3D Printed Mechatronic Design for Multispectral Camera Mounting Adapter on UAVs

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Resumen

El uso de vehículos aéreos no tripulados o Unmanned Aerial Vehicles (UAV) es hoy en día necesario para el análisis de los cultivos, y principalmente para optimizar su rendimiento. En este trabajo de investigación se propone el diseño de un dispositivo mecatrónico de bajo costo que adapta una cámara multiespectral para la adquisición de imágenes en UAV. Adicionalmente, el diseño de un software para el alineamiento y procesamiento de las imágenes es implementado para el análisis e interpretación de los datos mediante una intefaz de usuario.

Palabras Clave: Diseño mecatrónico, UAVs, agricultura de precisión, análisis multiespectral, índices de vegetación.

Abstract

The use of Unmanned Aerial Vehicles (UAVs) in agriculture is nowadays necessary for crop analysis and manage optimization. In this research work, a mechatronic design of a multispectral (MS) camera mounting adapter is presented. This design integrates a MS Red-Edge camera in an UAV for image data acquisition towards decision making of precision agriculture applications. In addition, an image processing software is implemented for multispectral bands alignment, image analysis and interpretation of crop activities with a friendly human interface.

Keywords: Mechatronic design, UAVs, precision agriculture, multispectral analysis, vegetation index.

I. INTRODUCTION

Many countries are strongly attached to their agriculture sector, and their economy survival depends on their food production. In some parts of the world, the strange climate behavior or plant diseases could also affect the vegetation

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health, their growing velocity or their quality. For instance, Mexico is nowadays considered as the 12th food producer in the world knowing that the agriculture sector provides 4% of global Gross Domestic Product (GDP) and employs 13% of the economically active population (Country Economy, 2018), but it can suffer of their tropical climate, and it is sometimes difficult for farmers to forecast and detect these different issues (lack of water, burnt leaves, diseases, etc.). Because the multispectral cameras capabilities, it is now possible to determine the condition of the ground vegetation (Zhang et al., 2012), (Berni et al., 2009). Multispectral cameras are used in a variety of UAVs because their implementation is cheaper than satellite images and hyperspectral cameras (Sheng et al., 2010) (Huang et al., 2010). Besides UAV can be used in cloudy days and it is a good option for fast data acquisition (Torres et al., 2014). In (Hoel et al., 2016), a 3D-printed wideband waveguide and horn antenna embedded in a UAV wing is presented This design represents an interesting option form rapid prototyping another work presented in (Mosaddek et al., 2018); describe the feasibility at utilizing Polyethylene Terephthalate (PET) as printing filament for UAV design. In (Nebiker et al., 2016)], a study of new light-weight multispectral sensors for UAV is analyzed. These studies are oriented for the design of 3D printed structures for UAV applications.

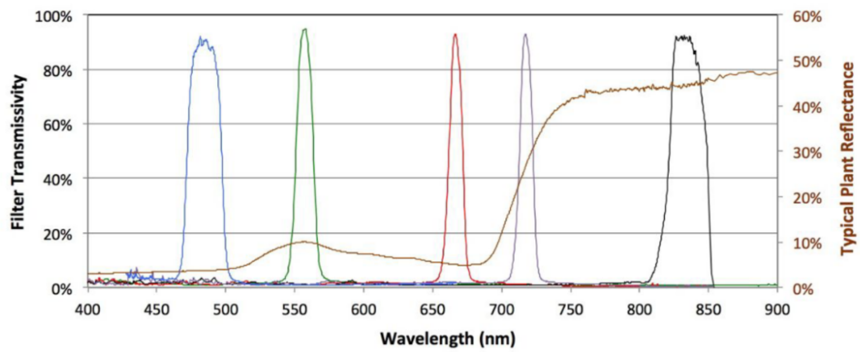
In this research work, a mechatronic design is proposed for adapting the Red-Edge multispectral camera with the commercial Phantom® 3 UAV. Experimental case studies show the integration of the device in the UAV with satisfactory results and the implementation of a software that demonstrates the data acquisition, bands alignment, and multispectral processing algorithms, such as the Normalized Difference Vegetation Index (NDVI) and Green Normalized Difference Vegetation Index (GNDVI).

The paper is organized as follows: Section II presents the background and a compilation of the Red-Edge multispectral camera characteristics. The 3D printed mechatronic design of the camera mounting adapter with the UAV is presented in Section III. The SW (Software) implementation for multispectral image analysis and interpretation is described in Section IV, and Section V presents the concluding remarks of this study.

II. MULTISPECTRAL CAMERA AND ITS MODULES

Multispectral cameras incorporate high performance CMOS sensors, which are able to simultaneously capture images at different bands at the frame rate of the camera. There is no need to use additional filters, filter wheels, or tunable filters in the optical path. All of the spectral information is captured simultaneously by the modified sensor. In this study, Micasense RedEdge multispectral camera is selected for its precision in smart farming applications. This camera is equipped with the visible bands Blue (475 nm center, 20 nm bandwidth), green (560 nm center, 20 nm bandwidth), and red (668 nm center, 10 nm bandwidth), but also with a near-ultraviolet red edge band (717 nm center, 10 nm bandwidth) and a near-IR band (840 nm center, 40 nm bandwidth), corresponding to the vegetation reflectance wavelengths as shown in Figure 1.

a)



b)

Figure 1 – RedEdge multispectral camera: a) RedEdge camera's modules, b) Camera spectral response (MicaSense, 2015)

With these five bands a number of analysis can be performed including NDVI and chlorophyll analysis. Compact and light with only 231.9 g (8.18 oz.), this camera is well-suited for a variety of agricultural applications where vegetation measurements are performed. RedEdge camera is also integrated with the Downwelling Light Sensor (DLS) and a Global Positioning System (GPS) as illustrated in Figure 2. DLS is used in conjunction with MicaSense's Calibrated Reflectance Panel (CRP) to enable improved reflectance calibrations in situations where ambient light conditions are changing in the middle of a flight. This light sensor is effective at correcting changes in lighting conditions, such as when the sky is completely overcast, and irradiance fluctuates during a flight.

To power the camera, a GAC-019 of *GHIA Volta* power bank is used. This power bank has a capacity of 2000 mAh and 5V/1A DC output. With this option, the UAV power supply output is not affected neither the flying time (about 30 minutes). A GPS module is also integrated with the mounting adapted mechatronic design. To properly geotag images, GPS data must be available to the camera. The GPS module is connected to the port of the camera with a 6-pin to 6-pin cable provided for this purpose.

Multispectral Camera	**RedEdge** (MicaSense, 2018)	**Parrot Sequoia+** (Parrot, 2018)	**PixelCam VIS+NIR** (PixelTeq, 2018)	**Buzzard** (Buzard. Cameras 2018)
Lenses	5	4	6	6
Focal Length (mm)	5.5	3.98	----	----
Image Sensor Size (mm)	4.8 × 3.6	4.8 × 3.6	----	6.9 × 5.5
Resolution (pixels)	1280×960	1280×960	1600×1200	1280×1024
Best resolution & height	medium	medium	high	medium
FOV (H^0 x V^0)(mm)	47.1×36.2	62.2×48.7	15.5×15.95	----
Spectral Range (nm)	465–860	530–810	400–1000	400–900
Bandwidth (nm)	10–40	10–40	-----	10–50
Weight (gr)	150	72	378	250
Size (cm)	12×7×5	6×4×3	0.525×0.525×0.794	8.65×6×5.4

Table 1 – Comparative analysis of multispectral cameras.

As shown in Table 1, RedEdge camera has five lenses with a good required image sensor size and resolution, but the Buzzard camera uses a larger image sensor size with the same resolution. The spectral response and bandwidth of RedEdge provides better than Sequoia with discrete narrowband information. Also, RedEdge has the benefit of generates high spatial resolution digital spectral images for precision agriculture applications (Jhan et al., 2016). Although Buzzard has a wider spectral resolution and Pixelcam has a better pixel resolution, the cost and the weight were important constrains for this selection.

III. MECHATRONIC DESIGN OF THE MOUNTING ADAPTER

A 3D printed prototype for the RedEdge mounting adapter is implemented with polylactic acid (PLA) polymer silicone resin. Figure 2 illustrates the design architecture of the system composed of three subsections: camera base, UAV mounting base and DLS, Power bank and GPS adapter.

Figure 2 – 3D printed mechatronic design.

A. Camera base

The idea of the camera base is to keep the roll and pitch balance of the multispectral camera with the UAV. The camera is positioned in the center of the UAV to maintain the vertical stability. Indeed, two X-shaped pieces are joined together by flexible rubber connectors that keep the camera axis to the ground, as shown in Figure 3. This design also helps to reduce vibrations due to accelerations or wind perturbations.

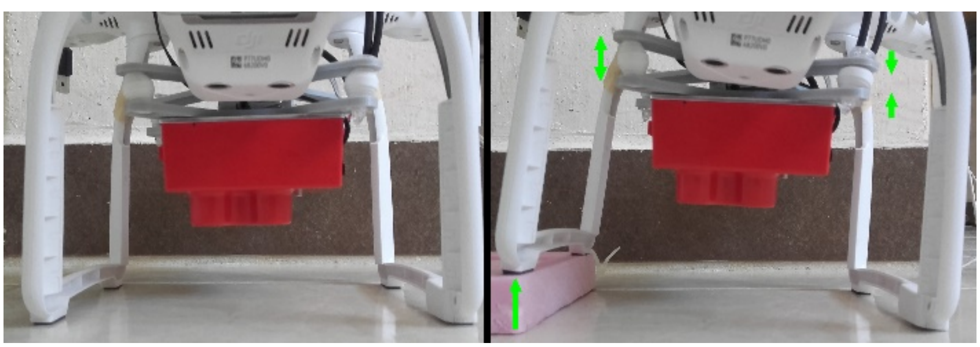


Figure 2 – Camera mounting base design.

B. UAV mounting base

The UAV mounting base gives support of the modules to the UAV. The design solution consists in two pieces which could be fixed on the cross-shaped, with standard bolts and nuts as shown in Figure 4. A space in the cross-shaped piece is provided allowing the nuts get stuck in, and in this way the bolts pass through the pieces holding them together.

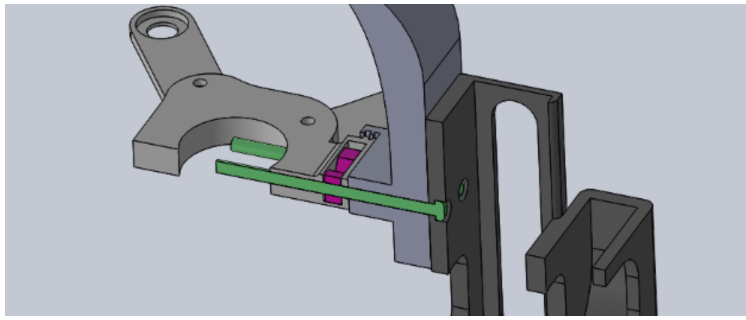


Figure 3 – Image showing the integration of the UAV mounting base.

The first section is curved and joins the top of the drone. Remark that DLS module should be in the top of the UAV measuring the irradiance, which is strongly dependent on the sensor's orientation relative to the sun as it flies. The curve fits the drone's shape, in which the trajectory is measured and replicated with the SolidWorks® design software.

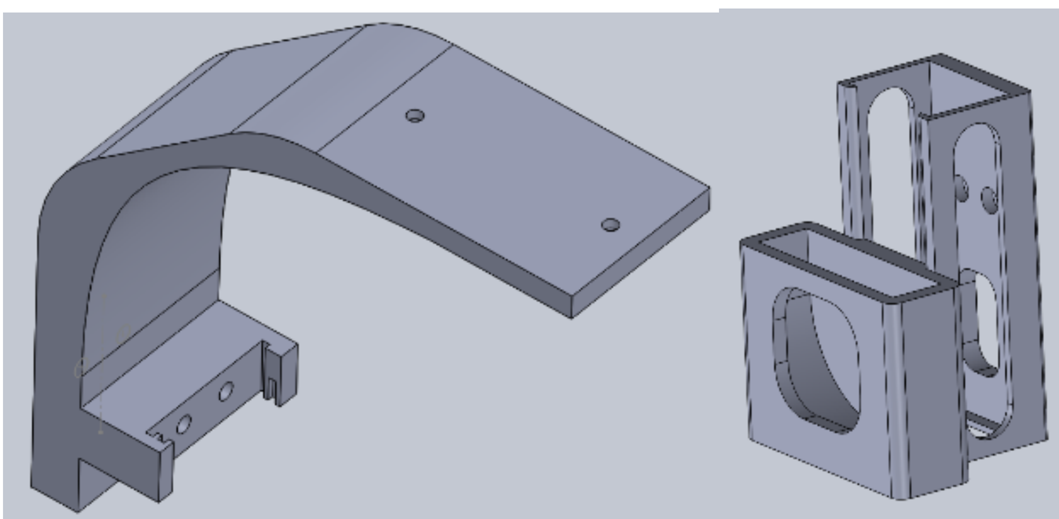


Figure 4 –DLS, power bank and the GPS adapter.

C. *DLS, Power bank and GPS adapter*

The DLS, Power bank and GPS adapter is designed as a fast-removable system. Another important requirement is related to the camera's GPS, because it must be placed horizontally on the top of the UAV. The challenge is the lack of space because the GPS could be struck by the drone's propellers, therefore it has been removed to place it vertically on the same side of the power bank as shown in Figure 5.

IV. MULTISPECTRAL ANALYSIS RESULTS AND DISCUSSION

A SW for multispectral analysis is implemented to compute four vegetation indexes, which are DVI, GDVI and their normalized version, NDVI and GNDVI. Once aligned the images for each band, the analysis and interpretation of the images is employed. The interpretation of the results is presented in a colour scale: the unhealthy level of vegetation is presented with red and the good level of vegetation with green. This multispectral camera of Micasense is equipped with a mini Wi-Fi USB stick which enabled us the image data acquisition with a server. The parameters are easily checked (angle, elevation, number of satellites detected, etc.), and the captured images are seen in streaming.

After data acquisition, the software stores the five images and the vegetations indexes are computed. NDVI measures the level of healthy vegetation in a crop. GNDVI is similar except that it measures the green spectrum instead of the red spectrum. The combination of its normalized difference formulation and the use of the highest absorption and reflectance regions of chlorophyll make it robust over a wide range of conditions as shown in Figure 6.

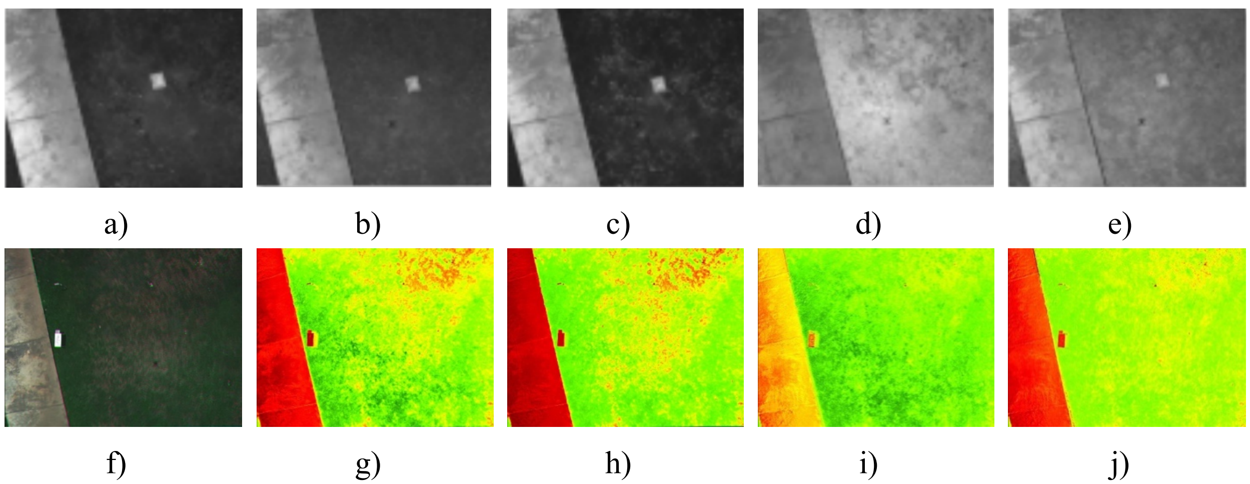


Figure 6 – Multispectral image processing results:

a) Input image Blue band (475nm), b) Input image Green band (560nm), c) Input image Red band (668nm), d) Input image RedEdge band (717nm), e) Input image Near-Infrared band (840nm), f) Output RGB image, g) Output DVI image, h) Output NDVI image, i) Output GDVI image, j) Output NGDVI image.

V. CONCLUSIONS

In this study, a new mechatronic prototype for adapting the Red-Edge multispectral camera with the commercial Phantom 3 UAV is proposed. The prototype is based on an inexpensive 3-D printing manufacturing process and has been tested with the UAV under multiple flight conditions. Experimental multispectral measurements of vegetation index, such as DVI, NDVI, GDVI and GNDVI, demonstrate that the SW toolbox is able to analyze the soil characteristics of the crops. The mechatronic design in combination with the SW platform represents a good technological solution system for precision agriculture applications.

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