Development of a Raspberry-Pi Based Multispectral Imager

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Abstract

When constructing a multispectral imager, there are many aspects of operation to take into consideration. From power requirements to focal distance, spectra bands to dimensional tolerances. A full analysis of the various aspects are covered within this paper. The system was engineered such that upgrades to operation could easily be implemented.

1 Introduction

After the introduction Raspberry Pi linux computer on the market, portable processing has become more and more convenient. It also goes without saying that the drastic reduction in cost and size of CMOS and microbolometer arrays allow for for the construction of a portable, low cost, multispectral imager. Unfortunately, utilizing a multi-camera assembly, requires the consideration of the existence of a synthetic aperture. However, treating the camera array as a synthetic aperture only needs to be done when forming a composite image, preforming rudimentary distance sensing, or as a means of seeing around occlusions. This paper only covers the basic design considerations (and actions taken) in constructing the device.

2 Broad Impact

The broad impact of this research opens doors for intelligent cancer detection, crop management, target tracking, and analysis of historic artifacts. The open-source nature of this project allows all labs equipped with a 3D printer to construct the apparatus and test their own algorithms. Furthermore, the modular nature of the entire unit allows for easy retrofitting and upgrades for specific applications.

3 Applications

While the imager was specifically developed for a nearly limitless combination of applications, a few will be highlighted. The first obvious use for an IR filtered camera is crop monitoring. It is entirely possible to gauge crop health through the use of the NIR band. By measuring the NIR reflection, a machine can determine the chlorophyll concentrations and therefore the plant health.[1] Another application for this camera is for use in analyzing topographies of objects. Because the combined set of cameras can be utilized as a synthetic aperture, the depth of field can be adjusted and used for gathering rudimentary 3D data. The implementation of the FLIR Lepton thermal camera further expands the applications of the device to include target tracking, and thermal measurements.

4 Past Research

Before any design of the system could be conducted, it was essential to preform research on methods of multispectral imaging and the technology surrounding. One of the obvious examples of multispectral imagers is use of them in satellite technolgoy. Current multispectral imagers of this variety are simply arrays of cameras mounted perpendicular to a satellite's orbital path. These arrays are then meshed together using a multi-sensor triangulation algorithm. [2] With this information it was concluded that it was possible to assemble an array of cameras and "stitch" together multiple images simultaneously.

5 Design Considerations

The first step in developing any project involves evaluating design considerations. The criteria for the camera also need to be broad enough to allow for flexibility and upgrades as the application changes.

5.1 Image Sensor Spectral Response

When choosing image sensors, it was important to consider the spectral response curves. While it was impossible to get the exact curves without contacting the manager, research was conducted between the two types of imaging sensors available today; CMOS (complimentary metal oxide semiconductor) and CCD (charged coupled device). CMOS sensors are the current state of the art and utilize digital multiplexers and can process large quantities of data in parallel. CCD sensors on the other hand are serial out and therefore slower. CMOS sensors are naturally less sensitive to near ir light as they are made with thinner components, while CCD sensors are more responsive to near ir light as their sensor arrays are thicker.[3] While the device was unable to be outfitted with CCD cameras compatible with raspberry pi's it was still a consideration worth accounting for. Tests were ran with filters in the NIR and UV range and it was concluded that CMOS detectors could in fact detect within the appropriate ranges.

Figure 1: A test was conducted with an open flame (guaranteed to generate a response in UV, Thermal, Visual, IR, and NIR bands.

5.2 Depth of Field

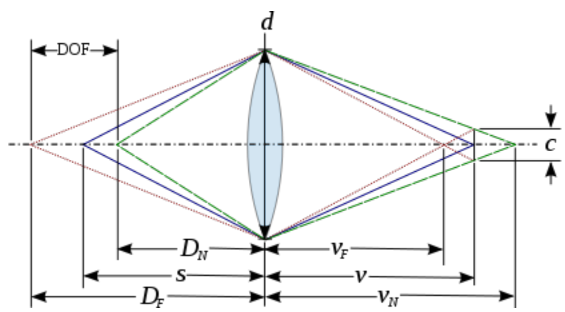

Figure 2: Visual depiction of depth of field.

$$D_n = \frac{sf^2}{f^2 + Nc(s-f)} \tag{1}$$

$$D_f = \frac{sf^2}{f^2 - Nc(s-f)} \tag{2}$$

$$N = \frac{f}{d} \tag{3}$$

There is a direct correlation between aperture size and depth of field. By synthetically changing the aperture at a certain focal point, a basic depth of field estimation can be obtained. By ”flattening” the depth of field around a point of interest, a rudimentary depth measurement can be conducted. If the point happens to be partially occluded, flattening the depth of field, can, to some extent, materialize the occluded object by blurring the occlusion. Depth of field also needs to be taken into consideration when stitching images together.

5.3 Image Translation

In order to obtain a composite image from 4 separate sources it is important to be able to manipulate the images taken from each camera. This is important because the aperture is only simulated by translating images from all of the cameras until a satisfactory depth of field is established. Since each individual camera is at a known distance and angle from the center of the array (the thermal unit), the images can be predictably translated until a satisfactory depth of field can be reached.

5.4 Power Requirements

Since the imager should be portable (for use in the field, and air) a battery and appropriate power system need to be sourced. After rudimentary research on the power consumption of raspberry pi computation units, screen, cameras, and switch the entire unit utilized around 20 watts absolute worst case scenario. Because of this, a beefy, 88WHr batter was selected. Utilizing maximum power, the unit will have a four hour battery life. While this seems sub-optimal, this configuration is utilizing the largest off-the-shelf battery that was available. To further increase the efficiency of the unit, a switching mode power supply was implemented as opposed to a linear drop out voltage regulator.

5.5 Programming Logistics

It was determined that an Ethernet communication link would suffice for coordinating the images as it was fast (¡.01 seconds/TCP packet) and the method of communication could double as a conduit for sending the images back to the master unit for aggregation and storage. As seen in figure 2, all communications are handled through a 5 port switch.

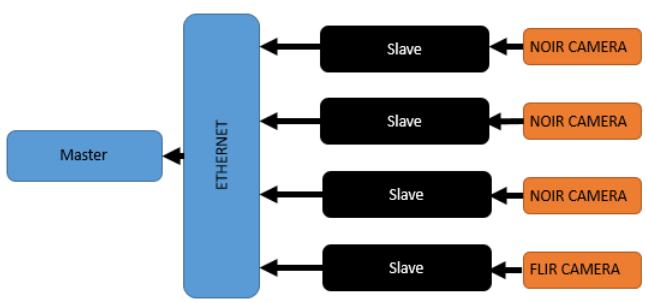

Figure 3: Peripheral map

5.6 Mechanical Design

As far as mechanical design was concerned, the components needed to be modular enough to be a) replaceable and b) modifiable. As a result, the camera ended up being composed of only six 3D printed parts. All of which are designed to be swapped out or modified. Figure 3 depicts this.

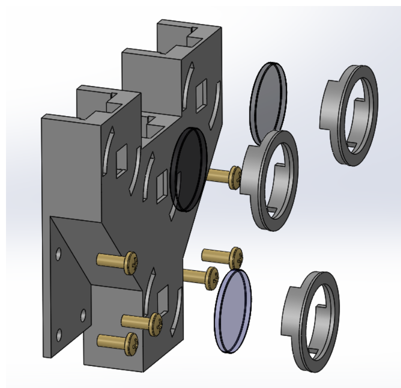

Figure 4: Exploded view of the modular nature of camera attachment.

Another convenient feature of the design is the self-tapping nature of all of the screw holes. This feature is only convenient when the device is ready to be used with little modification as the screw holes do wear out. However, for one-and-done assembly, this feature removes the requirement for having nuts embedded in the holes.

5.7 Electronic Design

While there were very few "challenging" design requirements electrically, an effort was made to increase the capability of the unit for future projects. For example, an array of 5, high power, NPN transistors were added to the power control board in case a user wanted to add fan control, light control, or wanted to reset the FLIR Lepton camera. In addition to the extra components, extra care was taken in the design of the voltage sources. With a traditional linear regulator, the terrible efficiency would have wasted enough power to necessitate a heat sink and to significantly decrease the battery life (88Wh). The board now utilizes a switching voltage regulator which has an efficiency that exceeds 80%. A linear regulator is still used as a 9 volt supply for the five port switch, however the entire switch uses less than half of a watt of electrical power.

To prevent electrical anomalies, a battery management circuit was installed between the power module and battery. The circuit cuts off power to/from the battery during short, over charge, and under voltage conditions.

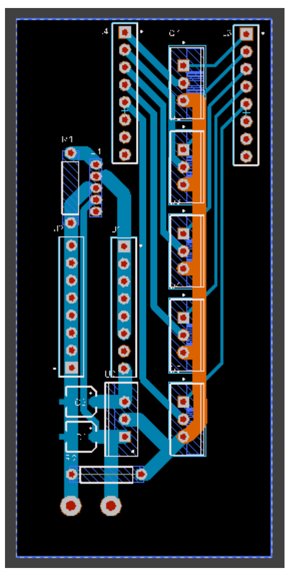

Figure 5: PCB view of the power module. The long array of TO-220 packages is the transistor array.

5.8 GUI Design

As there was a relatively small touch screen being mounted to the device, it was important to have a GUI that was both functional, and accessible. A person needed to be able to take and access images with the GUI, everything after that was considered extra. The code was written in java, a well-maintained and popular language. The main screen (figure 5) the graphical user interface boots into has a large button for picture taking, a display to the left, and three buttons below for scrolling through images as well as a menu. While all images that are captured are stored, only the last image captured is available for review on the display. The menu has several functions that include the selection of various color bands for each camera, an animal view option, and a page for managing the slaves. The peripheral management menu includes shutdown, restart, and flir reset buttons. As the unit is still in prototype phase, the software the controls the slaves and master is high level (python) and therefore unstable.

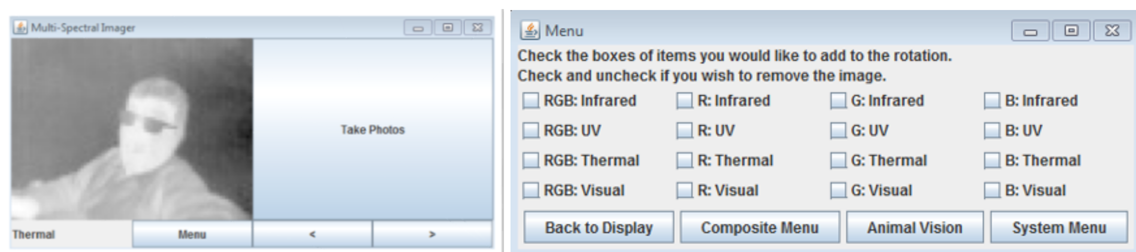

Figure 6: The main screen and band selection menu.

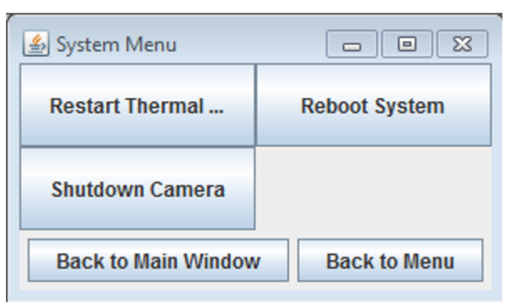

Figure 7: The peripheral management menu.

6 Expectations

While it was clear there was going to be no official testing or calibration within the time frame of assembling this device, the project was expected to have been completed and the design considerations fulfilled. Past experience was taken into account when designing the unit to assure that what was being conducted had been done before in one form or another. For example, it was already determined that minimal effort would need to be expended on the method used to network and synchronize the cluster of raspberry pis as it had been accomplished in a previous project.

7 Results

The results of the development of this device proved to satisfy all of the design considerations. The camera has room for improvements in several of the software and GUI areas, but otherwise functions as intended. There is room for expansion of features (as mentioned in the mechanical considerations section). These features are easily implemented given more time and programming experience.

8 Discussion

Being in able to view the spectra that exists outside of the limits of the human eye unlocks a plethora of information previously unavailable. Furthermore, having a device that is capable of preforming more functions than originally intended is also an advantage as the system can easily be upgraded and equipped for enhanced use.

Further revisions could use tighter tolerances on pockets for the power supply and five port switch. The LCD touch screen could use a bezel to hide the boarder and allow for screw mounting. Currently these three components are secured using hot glue adhesive. There was also little planning for the thermal output of the internal electronics. While there was great care taken to increase the efficiency of the discreet components, the entire unit still consumes around 10 watts of power. Since the unit is modular, a cooling fan can easily be installed in the hood or cable cover of the device.

9 Conclusion

Eight week's of work have yielded a working, multispectral imager. Further development of this imager ironed out any existing bugs in the code and mechanical design. While bugs still remain, the imager still functions on a primitive level and can easily be further refined.

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