A Low-Cost Six Band Multi-Spectral Camera Platform for In-Flight Near Real-Time Vegetation Index Computation and Delivery

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RESUMO

Ao longo dos últimos dez anos, o interesse no uso de Veículos Aéreos Não Tripulados (VANTs) para aplicações na agricultura tem crescido significativamente. Uma das áreas de maior interesse nesse campo é o monitoramento do crescimento e saúde das plantas, onde os VANTs podem ser utilizados em conjunto com câmeras multiespectrais, as quais excedem as capacidades das convencionais. Há alguns anos o custo de VANTs era muito alto, o que, juntamente com a necessidade de um operador especializado e elevado custo de manutenção tornavam sua aquisição inviável para a maioria dos agricultores. No entanto, o aumento do interesse em VANTs com uso recreacional possibilitou a redução destes custos, tornando este tipo de veículo uma ferramenta atraente e acessível para a inovação agrícola. Infelizmente, os equipamentos (e.g. câmeras multiespectrais) necessários para transformar VANTs recreativos em ferramentas de auxilio na agricultura não observaram tal redução de custos. Este trabalho apresenta um projeto que, usando principalmente materiais "de prateleira", visa criar uma câmera multiespectral de baixo custo, que além de funcionalidades similares às de câmeras comerciais, pode computar e transmitir índices de vegetação, durante o voo.

PALAVRAS-CHAVE: Câmera Multiespectral, Índice de Vegetação, Infravermelho

ABSTRACT

Over the last decade, the interest in using Unmanned Aerial Vehicles (UAVs) for agricultural applications has grown. One of the most appealing application, in this field, is plant and health growth monitoring, where UAVs can work in unison with multi-spectral cameras, exceeding the capabilities of conventional ones. Some years ago, UAVs were very expensive, which together with the need of a specialized operator and high maintenance costs made their acquisition not feasible for most agriculturists. The increased interest in recreational UAVs lowered those costs, making these type of vehicles an attractive and accessible tool for agricultural innovation. Unfortunately, the equipment (e.g. multispectral camera) required to turn recreational UAVs into agricultural auxiliary tools did not observe such a cost reduction. This paper presents a project, which mainly uses over-the-shelf materials to create a low-cost camera, which in addition to the features of current commercial cameras, can compute and deliver vegetation indexes during flight.

KEYWORDS: Multispectral Camera, Vegetation Index, Infrared

Introduction

Remote sensors have been used, for many years, as tools for acquiring valuable information. As time goes by, sensing is done with higher precision, thus, increasing the volume of the acquired data. Moreover, such precision enables tackling even the most diverse problems each day. A few examples of these uses are: vegetation management (MORAN; INOUE, 1997), forestry , land use (VOGELMANN et al., 2001), and planning (VOGELMANN et al., 2001). Agriculture is no different, having key characteristics being identified (BASTIAANSSEN; MOLDEN; MAKIN, 2000; GITELSON, 2016), managing and preventing plant diseases (RAJI et al., 2016), infestation observation (NANSEN; ELLIOTT, 2016), and water stress (TILLING et al., 2007), among other uses. Perhaps the single most valued statistic is yield estimation (SHANAHAN et al., 2001). These are just a few examples of a multitude of possible uses enabled by remote sensing.

One way to contain plant diseases is by monitoring their health throughout its growing cycle and identifying deficits or problems at their earliest stages. This can heavily influence the need to use agrotoxics, fertilizers and even reduce the amount of irrigation.

Governmental institutes can rely on data acquired from satellites, which sometimes has low resolution and long date intervals, for studies such as ecosystem changes. On the other hand, agriculturist require data with high resolution and low date intervals in order to take prompt action and maintain their crops safe. Moreover, many visible signs are only presented when a disease is greatly spread, therefore it is better to use multispectral images, which help to identify some of these diseases before visual signals appear. Consequently, this lack of readily available data has drawn attention towards Unnamed Areal Vehicles (UAV) equipped with multispectral cameras.

Together with the growing interest of the general public towards using UAV as recreational devices, UAV prices have been drastically dropping, easier control have been implemented, and are now becoming easier to obtain. Unfortunately the same has not been true for multispectral cameras. A popular UAV-quad-copter can cost upwards of $R\$3.000$, such as the

DJI Phantom 3 (DJI, 2017b), and a higher end model such as the DJI Inspire 2 (DJI, 2017a) can cost around $R\$15.000$. Meanwhile, a multispectral camera such as the Tetracam uMCA 6 Snap (TETRACAM, 2017) is around $R\$79.000$, and the Tetracam MCAW 6 (TETRACAM, 2017) will cost $R\$89.700$, a hefty price to be put on a craft with a high risk of falling out of the skies.

As most regular cameras have recently seen price drops, the idea of creating a cost-viable multispectral camera based on regular cameras comes to mind. By applying specific filters to high-end quality photography cameras, the authors in (DEAN; WARNER; MCGRAW, 2000) and (SAKAMOTO et al., 2011) were able to capture infrared bands and produce good quality sensed data. The main goal of the project is to create, with an even lower price, a near-commercial quality multispectral camera using mostly low cost off-the-shelf materials available nationally. This paper presents the first results obtained with a prototype of a six band multispectral camera platform. Results show that even though the selected commercial cameras were designed for normal RGB photography, they were able to successfully generate images after being filtered to a narrow band. Additionally, the presented six band multispectral camera platform, built with parts that cost 7.14% of the price of a commercial multispectral camera, was able to capture information that allowed the generation of indexes with distinguishable values for the different types of tested vegetation.

Materials & Methods

The six band multispectral camera platform presented in this paper, was developed within a multi-prototype road-map which began with the creation of a four band multispectral camera platform. Some four band multispectral camera prototypes were tested and the one with the best results, regarding capability to capture infrared ranges, was presented in (MENDONCA et al., 2017). The prototype presented in this paper is drawn up in two distinct parts, i.e. hardware and software, improvements and/or implementations, which are detailed in this section.

Hardware

Regarding hardware, the six band multispectral camera platform is basically an extension of our four band multispectral camera platform presented in (MENDONCA et al., 2017). This prototype incorporates: 1) Four identical cameras; 2) Three narrow band filters (inside the cameras); 3) A Single Board Processing Unit (SBPU); 4) A connections-unifying PCB; 5) Project-specific designed WiFi antenna; 6) A high capacity Battery; And 7) An enclosing 3D-printed box. The components are mounted as depicted in Figure 1 and detailed thereafter.

Cameras with wide lens were used to increase the captured area in a single image, such cameras are high speed shooting capable, which allow the UAV to transit at higher rates while capturing the images. Moreover, three of the cameras had their infrared blocking filters replaced by narrow band filters and the four cameras were hardwired in order to be controlled by the single board computer.

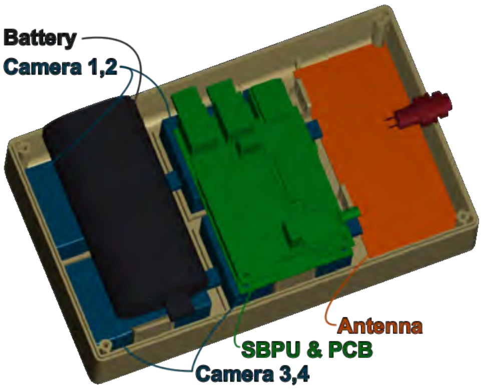


Figure 1: 3D View of the proposed multispectral camera.

Filters were added to narrow the sensed bands. The infrared blocking filter of three of the cameras were replaced by band pass filters to select the desired region of the spectrum. The response of the camera sensor, as presented by the manual (APTINA IMAGING, 2010), was taken into consideration when choosing the desired bands. The center wavelength of the chosen filters correspond to: 1) 675 ± 25nm; 2) 725 ± 25nm; And 3) 850 ± 25nm. A rough spectral response of the cameras with the tree filters can be seen in Figure 2.

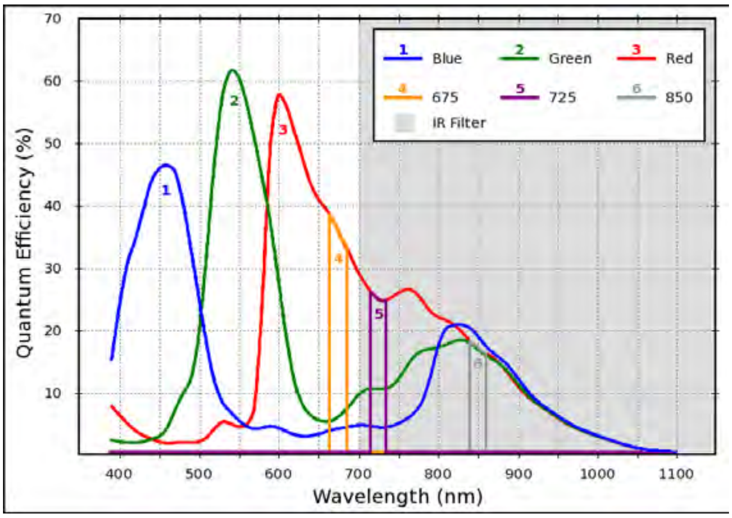


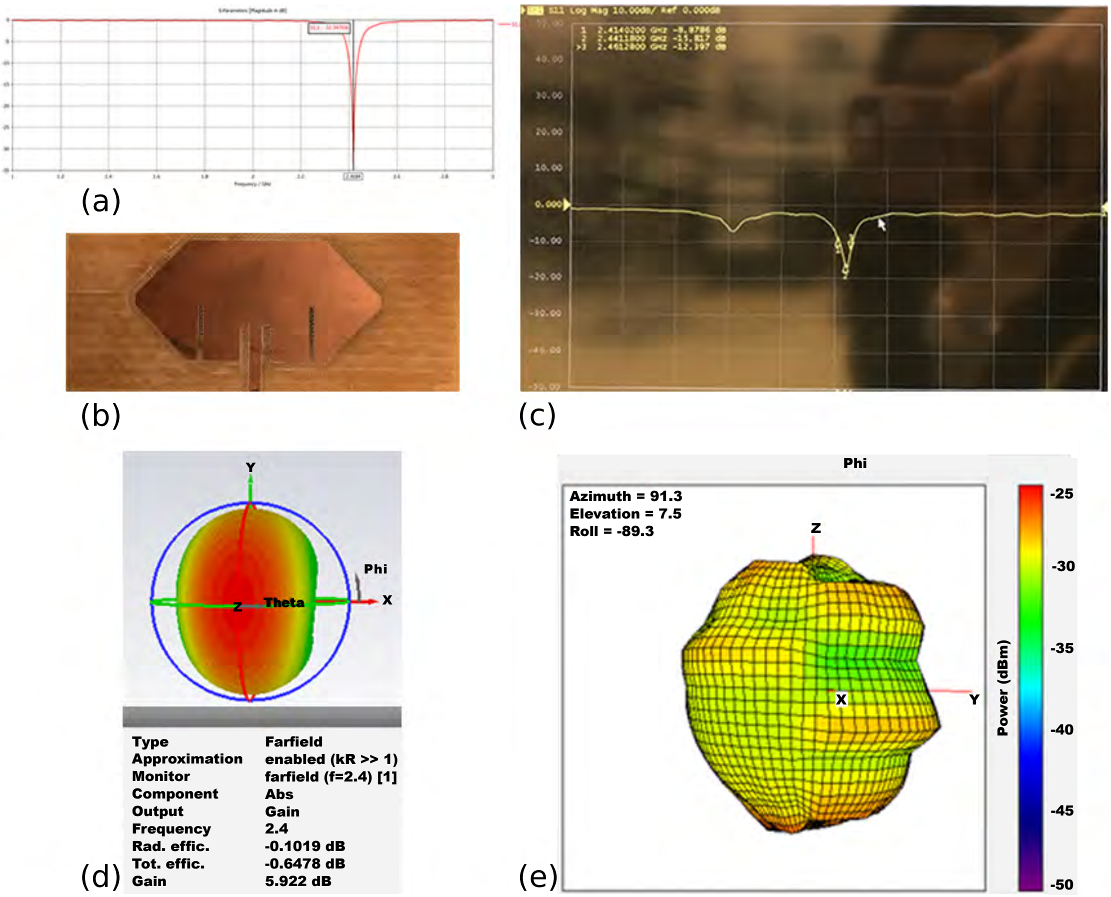
Figure 2: Expected Camera's Spectral Response.

Since the main purpose of the camera is agriculture mapping and anomaly detection, specifically the area around the vegetation slope (HUETE, 1988) within the near-infrared band was considered. The chosen values represent the narrow end of the red spectrum, the middle of the vegetation slope, and the top of the slope. These three bands are used to distinguish different plantations apart and are exceptional in displaying plant stress, as well as other characteristics.

A **Single Board Processing Unit (SBPU)** controls everything within the multispectral camera. With the cameras being electronically controlled, the SBPU was installed to allow varied functionalities to be programed into it, and have the cameras behave in unison. The SBPU capable of outputting simple controls signals has complete control over the cameras, allowing it to command the cameras as needed. The four cameras are commanded to shoot simultaneously and to transfer the captured images to the SBPU for processing. Also implemented within the SBPU are the protocols that turn it into an access point, making it possible for other devices, that are WiFi compatible to connect to it in order to access the generated vegetation indexes.

The **Unifying Printed Circuit Board (PCB)** simplified all the connections within the camera by having a central point of connection. All components that needed control or that gave commands were connected to this PCB. It simplified energy distribution, command connections, and data lines. The PCB was designed and printed internally specifically for the project.

A **Specific WiFi Antenna** was created for this project, due to the fact that common market antennas are designed to distribute their signal evenly in all directions. Since in the camera will be aboard a UAV, only one side of the antenna is needed for transmission/reception, thus allowing for a directed antenna to improve the communication range. The designed antenna is presented in Figure 3.b. Moreover, an over-the-air full anechoic chamber (Figure 3.e) was used to simulate a complex multi-path environment at the location of the camera (Figure 3.d) in a repeatable way by using radio channel emulators connected to a circular array of probes. The simulation of a realistic radio environment, was conducted in order to assess the communication performance of the antenna.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=2.4) [1]
Component	Abs
Output	Gain
Frequency	2.4
Rad. effic.	-0.1019 dB
Tot. effic.	-0.6478 dB
Gain	5.922 dB

Figure 3: Designed Antenna: (a) Simulated result; (b) Printed Antenna; (c) Measured result; (d) Close up in the full anechoic chamber; (e) Wide view of the full anechoic chamber

A **Battery** was added to give the camera stand alone functionality, powering the SBPU and increasing the cameras capturing time during a single flight. There is not much to the chosen battery, but a few options were evaluated, the best by means of space/weight ratio was chosen.

A **3D-printed Case** was created to encapsulate the previously listed components and reduce possible vibrations during a flight.

Software

A three level software architecture was developed in order to control everything as a multispectral camera and not as four separate regular cameras connected to a SBPU, such architecture is depicted in Figure 4.

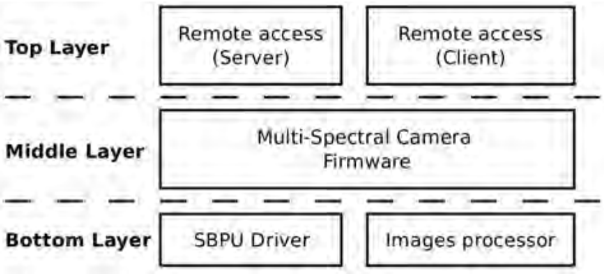


Figure 4: Software architecture of the proposed multispectral camera

The **SBPU Driver:** Implemented using the Python scripting language (ROSSUM, 1995), this Python library provides absolute control over the four cameras. Such control includes mainly: 1) Turning the cameras on and off; 2) Taking pictures simultaneously with all the cameras or a subset of them; and 3) Retrieving pictures from the camera's memory card.

The **Images Processor:** Implemented using C and OpenCV (BRADSKI, 2000), receives the pictures retrieved from the four cameras and corrects, aligns, and standardizes them. The wide lens distortion is estimated and the image undistorted. The images are then aligned to have the different bands match. Finally an RGB image displays the wide-band RGB captured image, while the second image is an RGB composed of the three narrow bands (i.e. 675nm,725nm, and 850nm respectively). The result of each capture after this process is two images: RGB and Infrared (multiple bands).

The **Multi-Spectral Camera Firmware:** Also implemented using the Python scripting language, orchestrates the entire data-acquisition/index-generation process.

The **Remote Access (Server):** Implemented using Bash scripting, interfaces the communication between the client and the *Middle Layer*. Such communication encompasses forwarding of commands from the client towards the *Multispectral Camera Firmware*, as well as the transmission of calculated indexes towards the client.

The **Remote Access (Client):** Implemented also using Bash scripting, enables a WiFi-compatible device to connect to the camera, and once connected, send commands and received computed indexes. Currently the computed indexes are: 1) NDVI by (CARLSON; RIPLEY, 1997); 2) RDVI by (ROUJEAN; BREON, 1995); 3) EVI2 by (JIANG et al., 2008); 4) OSAVI by (RONDEAUX; STEVEN; BARET, 1996); And 5) MSAVI by (QI et al., 1994). Moreover, All image processing procedures are also implemented within the *Remote Access Client*, allowing different visualizations of the data to be calculated locally, avoiding the need to re-transfer all the images.

Results

Since no VANT is available at the current state of the project, the proposed multispectral camera (Figure 5) was tested by generating the vegetation indexes of a nearly horizontal picture of an area with different vegetation densities, depicted in Figure 6 with the Infrared composite.

Figure 5: Pictures of the camera.

(a)

(b)

Figure 6: (a) Natural RGB; (b) Infrared composite.

All the resulting vegetation indexes are presented in Figure 8. Moreover, for a better understanding of the results, Figure 7 presents one of the indexes with arrows pointing at five areas o interest that correspond to: a) a well detailed border between three different responses, a building, pavement, and grass; b) an area that had its grass removed and that has been slowly growing again; c) higher vegetation, where its own leaves shadow each other; d) a path of trampled grass; and e) a well defined asphalt. A noted blurring in some strong edges was accounted and is believed to be less apparent on vertical images.

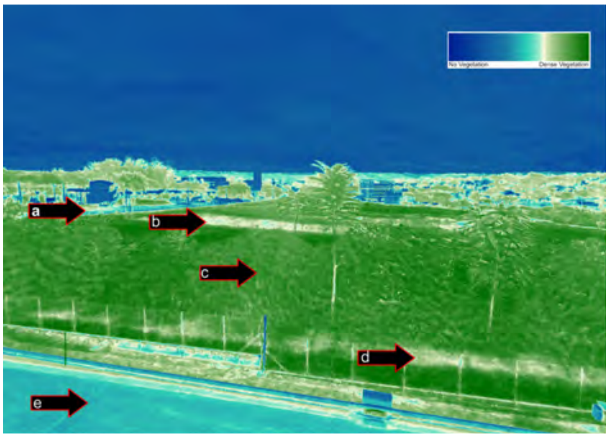
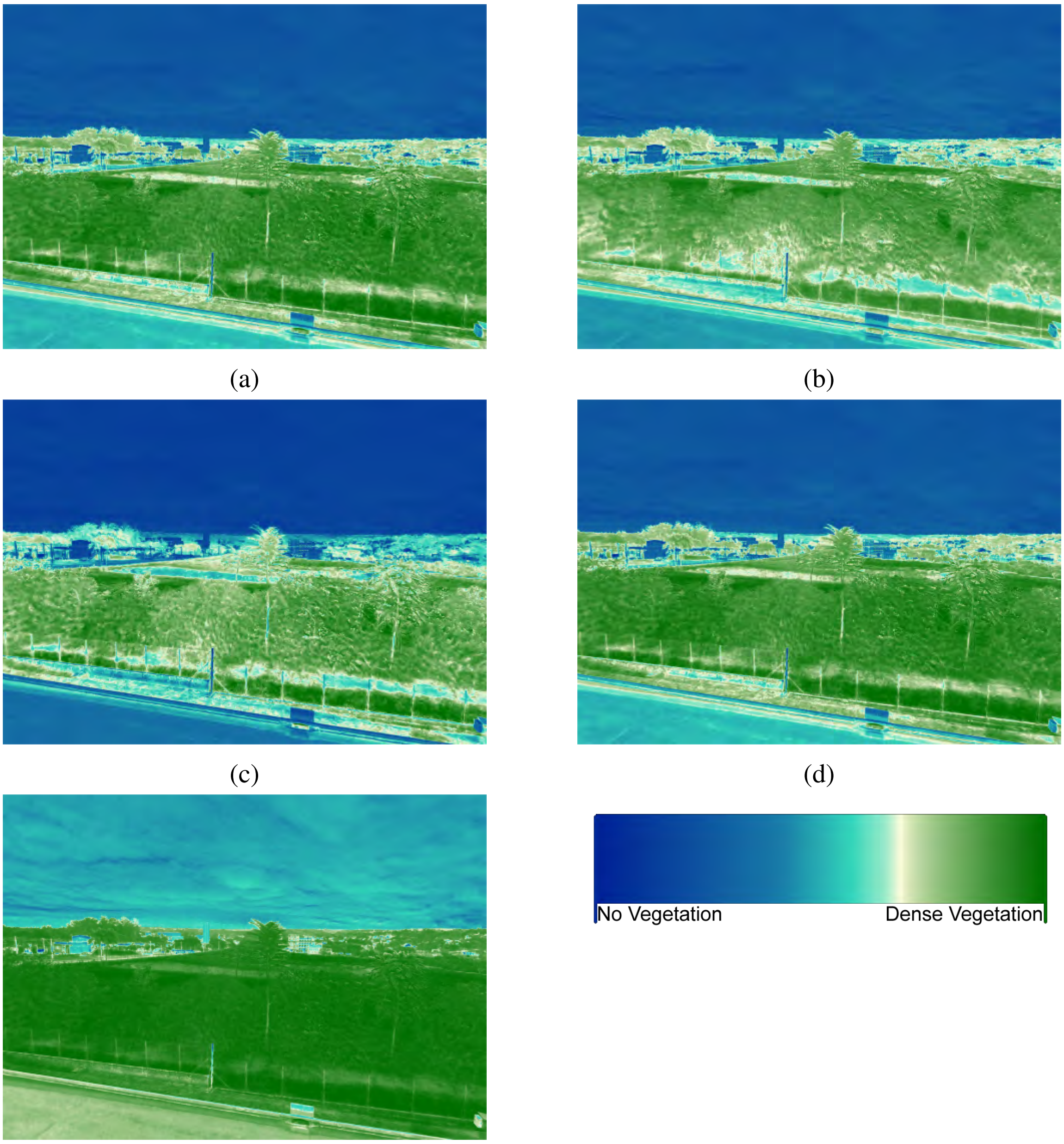


Figure 7: Comparative Result.



(a)

(b)

(c)

(d)

(e)

(f)

Figure 8: Resulting indexes: (a) NDVI; (b) RDVI; (c) EVI2; (d) OSAVI; (e) MSAVI; (f) Key Used in the Index Look-up-table

Conclusion

This paper presented a six band multispectral camera platform that, according to the presented test results, is capable of calculating indexes where different types of vegetation can be identified. Moreover, the materials used for building such camera cost $R\$5.000$, which can be considered low-cost knowing that the acquisition cost of a commercial grade multispectral camera in Brazil is roughly around $R\$70.000$. Additionally, the camera weight almost 800g, which is within the acceptable range for a medium sized UAV.

Future Work

Future work include: 1) testing the presented six band multispectral camera platform aboard a UAV so that perpendicular pictures can be acquired; 2) compare results with other equipment to obtain a quantitative accuracy; 3) the optimization of the used hardware in order to reduce the weight of the camera; and 4) an improvement on the software architecture so that a more flexible platform can be achieved, thus allowing researchers from universities and R&D institutes to customize it as needed and/or calculate other indexes.

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