An integrated camera system for effective acquisition, capturing and transmission of hyperspectral data

Julius Tschannerl*, Jinchang Ren*, David McKee† and Stephen Marshall*
*Center for Signal and Image Processing University of Strathclyde, 16 Richmond St, Glasgow G1 1XQ, UK
†Department of Physics, University of Strathclyde, 16 Richmond St, Glasgow G1 1XQ, UK

I. Introduction

The rapid development of hyperspectral imaging (HSI) camera systems leads to ever smaller and more lightweight devices. Integrated solutions for acquiring, capturing and transmitting the data however are rarely available off-the-shelf. Most HSI systems come with additional capturing software that needs to be operated on a Laptop or Desktop PC externally and therefore often limits the system to stationary operation or mobile vehicles that can carry a lot of weight. On the other hand, existing integrated mobile HSI solutions are often very application dependent and costly.

While most recent inventions of low cost HSI systems focus on the development of the sensor [1], [2], our focus lies on the recording hardware. We propose a prototypical multi-purpose mobile HSI camera system that can acquire, capture and transmit hyperspectral data with a focus on flexibility, mobility, low cost and ease of access.

II. Architecture

The proposed system comprises of a visible spectrum pushbroom camera covering a range from about 400 - 760 nm with a GigE interface. As a recording tool, the Single Board Computer UDOO Quad running a Linux distribution has been chosen as it provides a gigabit ethernet interface and sufficient computational performance. Detailed specifications can be looked up in [3]. As a consumer device, it is also easily available and of very low cost. A C++ command line application was implemented on the UDOO that controls the camera and records the HSI data. The HSI data is stored in the ENVI specified file format onto internal storage. The device is remotely controllable via the UDOO's WiFi interface and the data can either be retrieved over WiFi or directly from the storage. Figure 1 illustrates the architecture. The application also allows to set various camera parameters that regulate exposure and integration time as well as data transmission preferences. The recording process of the device can be triggered and runs without any further input to allow remote usage to allow maximum mobility.

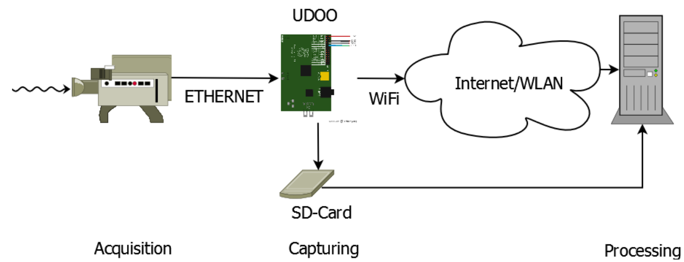

Fig. 1. Architectuer of HSI system

III. Radiometric validation

To validate the recorded data, different colour tiles have been imaged with the UDOO system and the SpectraSENS (SS) software provided by Gilden Photonics for the specified camera as a ground truth. The mean spectrum of a selected area in the images has been calculated and a visual spectral comparison can be seen in Figure 2.

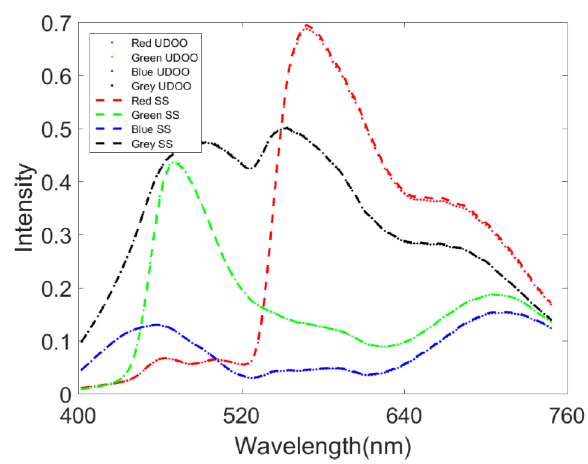

Fig. 2. Spectral comparison of recorded data

IV. Radiometric calibration

To compensate for variations in the lighting and reduce the amount of noise in the images in a controlled environment, a white reference image $\mathbf{W}$ and a dark current image $\mathbf{D}$ are imaged. Equation 1, as derived from [4], can be used to calibrate the recorded frames and results in the so called percent reflectance.

$$\hat{\mathbf{I}}_k = \frac{\mathbf{I}_k - \mathbf{D}}{\mathbf{W} - \mathbf{D}} \cdot 100\% \tag{1}$$

$$\mathbf{W} = \frac{1}{l}\sum_{k=1}^{l}\mathbf{W}_k \quad (2)$$

$$\mathbf{D} = \frac{1}{l}\sum_{k=1}^{l}\mathbf{D}_k \quad (3)$$

In pushbroom scanning, each captured frame represents a single spatial line in one dimension and each pixel's spectrum in the other. $\mathbf{I}_k$ is one such line image and $\mathbf{W}$ and $\mathbf{D}$ are acquired by imaging l lines $\mathbf{W}_k$ and $\mathbf{D}_k$ of a white reference and a dark image respectively and calculating the mean as shown in Equations 2 and 3. The white reference is achieved by e.g. imaging a spectralon plaque which exposes nearly lambertian scattering and the dark image is acquired by not exposing the camera sensor to any light. It should be noted that the above method retains the spatial information of one scanned line and therefore compensates for variations in the lighting along that line. It is believed that most systems use this approach already, but it has not yet been formalised.

This approach is only applicable for imaging in a controlled environment. For remote sensing data acquisition, different calibration techniques have to be employed and additional atmospheric effects need to be considered [2], [5].

V. Evaluation

To further evaluate the proposed system, a qualitative assessment of the recording with the UDOO process compared to that with the SS software was made. Table I details some major differences. Particularly interesting here is the increased framerate achieved with the UDOO, which is most likely due to a limit on the transfer rate in SS and possibly software binning. Binning is the technique of adding adjacent pixel charges to form an image with reduced pixel resolution and thereby induce higher light sensitivity, higher Signal-to-Noise ratio and a shortened integration time. As opposed to SS, the UDOO application can define different binning levels for the spectral and spatial domain. This can be desirable, as the spectral resolution of the spectrograph is much lower than the maximum pixels provided by the camera's sensor in the spectral domain. Operating the camera with no spectral binning usually results in redundant information. Reducing the amount of data is very advantageous for transmission but also for subsequent processing. On the other hand, retaining high spatial resolution can very well be desired. Treating these two separately enables the UDOO application to a much more efficient recording process.

The drawback of the UDOO however is the lack of preview capability and an aggravated handling by command line. SS comes with a Graphical User Interface and has an integrated function for radiometric calibration, which needs to be performed manually when capturing with the UDOO. During the testing period, a small amount of lost frames could also be measured on the UDOO, but this can be compensated for by interpolation and poses no major problem.

TABLE I
Comparison between recording performances

Feature	UDOO	SpectraSENS
Frame Rate	< 47 fps	< 115 fps
Calibration	Manual	Built-in
Control	GUI	CMD
Preview	Waterfall	-
Mobility	Stationary	Remote controlled
Binning	spatial = spectral	variable
Acquisition	Lossless	$\sim 0.3\%$ loss

VI. Conclusion and future work

The proposed HSI system poses a valid prototypical multi purpose imaging system for mobile and stationary data acquisition. It's radiometric correctness has been proven. The focus was laid on the recording hardware, as this particular aspect has not yet been very well developed yet. Due to the generic nature of the GigE interface, the application can potentially be used with many other cameras, either high end HSI cameras or specifically low cost built cameras. The lightweight nature and dynamic usage make the system particularly interesting for mobile applications. Additional testing for the mobile usage has to be done, but a proof of concept and the capability of a Single Board Computer to record HSI data have been given. Further work needs to be put into easing the usability of the recording software. Interesting would also be to explore data processing capabilities of the recording device to perform onsite feature extraction and decrease the transmission rate [6], [7]. The point of this work was to proof the possibility of consumer grade HSI systems on a small scale, which has been successfully shown and displays potential for future extension.

References

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