert the raw spectrometer, INS, and aerial image data into the desired output products such as a geo-rectified hyperspectral reflectance factor data cube, DSM, and RGB reflectance factor orthomosaic.

First of all, the raw airborne photogrammetric images are converted to 16-bit reflectance factor images using an empirical line method, a reflectance reference target, and a relative radiometric calibration. The reflectance factor images paired with INS data are then imported in photogrammetric software – *Agisoft PhotoScan Pro*. The software is used to further align the images photogrammetrically (with assist of RTK GPS ground control points), to calculate the DSM geometry (Figures 2 and 3), and to calculate a RGB reflectance factor orthomosaic.

Next, using the photogrammetrically enhanced image positions, the INS data is corrected for systematic bias errors, improving the alignment accuracy of hyperspectral lines. Once again, using an empirical line correction the raw hyperspectral data cube is converted to reflectance factor units. The reflectance factor data cube, with enhanced INS data, and the photogrammetric DSM is then input to *ReSe PARGE* georectification program [3], producing a georectified reflectance factor data cube. As both the hyperspectral observations and DSM are based on the same flight line and INS data, the geometric accuracy of the hyperspectral pixel projection is expected to be very accurate.

4. THE FIRST TEST RESULTS

For the first acquisition tests, the system was mounted on a cart and a simulated flight was performed in the hall of Gaia building of Wageningen University. The cart was pushed on a catwalk overlooking the entrance area from approximately 8-meter altitude (Figure 2). Over a distance of approximately 8 meters the cart was stopped every 10–15 cm to collect a spectral line and a photogrammetric image, collecting in total 68 lines. To bring the observations to the correct scale and orientation, relative positions of four ground control points were measured on the target area.

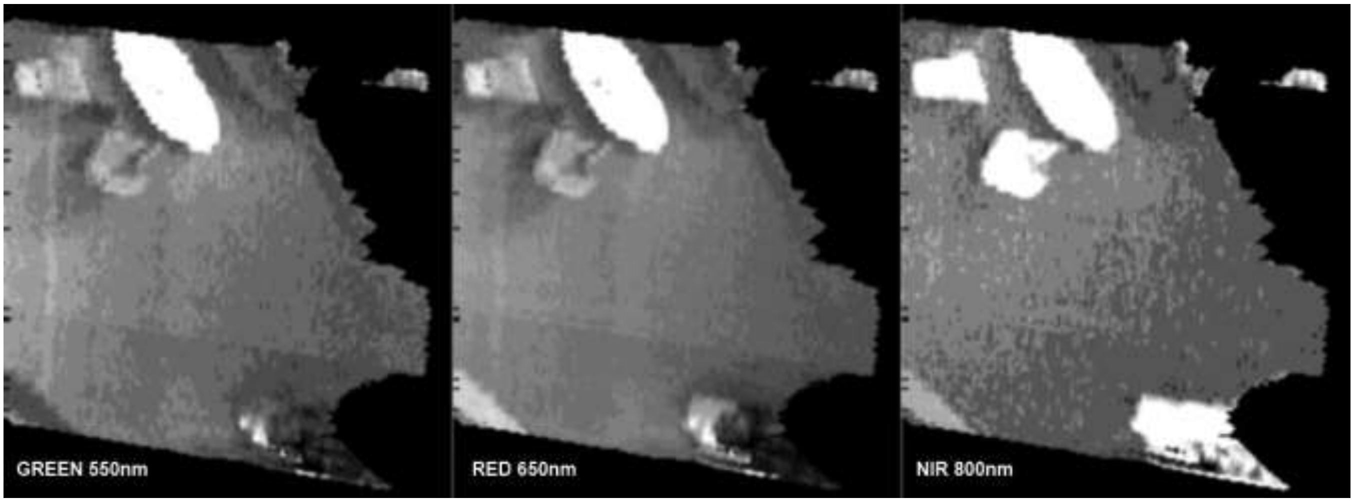


Figure 4. Single color channel extracts from a georectified reflectance factor spectral datacube. The indoor plants at the bottom right corner and the cotton chairs on the top, show a clear brightening on near-infra-red.

In processing, the system position and heading was based solely on the photogrammetric image positions, because the test was performed inside without reliable GPS or compass data. Other than that, the photogrammetric images were processed as described earlier, producing a orthomosaic and a DSM of the target area (Figure 3). The raw hyperspectral data cube was converted to pseudo-reflectance factors using a white reference panel in the image area. The lines were paired with the photogrammetric alignment data and processed in *PARGE* to produce a georectified hyperspectral data cube (Figure 4).

5. CONCLUSIONS

A prototype of a lightweight hyperspectral mapping system has been created by exploiting an integrated industrial DSP camera. To our knowledge, this is the first remote sensing spectrometer setup using a DSP as the onboard computer.

The presented setup and processing chain also exploits a cutting-edge combination of photogrammetric camera and INS allowing georectification and georeferencing of the hyperspectral data cube with a geometrical accuracy higher than would be possible using traditional GPS-INS alignment and external DSMs.

During the spring 2013 we will continue running calibrations and tests on the system. The system will be fully operational in summer 2013 when it will be used in a number of precision agriculture, soil erosion, and environment monitoring studies.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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