ULPGC
Universidad de Las Palmas de Gran Canaria

Instituto Universitario de Microelectrónica Aplicada

IUMA

Master's Degree in Applied Electronics and Telecommunications

IUMA

Master's final dissertation

Design of a system for obtaining a white reference in real time under variable light conditions and its validation in a drone capable of acquiring hyperspectral images

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Las Palmas de Gran Canaria. September 2021

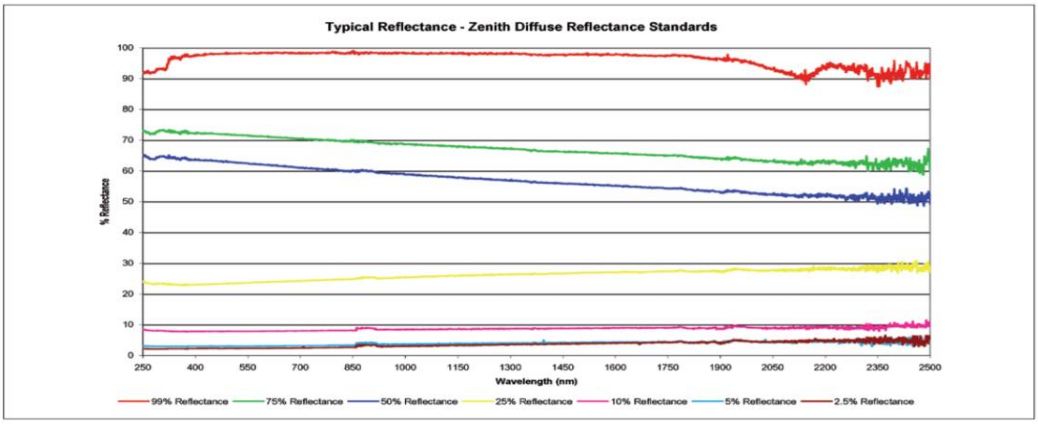
1. Summary

Images captured by a hyperspectral camera have "raw" data (.raw). This is a digital image file format that contains all of the image data as captured by the camera's digital sensor. [27]

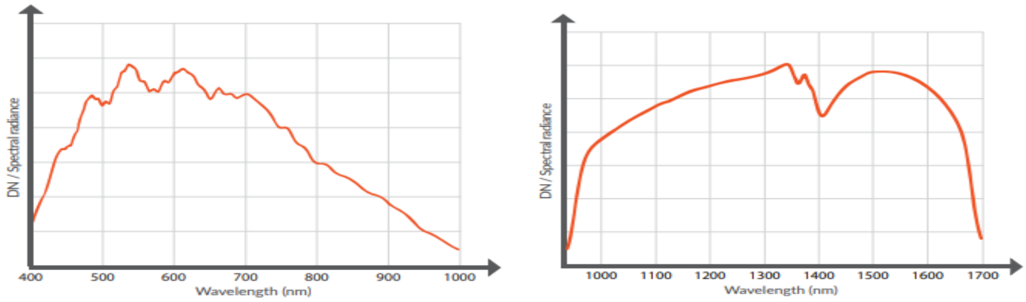
In order to extract useful information from them, either for target detection, classification, etc., the normal thing is to convert the data to reflectance or absorptivity. Reflectivity or reflectance is the fraction of incident radiation reflected by a surface or object and absorptivity is the exact opposite, the fraction of radiation absorbed by a surface or object. This Master's Final Project focuses on the measurement of reflectance to obtain spectral signatures. In order to obtain the reflectance of objects with hyperspectral cameras, they must be calibrated correctly.

In a laboratory setting, where environmental conditions can be controlled, a black and white reference is captured at the beginning and end of the process, keeping the light constant at all times. Once the camera's capture conditions have been configured (exposure time, light intensity, etc.), a scan is carried out on a calibrated material to reflect a high percentage of incident light or also called white reference.

To do this, the cameras are positioned pointing at this target reference. As mentioned above, it is a calibrated material that can reflect almost 100% of the light or different percentages depending on the type of percentage calibration that you want to perform. In this this Master's Final Project we work with the white reference of the Zenith Polymer brand, which is capable of reflecting almost 100% of the incident light between wavelengths from 400 to 1750 nm as shown in the following illustration the Red line being the one available to the IUMA in its laboratories.



Once the camera has been placed aiming at the target reference, a capture of it is obtained, this process is known as obtaining the white reference, (WR in its acronym in English). This capture contains the maximum values that the sensor is capable of measuring for each pixel and for each band according to the configuration adopted (exposure time, light intensity, etc.), the result is a spectral signature of almost 100% of the light reflected at between 400 and 1900 nm according to the red line in the illustration above. In the case of the cameras available at the IUMA, the wavelengths will capture between 400 - 1000 nm for the Specim FX10 camera and between 900 and 1700 nm for the Specim FX17 camera. Each camera has a different spectral response to the same target reference or a specific object. In Illustration 5, the capture of the white reference has been made with very specific cameras to accurately determine the reflected percentage. The spectral response of the cameras available at the IUMA to the white reference is shown below, where it can be observed that they have different responses depending on the wavelength.



After this process of capturing the reflectance of the white reference, the light source is turned off or the camera lens is covered, and a new capture is taken. This is often referred to as getting the black reference, (DR), and contains the minimum values that the system can provide for each pixel and band. Ideally, DR values should be very close to zero, however higher values can usually be obtained due to intrinsic sensor noise.

Once these two measurements of the hyperspectral camera have been taken, the scenes captured later, as for example in a field work on agricultural land, are corrected by applying the following formula:

$$reflectancia = \frac{raw - darkRef}{whiteRef - darkRef}$$

Each hyperspectral camera is made up of light sensors and optical elements such as lenses and defractors that focus or separate light at different wavelengths. These components of each camera differ between the different types of models and brands that exist. Additionally, each camera can have different memory types, buffers, and memory processes. All these small differences between these devices mean that the raw ".raw" data can differ extremely in a capture of a certain object or area between the different types of cameras available on the market. This means that when applying the previous formula, a scaled percentage reflectance value is obtained with which a global reference system is achieved and the measurement conditions are isolated when capturing with different cameras or different environmental conditions.

In conclusion, the value obtained in the formula of Equation 1 is the real reflectance value of each captured object or surface. If the described calibration process is applied with different cameras or environmental conditions, the value should be the same or very close.

In the case of drones or in any field work, environmental conditions are constantly changing causing the target reference to vary depending on the weather, the time zone or even atmospheric absorption. The sun is the main source of electromagnetic energy or EMR that receives the earth and constantly bombards with these EMRs but before reaching the earth's surface it has to pass through the atmosphere. The atmosphere protects us from high energy radiation such as X-Rays or Gamma Rays. The radiation that passes through the atmosphere interacts with the molecules and particles that make it up. In the atmosphere, EMRs are reflected or absorbed and a portion passes through it until it reaches the surface.

A portion of the radiation is absorbed by gases present in the atmosphere. These gases absorb certain wavelengths, therefore, in certain parts of the visible spectrum very little energy is absorbed, however in the part of the spectrum that corresponds to ultraviolet, almost all the incoming energy is absorbed. These portions of the spectrum that are absorbed by atmospheric gases are known as absorption bands. The main gases involved in atmospheric absorption are:

- Water vapor (H2O): absorbs a lot of radiation in the 5500nm - 7000nm range and above 2700nm. It must be taken into account that water vapor is not constant in time or in the space it occupies. This means that the absorption by this gas depends on the location and the time of year.
- Carbon dioxide (CO2): It absorbs mainly the thermal infrared of the spectrum.
- Ozone (O3): Absorbs high energy ultraviolet rays. It is very important since it protects us from the damage of this radiation and the main cause of skin cancer.

To solve the problem of field work, it is proposed to configure a system that allows environmental conditions such as: light intensity, temperature and / or humidity to be measured simultaneously; and capture a white reference with those environmental conditions. Carrying out these measurements a large database is generated that relates light intensity and environmental conditions to a specific white reference in real time.

Using optimization systems (regression) it is intended to determine which is the best target reference for the environmental conditions that exist at the time of the flight. Applying this possible solution, several advantages are obtained:

- Accuracy in obtaining information thanks to hyperspectral technology.
- Comfort and adaptability. Being able to have a reflectance value in real time does not force the drone to land to take a reflectance value again in case the environmental conditions change during the flight. Thus the images can be calibrated in real time by passing the values captured by the hyperspectral camera that are raw ".raw" directly to reflectance.

All this process is executed by a Jetson Xavier NX board. This acts as a controller for the DJI Matrice 600 drone and has the ability to control hyperspectral cameras thanks to its integrated operating system. The light intensity, humidity and temperature sensors will be controlled with an Arduino Nano board that transmits the information via serial port to the Jetson Xavier NX board.

In total, the devices to study, develop to be implemented later in the drone would be:

- FX10 or FX17 hyperspectral camera
- Light sensor BH1750
- DHT11 temperature and humidity sensors
- RGB ELP USB camera
- Arduino Nano
- Jetson Xavier NX
- STS-VIS spectroradiometer. This is integrated into the proof of concept for study and comparison with the other sensors. Its use in drones is not planned due to its high cost.

Another problem to solve is the total weight of all the elements in a drone. Even for a high-capacity drone like the DJI Matrice 600 it can be a problem. The objective is to be able t transfer this study to lower-end drones in order to cut the costs of the entire system.

2. Main objetives

In this Master's Thesis, from now on also referred to as TFM, the operational / partial objectives that are intended to be carried out are the following:

1. Set up a capture system that allows you to simultaneously measure environmental conditions and capture a target reference with the SPECIM FX10 hyperspectral camera under those conditions. All this work will also be adaptable to the SPECIM FX17 camera. To do this, the following methods will be studied:

a. Measuring only light intensity with the BH1750 sensor and also measuring light intensity in a few specific wavelength ranges. For this second part, the ELP RGB camera will be used that measures the intensity of light in the range of the spectrum corresponding to red (650 nm), green (550 nm) and blue (470 nm). These three colors are the composition of the color in terms of the intensity of the primary colors of light, that is, it is possible to represent a color by mixing by adding any of them. Adding all the above, there are 4 light intensity measurements useful for the study.

b. By way of study and comparison, using the STS-VIS Spectrometers panchromatic spectrometer that measures the intensity of light approximately equal in wavelengths between 350 and 800 nm with a number of bands between 300 and 75. It is configured to obtain results for the lengths waveforms that correspond to RGB. Captures of the environmental conditions are made to make the comparison with the other two sensors.

c. Measure environmental conditions such as relative humidity and temperature with the DHT11 sensor.

2. Develop a database by capturing with the system described in subsections a, b and c to create a data set with which to test. The purpose of this database is to be able to relate a white reference to specific environmental conditions and a specific gain and exposure time settings for the ELP RGB sensor and the hyperspectral camera. Ideally, it will try to achieve different environmental conditions to generate a complete database that covers as many situations with different environmental conditions, except for days when the weather is extremely harsh, such as rain or strong wind. To develop the database, .json and .csv files will be used:

a. .Json file: This type of file stores objects and simple data structures in JSON format. This is a standard lightweight data exchange format, they are text-based, human-readable, and can be edited using a text editor.

b. .Csv file: CSV files are used to handle a large amount of data in table format, without entailing any additional computational cost. It facilitates the cleaning of the data and is compatible with the platform used for the regression study.

3. Once the database is obtained, carry out a regression study to automatically determine in real time the optimal white reference value according to the environmental conditions measured instantly by the sensors, in addition to knowing the most appropriate configuration for the sensors and that these cannot saturate or lose data by setting the exposure time, gain, light intensity, etc. to be able to develop a model that allows real-time calibration.

3. Conclusion

After having done what was specified in the previous objectives, a total of 35 050 captures were obtained. With them, a study has been made in which different linear correlation models have been tested to estimate the appropriate white reference according to the lighting conditions and environmental measurements with the different devices. Based on the results obtained, it has been concluded that the approach is adequate and is an efficient solution for the problem in question, although it is necessary to continue capturing data in order to generate a more robust model.