Implementation and Calibration Methodology of Multispectral Cameras for Smart Farming Applications

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***Abstract*—A smart farming system based on spectral technology uses the information obtained from the energy reflected by the crops in different wavelengths to calculate vegetation indices that indicate the composition of those crops. This allows to remotely detect the current status of the crops, allowing an early detection of dry crops, pests, etc. This project aims to develop on the one hand, an own multispectral camera, that meets the specific specifications required by a spectral-based system for smart farming applications and that offers the characteristics of modularity, adaptation and customization that the multispectral cameras on the market today lack. On the other hand, in this project, a methodology of calibration and characterization is developed allowing to quantitatively calculate the quality of the results obtained by the developed camera. Thus facilitating the choice of the components that are part of the final design of the camera in function of the relationship between economic cost and the benefits offered.** *Keywords: spectral imaging, remote sensing, smart farming, multispectral cameras, vegetation index, drone.*

I. Introduction

Smart farming is the study of techniques that seek to manage the farming fields based on the measurements obtained through the observation of the crops.

The bases of smart farming are the study and observation of both the land and the harvest. Observing and studying the land and the harvest has been done for centuries. This has been possible given the small dimensions that farming fields historically have had. The era of technological revolution in which we find ourselves, is allowing us to continue with these work of study of farming fields with much larger dimensions, as they currently are, and which, due to these characteristics, is impossible to realize manually by a small number of farmers [1]. The advances in smart farming are sustained thanks to the improvement of diverse technologies such as the global positioning system (GPS), the geographic information system (GIS), the miniaturization of computers and electronic components, the improvements in automation and control of systems as well as the improvement in telecommunications.

All of this allows the development of precision farming systems that are capable of gathering a greater amount of data, as well as a greater amount of information on spatial and temporal variations in agricultural production.

The spectral technology consists in taking advantage of electromagnetic radiation that reflects or absorbs all the bodies to obtain information about them. In general, all bodies absorb an amount of energy that they receive in the form of radiation, reflecting the rest of it. The spectral technology aims to identify the particularities of each material in its ability to absorb or reflect the radiation at different wavelengths. From this data it is possible to obtain physical-chemical information of the object that is being observed, this being the main benefit granted by this technology. Spectral technology allows not only to detect objects, but to identify their composition. Spectral technology is used to simplify the infrastructure needed to monitor a crop field, replacing large and expensive sensor networks with a single spectral sensor that, mounted on an unmanned acquisition platform, such as a drone, can obtain the information required for the decision-making and automation of the agriculture work. The study to obtain information on the composition of a farming field, and, therefore, information on the state of the land, the health of the crops, the dryness or the stress of the harvest or the existence of pests, is carried out through the calculation of vegetation indices [2].

An example is the Normalized Difference Vegetation Index, or NDVI. This index indicates the quantity, quality and development of the vegetation, and is obtained from the equation:

$$NDVI = \frac{NIR - Red}{NIR + Red} \qquad (1)$$

where NIR states for the Near Infra-Red wavelength (≈800nm) and Red states for the visible-red wavelength (≈670nm). As it can be seen in equation 1, the number of bands needed to calculate this particular vegetation index is small. Therefore, the amount of spectral information that the smart farming system must obtain is known. That is why a multispectral camera is enough for this particular application.

II. Multispectral camera development

A. Mechanical Design

The camera developed in this project aims to have a modular structure, which allows to easily modify its components, thus being able to adapt its characteristics to different applications, or introduce improvements to the system as necessary. The camera has a wheel in which the different bandpass filters are placed allowing the sensor to capture the spectral information at the required wavelengths. The movement of this wheel is carried out by a stepper motor controlled by a Arduino Nano. To know the position of the filter wheel at any times, a limit switch has been installed, consisting of a metal flap that closes an electrical circuit when the filter wheel reaches a certain position. The entire design of the camera structure has been made taking into account the limitations of being installed on board a drone, in terms of dimensions and weight.

B. *Electronic Design*

The main element is the processor, since it will be in charge of managing the entire capturing process, the movement of the wheel and the communication with the drone's flight processes. The Odroid monoprocessor board is the selected CPU, responsible for controlling all these aspects. To facilitate control of the stepper motor, an Arduino board has been used. Additionally, the system has a mobile network transceiver device. It connects to the Odroid board by USB and containing a SIM card, allows communications with the Odroid board through the mobile phone network. This is the methodology used for carrying out a direct communication with the developed system. Nevertheless, it is not necessary when performing automatic flight missions with the drone.

C. *Software Development*

For the control of the camera a software in C++ has been developed. This software initializes the camera sensor and communicates with the Arduino board through the serial port. In addition, the process reads from an XML file the settings relevant to the capture process, such as which filters should be used or the exposure time and gain to be set for each of them. This software controls the position of the filter wheel, the images capturing processes, the exposure times to be used etc. On the other hand, a software has been developed for the Arduino board, which receives messages from the Odroid board through the serial port and moves the motor to the required position. To integrate the capturing process of the multispectral camera with the flight control process of the drone, the shared memory space of the Linux operating systems has been used. In this way, the process has been configured so that it can be automatically controlled by the flight control process of the drone, being this the one that tells the camera when to start taking images and when to stop.

III. CALIBRATION METHODOLODY

The calibration of the spectral camera is an essential procedure in every capture process. The goal is to represent the amount of energy captured as a percentage relative to the amount of incident light in the photographed scene. Otherwise, it would be impossible to correctly interpret the values obtained due to differences in the spectral response of the acquisition systems as well as differences in lighting conditions. Prior to spectral sampling, it is necessary to previously perform a spectral calibration in order to know the maximum and minimum values that can be captured in the exact conditions in which the sampling process will be carried out. Once these values are measured it is possible to scale any value measured by the sensor between that maximum and minimum value, allowing to transform this values to a percentage of reflected energy at any wavelength.

Another important goal of the calibration is to ensure a proper exposure time to the camera that prevents overexposed or too dark photos from being captured. If the calibration is not carried out, it is possible that the captured images are saturated on very sunny days, losing information; or too dark on low light days, also supposing a loss of information. In the case of the camera with filter wheel designed in this project, this supposes an extra complexity due to the particularities that each filter adds. In general, the filters to be installed in the filter wheel are bandpass. Meaning that each filter has a bandwidth in which the pass of light is allowed centered in different wavelengths of the spectrum. Thus, a filter with a greater bandwidth will allow, irremediably, the passage of more energy. Therefore, the exposure time of the camera should decrease when it is captured with that filter to avoid that that amount of energy saturates the image. On the other hand, a filter with a narrow bandpass, allows the pass of very low amount of energy, obtaining darker images, forcing to use higher exposure times. In the same way, the amount of light absorbed and transmitted by each filter will also depend on the transmittance of each filter. This property is given as a percentage, and indicates what percentage of the light energy received by the filter, at a specific wavelength, is capable of passing through it. Additionally, the spectral response of the sensor also varies for different wavelengths.

All this means that each filter must have a different exposure time, which also varies with the environmental conditions at the time of capture. Therefore, given the particularities of the camera designed in this project, a C ++ program has been developed in charge of automating the entire calibration process, thus facilitating the use of the camera. The calibration methodology developed in this project consists of the following steps:

1. The program initializes the camera and checks that all connections are in the correct state.
2. The wheel is moved until the first filter is correctly placed.
3. A sweep of the exposure times is made, from the lowest one to the highest exposure time allowed by the camera.
4. With each exposure time, ten images are captured, from which the average brightness value in the grey scale image is calculated.
5. This mean value is compared to the target average value, specified prior to the calibration process.
6. Once the exposure time that ensures the value closest to the objective value time has been obtained, this exposure time is written in an XML file so it can be used in the posterior sampling process.
7. This process is repeated with every filter in the wheel.

Therefore, if the white reference, which theoretically reflects more energy than any other element, excites the sensor to a value close to the maximum but without

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IV. CHARACTERIZATION METHODOLOGY

The characterization is the process by which the performance and the quality of a system is quantified. That is, when characterizing a system or a tool, we are numerically assessing how well the system performs its tasks. This is very important given that it gives us information about how reliable the results we obtain from this system are. When a completely proprietary system is designed and developed, the characterization becomes twice as important. On the one hand, characterizing the different elements that make up the system, we can quantify its level of precision and accuracy, thus allowing us to compare different elements and choose the most suitable one according to the specifications pursued in the design. On the other hand, the characterization of the complete system allows quantifying how good the final result has been and the system as a whole.
To characterize the spectral camera, a special polymer with a certified spectral signature has been used. The polymer is used for measuring the accuracy of the camera when capturing it at different wavelengths. The error committed by the camera is calculated as the difference between the obtained spectral value measured by the camera and the certified one for each specific wavelength. The real value is obtained simply by using the developed camera to capture images of the polymer, obtaining the values in each wavelength. The average value of the pixels that make up the polymer in the image is the value used to compare with the theoretical reflectance value of the polymer at each wavelength. To calculate the theoretical value, it is necessary to take into account how the use of each filter affects the sampled value and how it modifies the value of the certified spectral signature. Each filter has different characteristics, being the wavelength in which the filter is centered, the bandwidth of the filter and its transmittance the most important ones.
The theoretical value that should be obtained is the calculated as shown in equation (2). This calculation takes into account the reflectance value of the polymer at each wavelength P_i, the transmittance value of the filter at each wavelength F_i and the maximum value that can be detected by the sensor to be characterized at each wavelength, obtained from the certified spectral signature of the white reference, WR_i.

$$T.V. = \frac{\sum_i F_i \cdot P_i}{\sum_i F_i \cdot WR_i} \qquad (2)$$

In this project, this characterization process has been carried out with four different CMOS sensors, thus obtaining the errors committed by each one. In this way, it is possible to numerically compare the performance of the sensors and thus select for the developed multispectral camera the one that best meets the necessary quality and cost requirements. Furthermore, the characterization process has been completely automated so it can be used for evaluating other multispectral devices in the future.

V. RESULTS

The first result of this work is the final product of the developed camera, which specifications can be seen in table 1.

TABLE I.

Dimensions (cm)	8,5 x 10 x 10
Weight (gr)	300
Spectral Resolution (wavelengths)	5
Spacial Resolution (px)	1280x1024

Final specifications of the developed multispectral camera.

The second result of this work is the result of the characterization, in which the different sensors are combined. The error obtained by each sensor can be seen in table 2.
The sensors used in the characterization are two belonging to cameras of the manufacturer ELP and two belonging to cameras of the manufacturer IDS. The sensors of the ELP cameras are the Sony IMX179 5-50mm [3] and the AR0130 1/3 [4] of ON Semiconductors. On the other hand, IDS brand sensors are the uEye 3360CP NIR [5] and the uEye 3240LE [6], both from the CMOSIS manufacturer.

TABLE II.

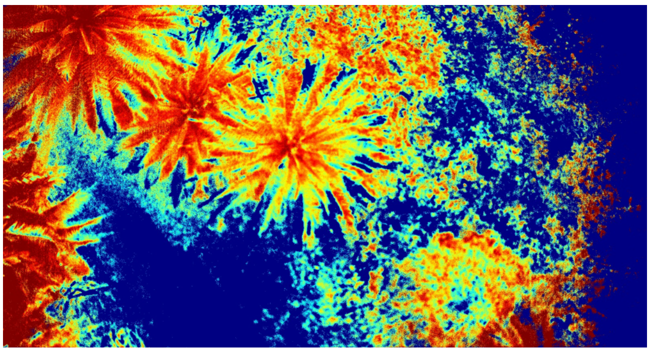
CMOS Sensor	Mean Error with each filter (reflectance)			
	475AF20	560BP20	670BP20	8075DF20
IMX179	-0.48	5,70	6,99	13,56
AR0130 1/3	0.61	2.37	5.98	5.04
3360CP NIR	0.63	-0.11	-1.59	0.90
3240LE	0.94	0.22	6.06	3.93

Error comparison of the four different CMOS sensors.

As it can be seen in table 2, the sensors of the IDS cameras offer the best results. In addition, it is observed that the error uniformly increases in all the sensors with the wavelength increment. This may be due to the loss of sensitivity of the CMOS sensors in that part of the electromagnetic spectrum.

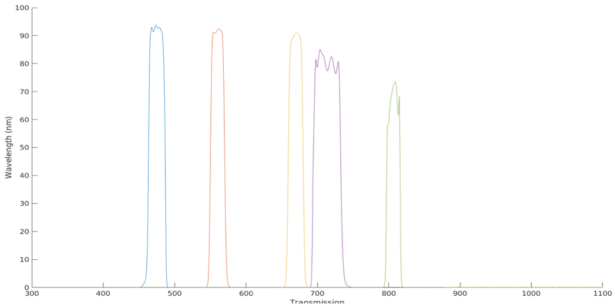
The third result obtained in this project are the images captured by the camera developed on board a drone, and the calculation of the NDVI vegetation index from these images. Figure 1

Figure 1. NDVI colourmap taken from a dron.



represents the calculated values of the NDVI index during a real flight. Values close to one are represented by the colour red, while lower values are represented by the colour blue. As it can be seen, the values obtained correctly spotlight the existing vegetation in the image, thus confirming the correct performance of the developed camera. The spectral response of the developed camera can be seen in figure 2.

Figure 2. Spectral response of the developed multispectral camera.



VI. CONCLUSSIONS

A multispectral camera for smart farming applications has been developed in this work. This camera is based on a filter wheel and has been specifically designed for being couple on-board unmanaged aerial vehicles. The developed device satisfies the necessities of the PLATINO project, including modularity, flexibility and possibility of integration into more complex systems. Additionally, an automated calibration methodology has been also developed for simplifying the use of the aforementioned camera in smart farming applications, as well as a characterization methodology that enables a quantitative analysis of the response of multispectral devices, including the developed one.

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