Development of a Stereo NDVI Imaging System Using Raspberry Pi

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Abstract

Multispectral imagery for sensing applications are very pricey and sometimes not available. This paper shows the development of an imaging system that captures near infrared light and visible light to produce a Normalized Difference Vegetation Index (NDVI) image. It utilizes the Raspberry Pi microcomputer which was capable of performing different image processing techniques to process images captured by the multi-spectral band digital cameras. The system applied image rectification, and stereo correspondence prior to calculation of the NDVI. Images produced were validated and are 70 percent comparable to an existing system.

Keywords: multispectral image, stereo, vegetation index, microcomputer, image processing

1 Introduction

Plants are susceptible to the change of the climate, change in temperature and water irrigation causes 32% - 39% of crop yield variability [14]. Monitoring vegetation growth in relationship to the climate variability and different environmental conditions involves different remote sensing techniques such as image sensing, as it allows measurements that are not easily obtained with field measurements. Different imaging systems have evolved from analog cameras in the 1980s to digital cameras today. Digital cameras have been widely used commercially and in different scientific data acquisition including remote sensing because of its capability in obtaining data in different bands [1, 5].

Information on vegetation health from the images commonly relies on indices which compares the reflectance of vegetation in different spectral regions. Live plants absorb solar radiation at the visible spectral regions for photosynthesis whereas most of the radiation at the Near-Infrared Region (NIR) is reflected. The Normalized Difference Vegetation Index (NDVI) has been widely used in the utilization of the light energy absorption characteristics of plants at the near-infrared region (NIR) and the visible regions of the electromagnetic spectrum [15, 12] which is shown in figure 1.

Commercially available multispectral imaging systems provides new developments for near and remote sensing applications. For satellite imagery, systems such as IKONOS, Quickbird, GeoEye-1, and WorldView provides high spatial resolution image data that consists of multiple spectral bands that can be used for many applications for precision agriculture [11].

For near sensing multispectral imagery, systems from Microsense and Tetracam camera provides images with multiple bands for crop management [17, 16]. More importantly, these devices as well as satellite imagery are very expensive to acquire. Satellite imagery has a high noise profile due to weather effects and is not always available due to satellite orbits [19]. With these limitations, technological advances have made consumer – grade digital cameras an attractive option for near and remote sensing applications due to their low cost and availability [16, 19].

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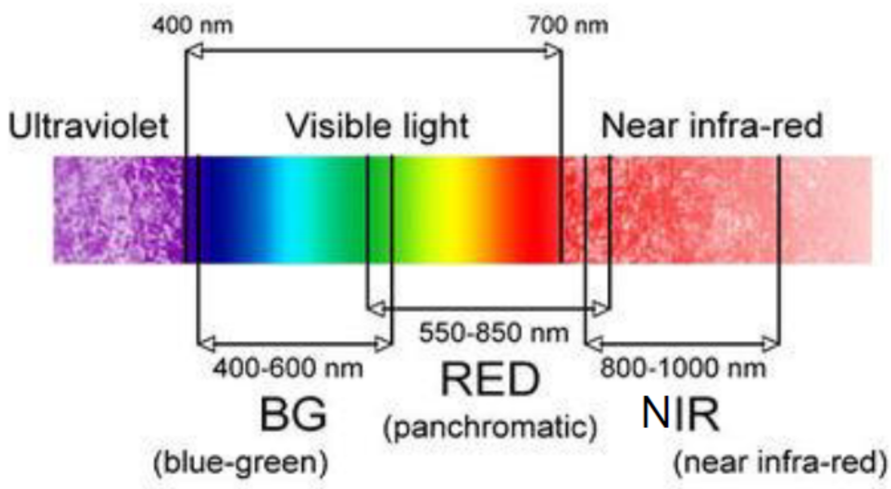


Figure 1: The Electromagnetic Spectrum

Since NDVI uses the NIR region of electromagnetic spectrum, a consumer grade digital camera must be configured to detect bands in the NIR region. Most digital cameras are sensitive to infrared light, but a filter is attached to the camera to block the infrared waves and to keep the visible parts of the spectrum which are red, green and blue (RGB). By removing or changing the filter, the camera is now allowed to collect infrared light and will store it in the red channel while the blue and green channels stays the same [16]. With the configurability of digital cameras today, different application of imaging systems that are processed to perform multispectral sensing for vegetation analysis using consumer – grade digital cameras now exist [15, 12, 19, 16, 13, 10]. One of these systems uses one camera that is filtered to capture NIR wavelengths and to capture NDVI [10]. With the absence of the RGB channel, visual inspection of the image for comparison is difficult. Two-camera multispectral imaging systems are usually implemented to achieve a separation of the visible and NIR channels of the system and the advantage of having an RGB image for visual inspection of the image captured. Having two cameras with different bands will require the system to properly align the captured images to match the NIR image to the RGB image for NDVI generation which is difficult to achieve optically or mechanically, so a software-based processing is commonly used to align the images from cameras in stereo and generate the NDVI image [19]. Current multispectral imaging systems are only limited for capturing images in different a desktop computer that has a software dedicated for image processing. Logistically, to use these existing systems for plant health monitoring will be time consuming and bulky if there is a need of immediate image analysis to be implemented [19, 10]. Thus, with the availability of an NIR camera, RGB camera and a credit-card sized computer, a hand-held NDVI imaging system can be developed.

The goal of the study was to develop a multispectral imaging system that can capture and process NIR and RGB images to produce an NDVI image that is 70 percent comparable to an existing NDVI image produced by an existing software. The objectives were:

- Build a camera system that uses RGB and NIR cameras positioned adjacent to one another.
- Capture images that contains RGB and NIR data.
- Process the images and generate the NDVI image using Raspberry Pi.
- Validate NDVI images captured from the system through comparison from an existing software.

2 Methodology

The development of the system started with the design of the prototype as illustrated in figure 2. Positioning, placement, and protection of the cameras and microcomputers were considered. The cameras went through validation to check their ability in capturing the required pixels for NDVI production and then subjected to stereo calibration to obtain calibration parameters for software stereo image processing. After validating and calibrating the cameras, the system can process the images taken for NDVI production.

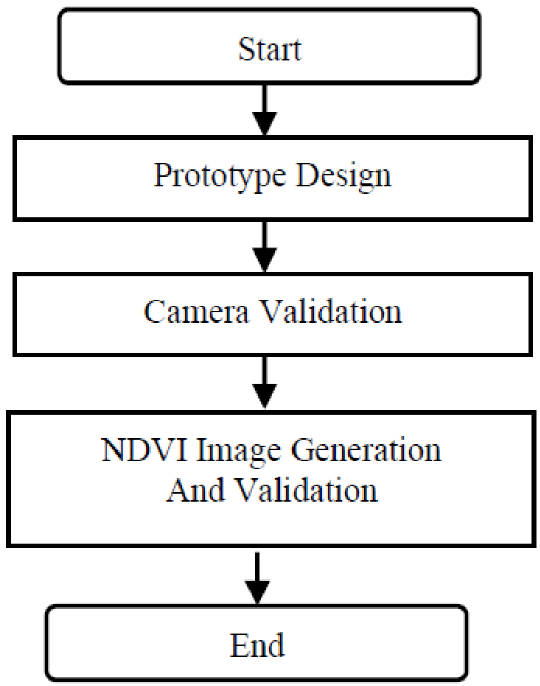


Figure 2: Development workflow of multispectral imaging system

2.1 Prototype Design

Materials The imaging system used Raspberry Pi as its processor, it is a low-cost credit-card sized computer and has been famous for its ability to do different applications such as music machines, weather stations, mobile robotics, and image processing. For machine vision purposes, two different cameras are available, the Raspberry Pi (RPi) camera which is an RGB camera and the No Infrared (NoIR) camera which is an RPi camera with no IR filter [8].

Imaging System Block Diagram Figure 3 shows the block diagram of the developed imaging system. It was designed to capture NIR and RGB images that are processed to generate an NDVI image. The system is composed of one RGB camera, one NIR camera, two Raspberry Pis to accommodate the two cameras since Raspberry Pi can only interface one camera, and a storage device which is an SD card. The cameras capture the target images and send them to their corresponding Raspberry Pi for processing, and the Raspberry Pis communicate to enable transfer of data. The output NDVI image is stored in the storage device and can be accessed through a displaying device.

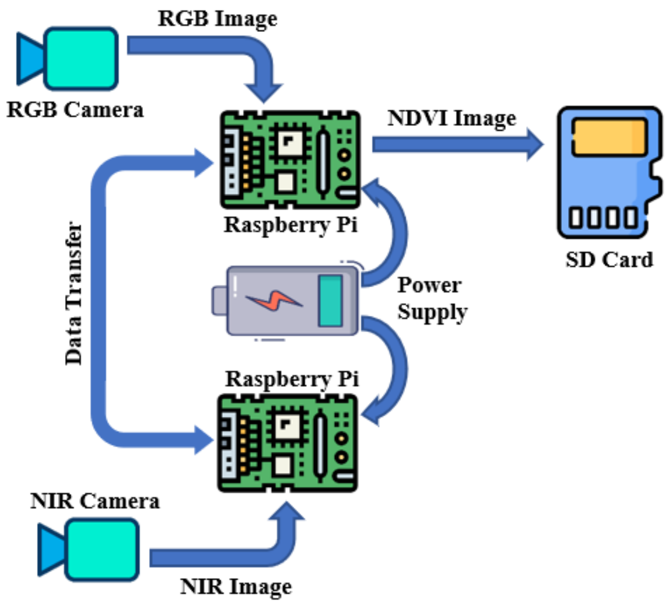


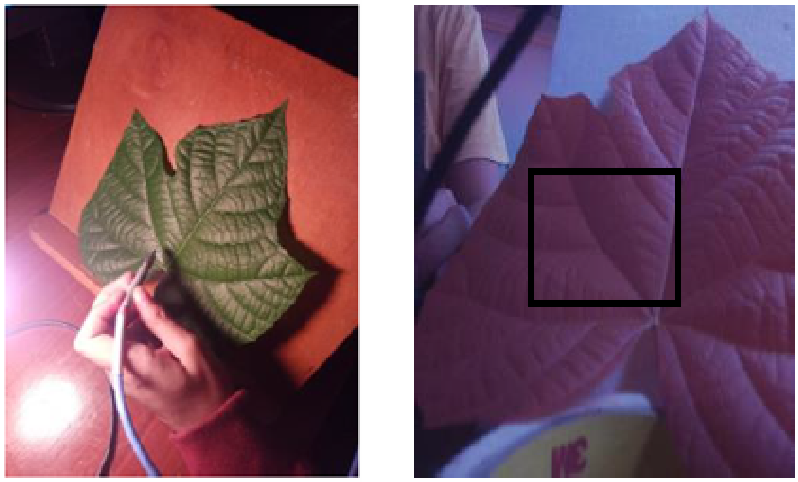
Figure 3: Block Diagram of NDVI Imaging System

2.2 Camera Validation

Camera NIR and RGB Capture Validation To validate the cameras' ability in capturing the proper NIR and Red data, 30 objects with different shades of NIR and R were selected and were subjected to reflectance and pixel intensity acquisition, as shown in 4. The method was used to get a relationship between the reflected light of the objects and the intensity of the pixel captured by the camera (Fig. 4a and Fig. 4b, respectively) and to determine if the system were able to capture the correct Red and NIR values reflected by the objects. To measure the light reflected by the objects, a RED TIDE USB 650 spectrometer by Ocean Optics was used by measuring the reflectance in its corresponding wavelength range: Red (600 nm – 700 nm) and NIR (700 nm – 800 nm) (Fig. 4a). For the pixel intensity, a portion of the object was selected (black lined box in Fig. 4b) and the mean of the Red and NIR pixel values of the selected portion was obtained using OpenCV.

Camera Stereo Calibration The NoIR camera was attached with a filter which is called as Blue Rosco Filter (See Fig. 5) that is manufactured by the Raspberry Pi foundation and is capable of converting the captured IR image of the NoIr into an NIR-Green-Blue (NGB) image where the Red channel is being replaced with NIR values and is the source of NIR data for NDVI processing.

Both cameras were subjected to stereo calibration by computing the geometrical relationship between the two cameras. Stereo calibration gets the following parameters: rotation matrix of the images that is used to rotate the images, translation vectors of the images that is used to locate the rotation direction of an image to a certain point, focal length of the two images which is the distance of the image sensors and lens when the subject is in focus, image centers, and parameters of lenses distortions which are caused by the characteristics of the lens or position of the camera with respect to the subject [4]. The system used chessboards, as shown in Fig. , placed in different positions in determining the calibration parameters, the pattern of alternating black and white squares is detected to determine different position and angles in the image.



(a) Reflectance Sampling using RED TIDE USB 650

(b) Pixel Intensity Sampling using OpenCV

Figure 4: Captured images in validating the NIR and RGB camera

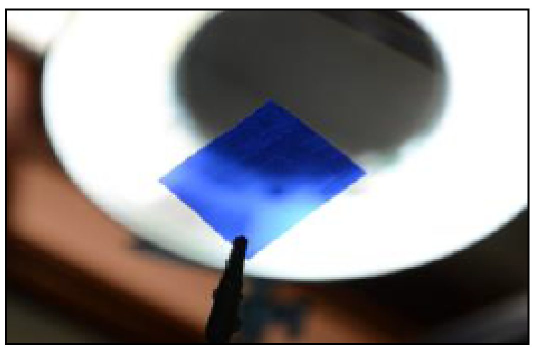
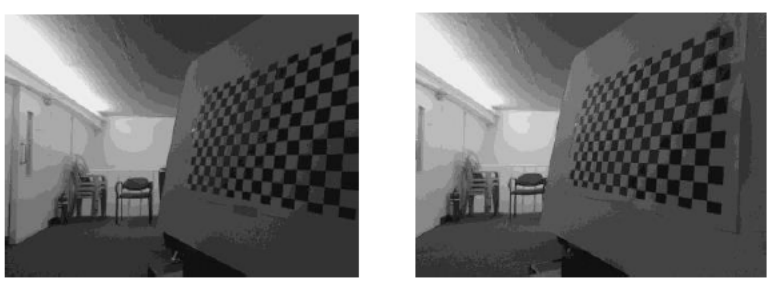


Figure 5: NoIR Blue Rosco Filter



(a) Left chessboard image

(b) Right chessboard image

Figure 6: Chessboard Images for camera stereo calibration

2.3 NDVI Imaging System Generation Process Flow

Figure 7 illustrates the proposed algorithm of our NDVI imaging system. When the Raspberry Pis are turned on, it will wait for a signal to capture the images. The captured images will undergo the process of rectification for alignment, stereo correspondence for identifying common Red and NIR features and

NDVI calculation to produce the NDVI image.

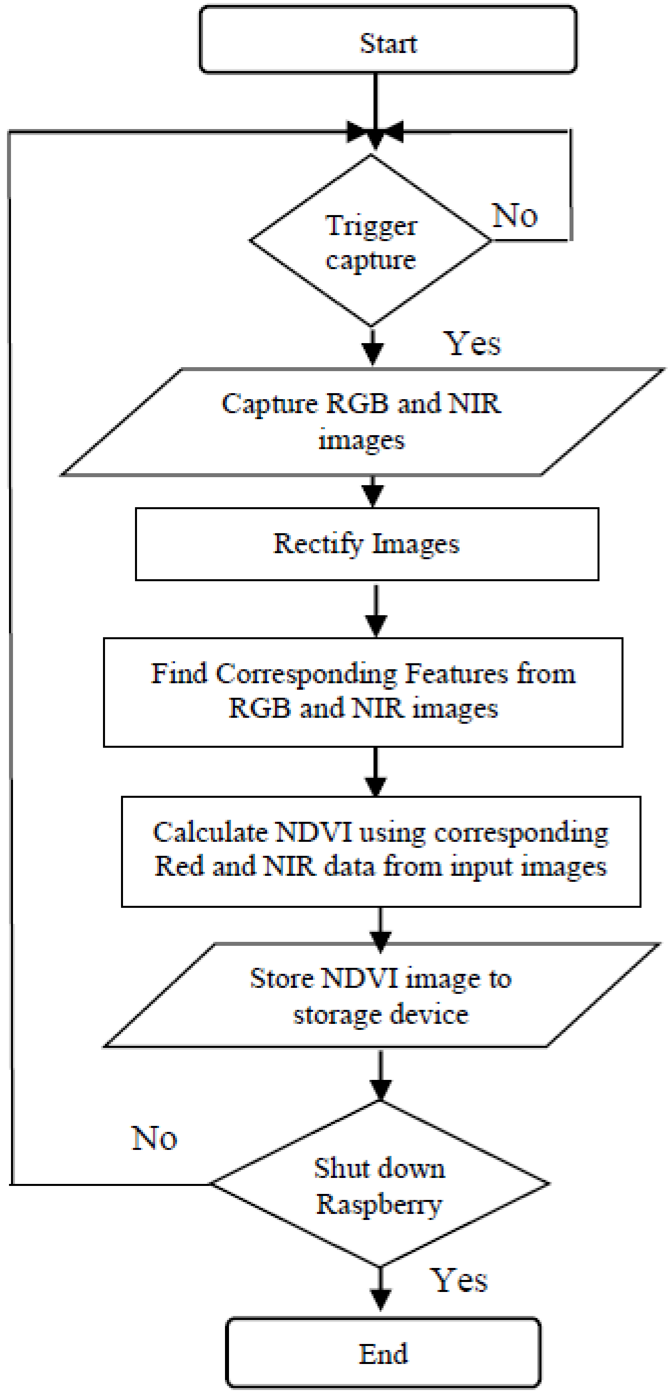


Figure 7: Proposed algorithm of the imaging system

Rectification Even if the RGB and NGB cameras are physically aligned in its placement, obstructions and areas of overlapping causes the cameras to see different views of the subject being captured [4]. Image rectification is the process where the RGB (left image of Fig. 8) and NGB (right image of Fig 8) image were projected to a common plane by using the parameters that were gathered in the calibration. The system leveraged Bouguet's algorithm, illustrated in Fig. 9, where it utilizes the rotation matrices (R) taken from the stereo calibration to rotate the images for them to be aligned, matrices (M) from the left and right image data, and the projection matrix (P) to determine where to protrude the images when it is rotated [4]. These simplify the problem of finding the matching NIR and visible points between the images captured. The images captured by the two cameras placed adjacently are not aligned since the two cameras do not have aligned imaging planes. Figure 8 shows a pair of unrectified image pair with a line indicating vertical difference between the two images. From the parameters taken from the calibration, rectification corrects the image distortion by transforming the image into the standard coordinate system by aligning the image rows into the vertical axis. Figure 10 shows the image pair after rectification and the black line showing each image has approximately captured the same view of the object.

Figure 8: Image pair without rectification, RGB (left) and NGB(right)

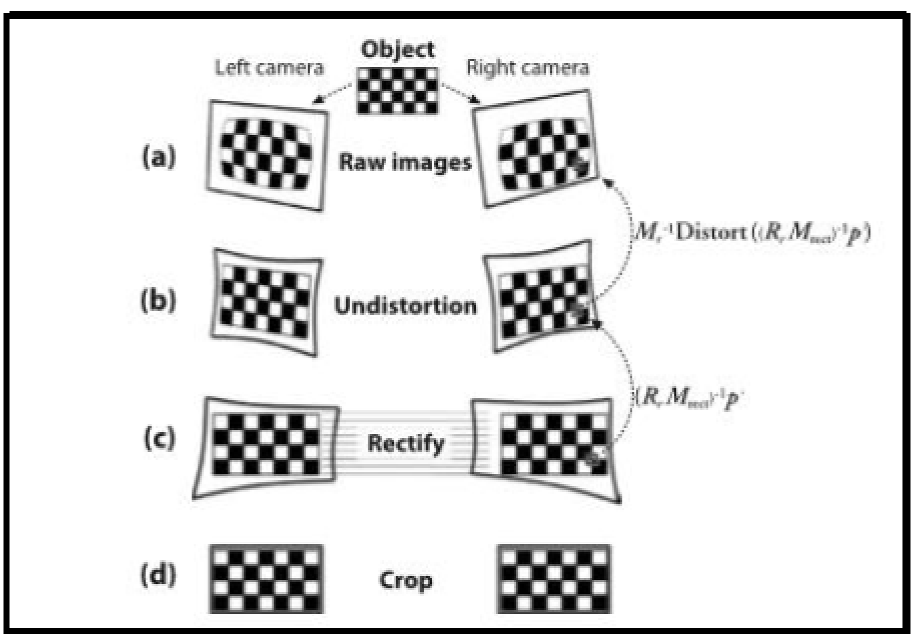
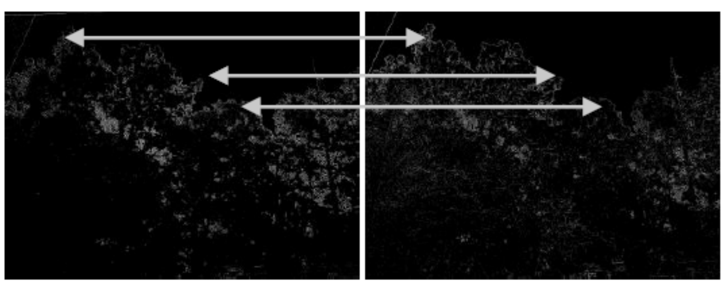


Figure 9: Illustration of the rectification process

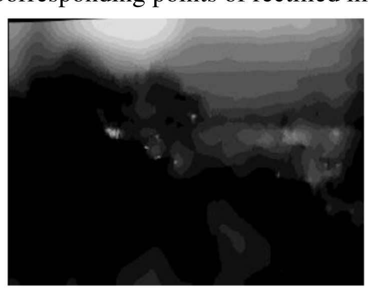
Figure 10: Image pair after rectification, RGB (left) and NGB(right)

Stereo Correspondence Stereo correspondence is a procedure where it aims in finding the equivalent Red and NIR points in the rectified NGB and RGB images. Stereo correspondence starts by assigning matching points between corresponding rows in the left images and matching the features of those points.

After rectification, the images were converted to its equivalent grey image generated from their adaptive thresholds. This process was done because the pair images do not belong to the same color space. The system used Semi global block matching (SGBM) method for identifying the corresponding points of the left and right images [7]. After finding the corresponding points, a new grey image was generated depicting disparity map, as shown in Fig. 11b, which the difference of the two corresponding points found between the two image pair in Fig. 11a.



(a) Corresponding points of rectified images



(b) Disparity Map

Figure 11: Image results for finding stereo correspondence

Software Implementation The capture, rectification, stereo correspondence and NDVI processing of images were done using the OpenCV libraries, OpenCV is an open source computer vision library that can provide methods to perform different image processing algorithms such as pixel data acquisition, object detection, color mapping and etc. To perform the processing of the NIR, RGB and NDVI images, the proponent decided to use OpenCV library because it is optimized for efficient Raspberry Pi processor performance and Python programming language which is the native language for Raspberry Pi programming.

NDVI Calculation and Validation Generally, healthy vegetation absorbs Red and Blue light for use of photosynthesis and create chlorophyll. If a plant has more chlorophyll, it will reflect more NIR light. Thus, analyzing the absorption and reflection of light from the plants can provide information about the plant's health [12]. NDVI is expressed as:

$$NDVI = (NIR - R)/(NIR + R) \quad (1)$$
$$R: \ Red\ data\ from\ RGB\ image$$
$$NIR: \ Near\ Infrared\ Data\ from\ NIR\ image$$

Equation 1 was normalized from -1 to 1 by dividing the difference of the NIR and R with its sum to adapt different weather condition such as bright sunshine and cloudy skies where visible lights reflected to the plants are extremely high or low. Negative values represent water, values around zero represents soil and values greater than 0.6 represent dense vegetation [9].

Using the difference of the points of the two images found in the disparity map, corresponding points were accessed from the Red and NIR channels of the pair image and were used to calculate its equivalent NDVI value using Equation 1.

Since NDVI ranges from -1 to 1, different range of color values can be used to represent the level of NDVI. Infragram by PublicLAb, is an online tool for analyzing plant health by using near infrared imagery. The tool is open source and can be used to generate NDVI images from a given image that can capture NIR and visible bands.Subsequently, it was used by different researches related to plant health monitoring. Infragram uses the Grey color map to represent -1 - 1 to 0 – 255, as presented in Fig, 12 [6, 18]. This study used the grey color map to compare this system and Infragram's NDVI images.

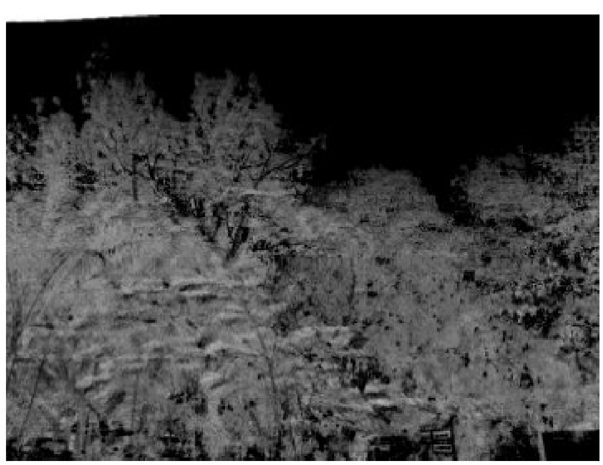


Figure 12: NDVI image using Grey Color Map

3 Presentation, Analysis, and Interpretation of Data

3.1 System Prototype

The imaging system is composed of two Raspberry Pis to accommodate the two cameras that were used. As shown in Fig. 13, it was designed to be a hand-held device with a volume of 185 cm x 120 cm x 80 cm. The NIR camera (1) and the RGB camera (2) are positioned adjacent to each other to obtain NIR and RGB data from the captured scenes that are common to both cameras, the power ports (3) on the side were used to connect power source using micro-USB connectors, HDMI ports (4) were used to display files found inside the camera, Ethernet ports (5) of the Raspberry Pis are connected and used for the communication and transmission of data, and the USB ports (6) were used to access the data processed by the system.

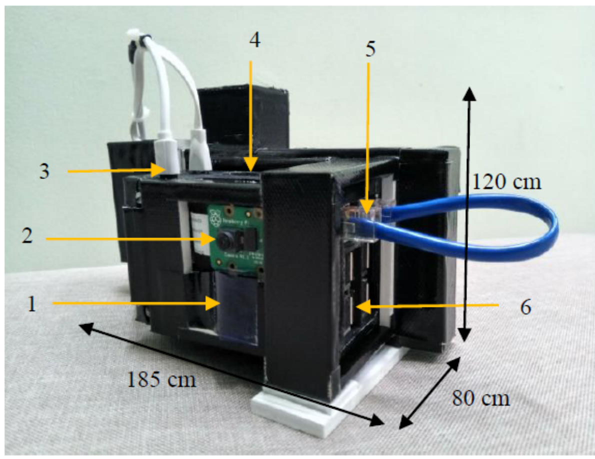


Figure 13: Prototype of the multispectral imaging system

3.2 Camera Validations Results

Data taken from the reflectance and pixel Intensity acquisitions of the thirty samples were subjected to Pearson's Correlation Coefficient analysis to show their relationship linearly. Illustrated in Fig. 14 and Fig. 15, the R values (0.87 for Red and 0.77 for NIR) obtained from the relationship shows that the Pearson coefficient is large enough to indicate a strong relationship between the reflectance values obtained from the spectrometer and the pixel intensity values captured by the camera [3]. Using the Red and NIR data from the camera validation test, NDVI values were also computed to check if the NDVI reflected by the objects were also related to the NDVI captured by the system. The Geometrical parameters from the stereo calibration were not presented since it was generated by the OpenCV process and were not shown. The data which are the parameters that is in OpenCV format were passed and used within the process.

Fig. 16 depicts the analysis of variance (ANOVA) testing the difference of the NDVI values obtained from the test . The calculated probability (p) was 0.322 which is greater than the alpha level of 0.05. This indicates that there is no significant difference between the calculated NDVI values from the reflectance and pixel intensity values [2].

In addition, thirty different samples were captured continuously without resetting the system, the produced NDVI images were all from the correct samples giving 100% success rate.

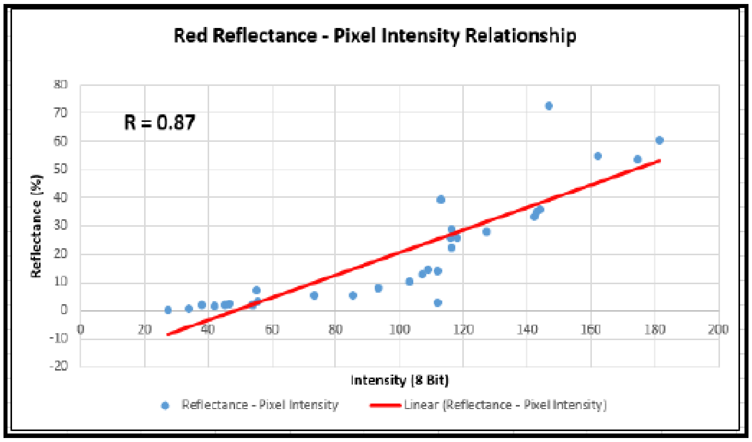


Figure 14: Linearization Curve Reflectance vs Pixel Intensity for Red

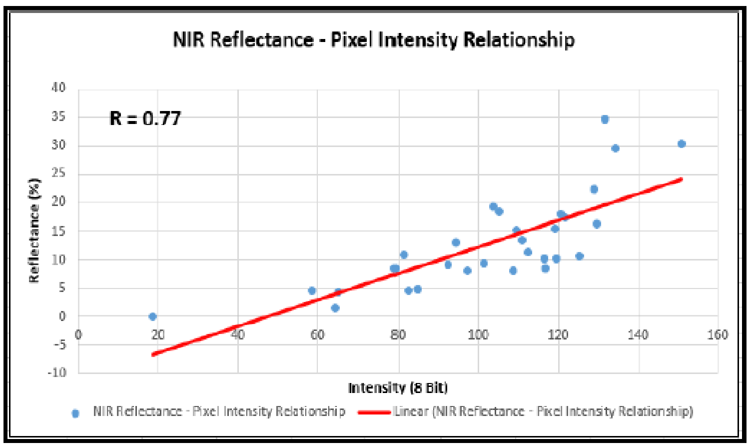


Figure 15: Linearization Curve Reflectance vs Pixel Intensity for NIR

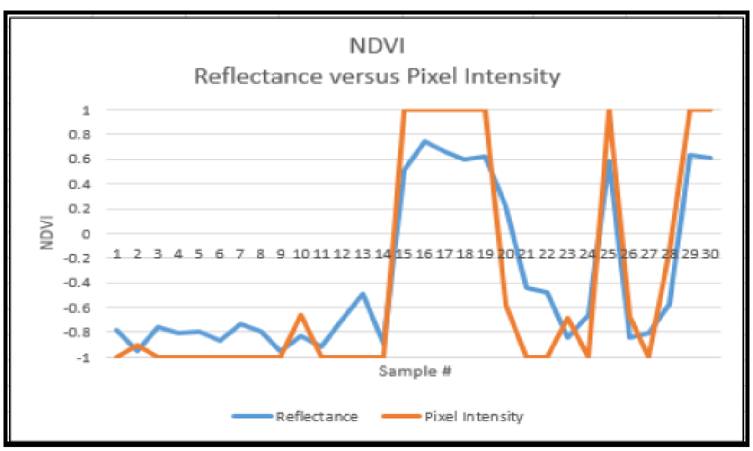
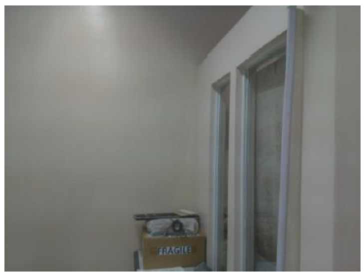


Figure 16: NDVI values from thirty samples

3.3 NDVI Validation

The system captured sceneries that were divided into three categories: no vegetation (Fig. 17a), medium vegetation (Fig. 17b), and high vegetation (Fig. 17c), with thirty samples for each category. The categorization was based from the presence of vegetation on a certain scenario to be captured. Samples for no vegetation were taken from rooms with no plants, medium vegetation samples were taken from sceneries with trees, small plants, and inanimate objects on it, and high vegetation samples were taken from sceneries that are mostly plants and trees.



(a) Captured Image with no vegatation

(b) Capture Image with medium vegatation

(c) Capture Image with high vegatation

Figure 17: Captured Images for NDVI validation

Table 1 prensents the variance in the different group of samples and Histogram mean of the NDVI images produced from the samples shown Fig. 18 depicts the difference of the categories where high vegetation having the highest means indicating the system detected high vegetation presence and no vegetation with the lowest means indicating the system detected low vegetation presence.

Table 1: Variation between the three group samples

Source of Variation	**Sum of Squares**
Between Groups	4844.41795
Within Groups	13137.91567
Total	17982.33362

Analysis of Variance was used to statistically verify that there are significant differences between the three categories. With some of the first few samples showing outlying data, a 95% confidence interval was set. The calculated probability was 0.00000118 which is less than the alpha level of 0.05 and tells that there is a significant difference between the three categories entailing that the camera system can produce NDVI images from scenes with different vegetation volume.

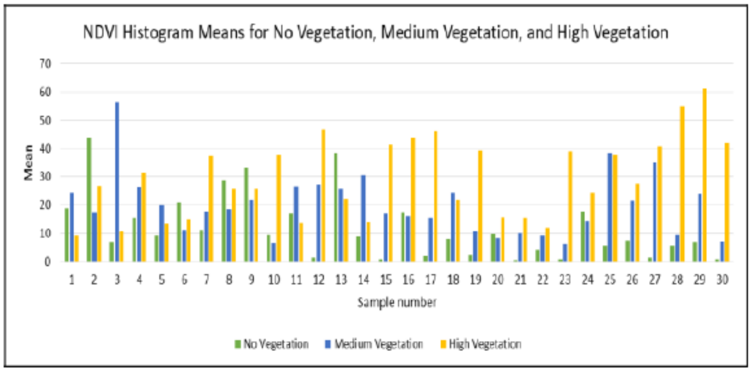
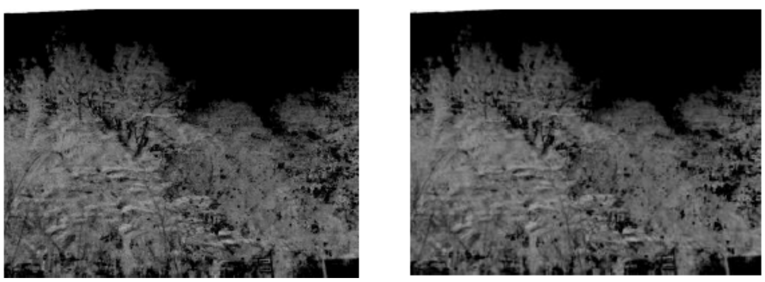


Figure 18: NDVI histogram mean per sample

To compare the ability of the system to produce an NDVI image to an existing system that also produces an NDVI image, the NDVI images of the samples from each category were compared to the NDVI images produced by PublicLab's Infragram. Since the NDVI images are represented through histograms, Chi – Squared distance was used for histogram comparison. The NDVI images used in the analysis were both in grey format (See Fig. 19) where the NDVI value -1 to 1 were normalized to 0 to 255 since it is the default Infragram output image format. The corresponding histograms, shown See Fig. 20, were all generated from ImageJ image analysis software.



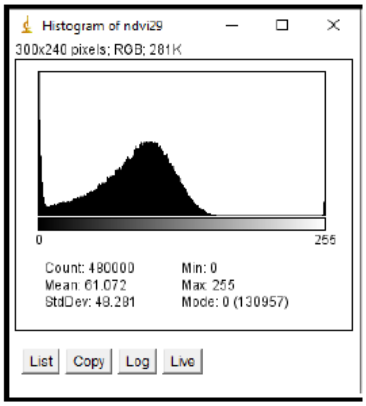
(a) Infragram capture (b) Raspi System capture

Figure 19: Comparison of NDVI Images from Infragram vs Raspi System

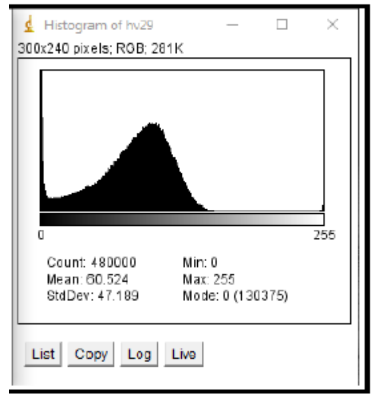
Chi-squared comparison results, presented in Fig. 21, shows that high vegetation category have higher percent differences compared to the other categories. Furthermore, it also shows consistent percent difference from each category which is below 20% except for one (1) sample where the Infragram histogram value generated a different result to the Raspberry Pi system. The reason cannot be identified since both systems has its own way of generating NDVI images and Infragram was used for comparison purposes only. Though this sample was a part of the overall data gathered, it did not affect the outcome of the study.

4 Conclusion

The imaging system was built using the cameras and the Raspberry Pi microcomputer. In stereo position, cameras were able to capture corresponding sceneries with NIR and RGB data and were verified by using a spectrometer. With the Raspberry Pi microcomputer, the captured images were processed for finding corresponding images and used for the calculation of its NDVI values. The NDVI data produced by the



(a) Histogram from Infragram



(b) Historgram from Raspi System

Figure 20: Comparison of Histogram from Infragram vs Raspi System

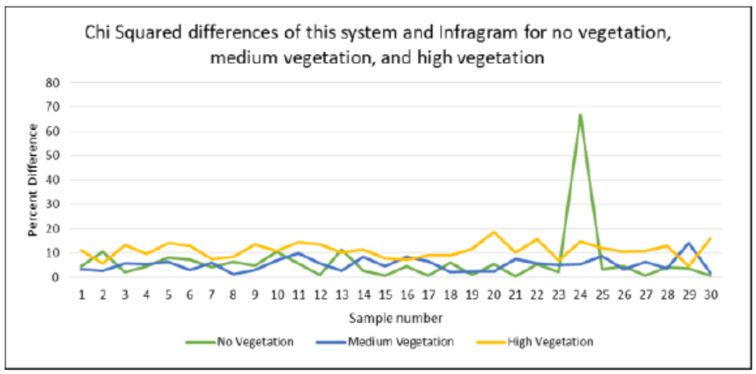


Figure 21: Histogram similarity test results using Chi-Square method

imaging system were then compared to the produced NDVI images from Infragram using three categories of image scenery with thirty (30) samples each which yielded a similarity greater than of 70%.

5 Recommendation

To move further in this study, sensor enhancement should be considered, using camera sensors that are independent to light conditions are preferable in obtaining the exact reflectance or light properties of a scenery or an object.

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