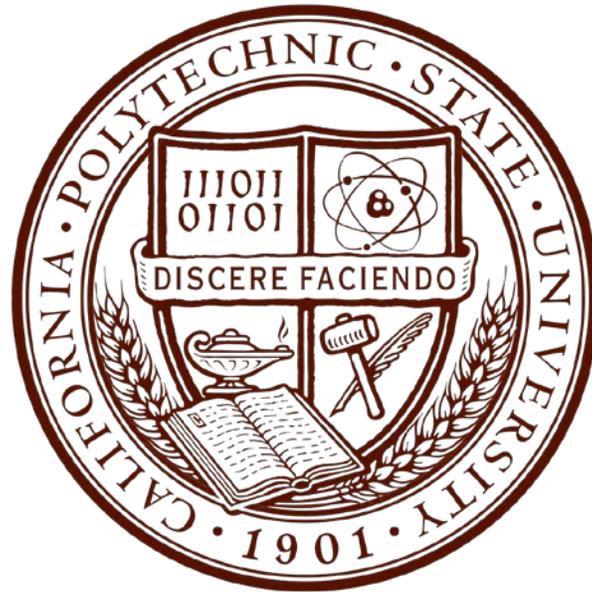


Multi-Spectral Identification Array

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Statement of Disclaimer

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Abstract

The Multispectral Identification Array is a device for taking full image spectroscopy data via the illumination of a subject with sixty-four unique spectra. The array combines images under the illumination spectra to produce an approximate reflectance graph for every pixel in a scene. Acquisition of an entire spectrum allows the array to differentiate objects based on surface material. Spectral graphs produced are highly approximate and should not be used to determine material properties, however the output is sufficiently consistent to allow differentiation and identification of previously sampled subjects. While not sufficiently advanced for use as a replacement to spectroscopy the method has proven effective for machine vision applications.

Acknowledgments

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Background

Multispectral imaging is the practice of taking pictures with multiple discrete color bands. Most commonly utilized to produce the standard Red Green Blue image we are accustomed to seeing; multispectral imaging can provide vastly more information than a simple bitmap or grayscale image. Commonly multispectral imaging utilizes between three and twenty distinct bands of color, each of which provides a different view of the subject. [1] Deep red or near infrared light for example will show less fine detail however it can often pass straight through the first few microns of an object's surface to reveal pigments below. [2] On the other side of the spectrum blue or ultraviolet light can reveal surface details far finer than a human hair and will produce a much crisper image. [1] By combining these features Multispectral imaging can reveal information which is otherwise hidden to the human eye.

Multispectral imaging is commonly accomplished through either filtering of ambient light or illumination of the subject with controlled spectra. The two methods each have merits and limitations. Multispectral imaging via a dedicated multispectral camera or set of lens filters traditionally suffers from mechanical failures when moving the filters, or from low numbers of filters. Some image sensors have been developed which have up to six built in filters, however these are extremely expensive and the filters cannot be modified. [3] Traditionally because of the high cost of manufacture these sensors only have between three and six filters. Multispectral imaging via illumination on the other hand suffers from the inverse square law of light, which limits the depth of field. [2] Illumination also faces challenges due to high cost of the controlled spectra light sources. [4] This high cost is one of the challenges this project hopes to address.

Commonly multispectral cameras utilise between three and six filters spanning the infrared through ultraviolet bands. Infrared light is most notably utilised in imaging systems such as the FLIR heat vision cameras and the Landsat global satellites.[5] The ultraviolet bands on the other hand are more commonly used to reveal fine detail in paintings or surface finishes.[6] The most common multispectral cameras are centered in the visible light band. These are the standard Red Green Blue cameras used by most photographers. A common practice in the agriculture industry is to remove the infrared filter from a standard RGB camera, changing it to a Red Green InfraRed allowing broader spectra imaging.[5] However this still allows only three distinct spectra of color.

Multispectral illumination is commonly utilized in the production of high quality image capture for movies augmented with computer graphics. [4] Other applications include crime scene investigation, medical imaging of skin disorders, and art forgery detection. Commonly multispectral illumination is accomplished using Light Emitting Diodes, gas discharge lamps, or low width band pass filters. [7] The filter method is prohibitively expensive for amateur photographers and some research institutions. Similarly the gas-discharge method often uses expensive and fragile materials not suitable for common use. While not prohibitively expensive LED's are only produced in the most common wavelengths which makes sourcing enough for a high resolution spectra functionally impossible. [4]

Applications

This Multispectral imaging array is intended to reduce the cost of full image spectrometry. The primary uses under consideration are pollution monitoring, plant health monitoring, inert sample and full scene cataloging. The Array is most effective in dark environments so would be ideal for undersea applications. While the array is not sufficiently accurate to be used as a final indicator of material properties, it can serve as a preliminary scanning method to rule out obviously irrelevant or to identify potentially interesting subjects. [8]

The array should be used primarily on objects between two and ten meters from the illumination source though the camera may be placed closer. The principles considered here can easily be adapted to alternative light sources depending on what is readily available, allowing variable range of use and manufacturing techniques.

The array has some applications for true color reproduction if the emissions spectra of the displaying screen is known however this has not been considered in this project. [9]

The array could also be used as a variable color constant illumination source for applications such as theatre lighting, however this would require vastly improved heat sinking and increased safety tolerances.

System Design

The Multispectral Identification array consists of nine components, two of which, the human user and the environment under test are actually considered outside the system. The other seven components are the main computer which provides all synchronization and processing, the camera which provides images of the environment, the LED microcontroller [10] which provides program control to the electronics, the LED power supply which provides the 24V power supply necessary to run the LED's, the LED controller which provides multiplexing of the LED's, the LED array itself, which allows illumination of the environment, and the filters which allow each LED in the array to emit a different spectra. This system is detailed in *Figure 1*.

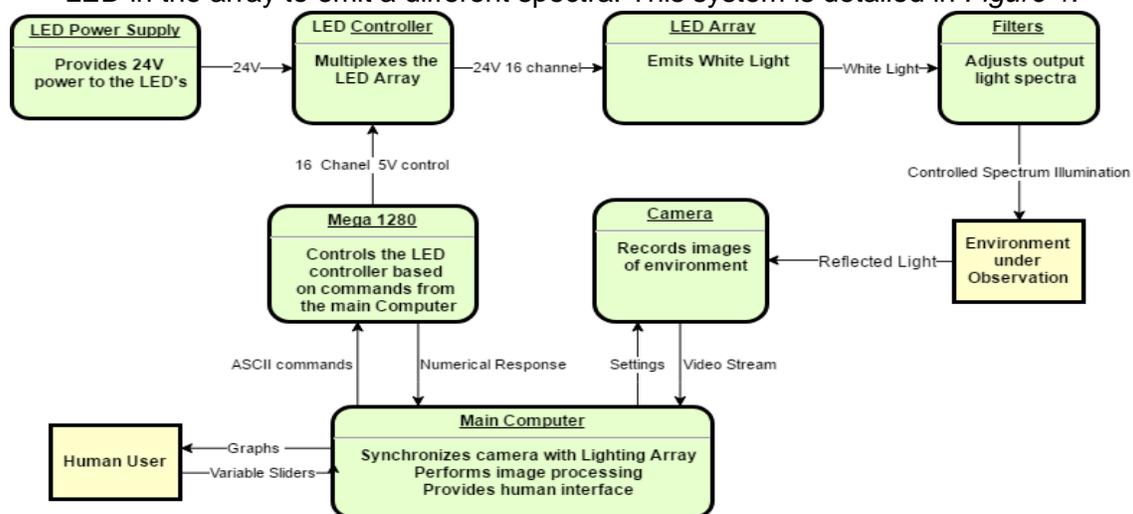


Figure 1: Functional Decomposition of MIA

LED Selection

The LED's used were chosen for high luminosity and a relatively broad spectrum. Multiple high power white LED's were examined for traits such as luminosity, viewing angle, spectrum, heat dissipation and input voltage. By these metrics the Luxeon L150-3080502400000 was chosen. [11] This Luxeon model is a 24v high efficiency LED in a standard SMD5050 package. The broad double peaked spectrum as seen in *Figure 2* is produced by passing the light of a blue LED at 450nm through a phosphor coating which absorbs and emits the energy in a broader peak centered at 600nm. [11] This spectrum is as close to ideal as is possible with current commercial grade LED's. Of particular importance are the rapid drops in power at either end of the spectrum. These drops provide a clear range over which the array can be expected to operate, and ensures that no significant light is emitted outside the range of the calibration spectrometer.

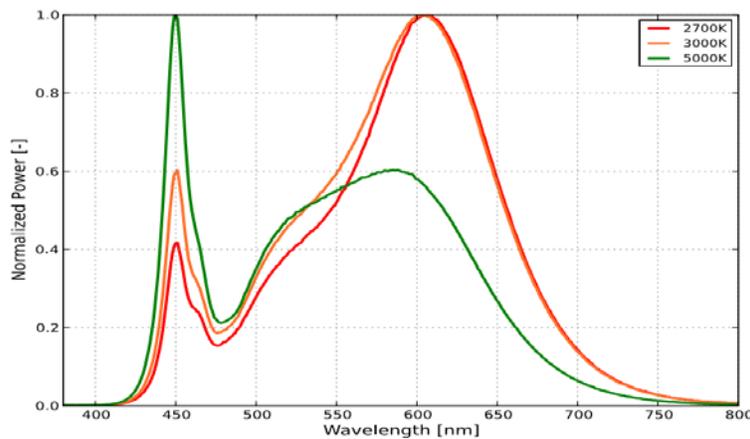


Figure 2: Luxeon LED Spectra

Filter Selection

RoscoLux theatre and cinema grade filters were chosen due to their high availability, low cost, and high thermal stability. [12] Initially, random filters were chosen from the RoscoLux Swatchbook with consideration given only to total absorption percentage. Only filters with absorptions between fifteen and sixty percent were considered. Lower absorption levels tended to produce spectra which were largely indistinguishable from the LED's alone while higher absorption filters tended to be too dim for use at ranges of more than a meter and also became much hotter during prolonged use.

Later filters were specifically chosen to fill in gaps in the net spectra and to compliment filters with double or triple peaked spectra. *Figure 1* and *Figure 2* show the measured output spectra of three filters combined with the array LED's. Other filters are shown in Appendix B.



Figure 3: Captured spectra of a filter

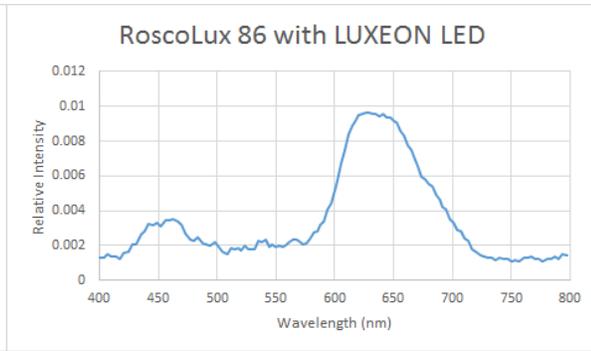


Figure 4: Captured Spectra of a filter

Camera Selection

The camera used was a Logitech C920 webcam. [13] This webcam was chosen for high compatibility with the openCV library. The C920 provides a full size 1080p uncompressed 30Hz video stream from which single images are taken in coordination with the lighting array. Settings such as ISO, exposure and aperture are set based on a few frames taken at startup. [14] All automatic features are then disabled to ensure consistent images regardless of changes in the scene or lighting.

To demonstrate the versatility of the design with other cameras a Nikon D3500 was integrated with the lighting array. This full DSLR still photo camera is not directly supported by openCV and has a far lower frame rate than the C920. [14] However, the Nikon D3500 is able to take far higher resolution images with greater color depth. Integration with the openCV libraries required triggering through the external software package gphoto2.

Electronics Design

Array Board Design

Several board designs were considered for the LED array. Initial concepts included a standalone square, or circular array, with even spacing of LED's. However in order to present as even an exposure as possible from each LED, and to minimize shadows caused by a nonzero angle of incidence it was chosen to place the LED's in a circle around the camera. This was later revised to the final circular arrangement of eight groups of eight LED's.

Due to manufacturing constraints the Array was designed in standalone quarters which can be combined to form a full circle. As shown in *Figure 5* each quarter contains two groups of eight LED's and is capable of operating independently of the others. Each LED is paired with its own current limiting resistor. These resistors can be replaced with a wire short in the event that the anodes or cathode inputs are limited by the array multiplexer, and it is known that more than one LED will never be illuminated simultaneously.

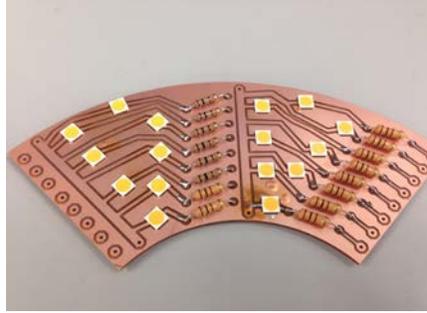


Figure 5: One quarter of the LED array showing two groups of eight LEDs

The Array board was milled from FR1 double sided copper clad using an Othermill provided by the innovation sandbox. If chemical etching is used, then the more common FR4 fiberglass copper clad may be used. However, if used with the Othermill FR4 will dull the bits and produce harmful fiberglass dust. [15]

LED Array Multiplexer

The LED Array Multiplexer controls power to the array. The multiplexer uses N channel MOSFETs to control the connection of the Array anode line to the 24V input supply, as well as the connection to ground for the Array's cathode lines. So long as the electrical connections for the LED's in the array are compatible, the physical layout is unimportant. To power a single LED both the anode for that LED's row and the cathode for that LED's column must be active. Powering multiple LED's is possible by activating multiple anodes or cathodes simultaneously. When powering multiple LED's, it is important to keep in mind both the current requirements and heat dissipation. Since the MIA array was not designed to dissipate heat from more than one LED at a time the board can quickly exceed the thermal limits of the FR1 substrate. Similarly, the 24v power supply chosen for this project was not designed to handle the current draw of more than three LED's at a time and will shut down to prevent damage.

Because N channel MOSFETs were used for both anode and cathode in the multiplexer, the anode side has a second stage of NPN transistors to drive the MOSFETs. The result of this driving layer is that the anode side has a logic HIGH of 0V and a logic LOW of 5V. This is inverted from the logic levels of the cathode side where LOW is 0V and HIGH is 5V. The anode

MIA

side is shown in *Figure 6*.

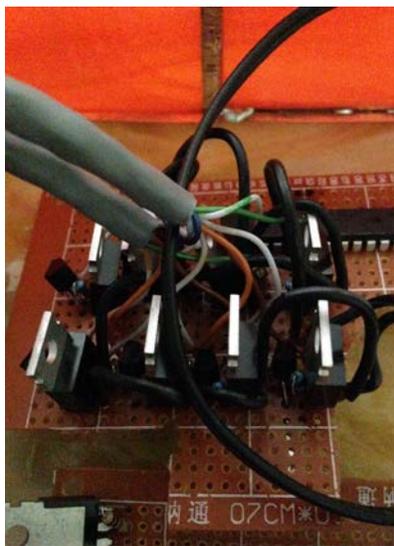


Figure 6: The Anode Control Circuit

Software flow

Over the course of the project several software designs were used to achieve different effects. To achieve real time image processing a multithreaded version was used which broke image retrieval and lighting coordination into one thread, while image processing and display was separated to a second thread. Using this method, a processed frame rate of nearly five frames per second was achieved. However, the performance was inconsistent even with all other programs closed and this version suffered from frequent loss of coordination with the lighting array.

The final version of the software is much reduced in scope however provides much more consistent results. The final version utilizes a single threaded flow which allows blocking until lighting array and camera are synchronized, this reduces the frame rate to as low as one processed frame every three seconds however each image used is guaranteed to represent the full brightness of its associated lighting environment. To reduce the appearance of a slow frame rate, captured images which would otherwise be discarded are redirected to the main image display. This provides real time video allows a more fluid user interface. It should be noted though that this means analysis of pixels will not correspond to the objects selected for viewing if those objects moved between the time selected and the last multispectral frame.

Valid Pixels

Validity of pixels for use in a solve is determined by two factors, the saturation of the pixel, and the difference between the intermixed ambient, or white light frames.

The saturation of the pixels used is restricted to the range between twenty and eighty-five percent of the brightest pixel in the image. This filters out most external light sources which may appear in an image as well as removing pixels which are black except for noise data. Black pixels may actually be the result of a black material however most often they are simply the

result of shadows or objects which are out of the range of the lighting array. Additionally, most cameras do not have linear sensitivity outside this range and so as a general rule, pixels outside this range should be considered invalid.

Since it is not always known when taking data whether the objects under observation are moving or not, a series of frames are taken before, after and interspersed with the illuminated images. If ambient light is sufficient, these frames may be taken with no illumination otherwise an unfiltered white light source is used. To determine motion in the image which may corrupt a solve the difference of these frames is compared to a threshold value. Pixels which change more than the threshold value between any two interspersed frames are considered invalid. Generally for slow moving objects motion is only a problem at the edges however fast moving objects may be thrown out entirely.

All remaining pixels are considered valid, at this point the average ambient light for each pixel is subtracted from the illuminated frames which leaves only data from the illumination source and noise. Figure ?? shows the valid pixels in a bright room, fluorescent lights are almost entirely removed from consideration and pixels which are entirely green red or black indicate a location the filters have identified as potentially moving. In the case of moving pixels the color displayed is indicative of the direction the filter thinks the pixel is traveling however this is a feature from an earlier use of this filter and all moving pixels are simply ignored.



Figure 7: filtered image on the left, unfiltered image on the right

Array Communication

Communication between the main computer and the Array microcontroller is achieved by UART serial communication. The baud rate is 115200 with a single stop bit and odd parity. The Array is considered slaved to the computer and will only respond to data received. Acceptable commands are shown in table COMS 1. When a command has been received and the Array's task is complete it will reply with the value of the current lighting environment. The value of the black environment where no LED's are illuminated is always equal to the total number of environments. Because of this the true number of lighting environments available is always one more than the actual number of LED's. All commands are terminated by newline and only one command at a time will be accepted on either side. Additional serial data is always thrown out until either the main computer is ready to send another command or the Array has completed its task and has responded with the new illumination value.

Camera Communication

Communication with the camera is twofold, during initialization some settings which are not supported by openCV are handled via the V4L2 Linux video API. This allows greater control over camera settings however is a much more complicated API so once settings have been written to the camera's memory the file handle for this API is closed and the camera is reopened using the standard openCV methods. This is effective for the Logitech C920 camera used however other cameras may not maintain the settings once the V4L2 handle is closed.

Since the openCV library does not support taking single images from webcams the file handle to the C920 camera points to a FIFO buffer in which up to eight frames are stored. This buffer updates continuously at a measured speed of 29.8Hz. The exact buffer size is a function of the particular version of openCV used and the underlying platform specific driver. In order to ensure that frames read from this buffer are the latest and thus correspond to the current lighting environment, the buffer must be continuously emptied. This was the great advantage of the multithreaded version of the MIA software which allowed continuous retrieval of images to keep the buffer empty. Frames retrieved which have been buffered require slightly less time to load than frames which are retrieved directly from the camera, thus by timing the retrieval, the software determines whether or not a frame is valid under the current lighting environment. To be safe the current code always throws out at least one frame for every lighting environment. This reduces the maximum frame rate dramatically but ensures valid results.

Spectral Solve

The spectral solve used in the array relies on the assumption that 64 spectra, is sufficiently close to infinite random spectra to produce an approximately true result. The ideal version of the array would use an infinite number of randomized spectra whose average sum is 1.

Mathematically the solve used to produce the spectral graph is as follows.

$$S_P \approx \sum_{n=0}^N \left[S_I[n] * \frac{I_R}{I_C * N} \right] \text{ when } \lim_{N \rightarrow \infty} \text{ and } \sum_{n=0}^N \frac{S[n]}{N} \approx 1 \text{ and } I_C \geq I_R$$

Where

S_P = Spectra of one pixel

N = Total Number of illumination spectra

S_I = Spectra of illumination source

I_R = Illumination value recorded by pixel

I_C = Illumination value recorded by calibration pixels

In practice this involves at least one pixel in the image which is considered to be flat white and completely reflective. For practicality a retroreflector or white paper is used. Each Illumination source must have a known spectrum within the range of the camera's sensor. This spectrum is then scaled by the ratio of the pixels recorded value for that spectra divided by the recorded calibration pixel and the total number of illumination sources. The resultant spectra are then summed with the results from all other illumination sources. As the number of illumination sources becomes sufficiently large the resultant calculated spectra for the pixel will approach

the actual spectra which would be received by a spectrophotometer when the subject is illuminated by a flat white light.

Testing

Testing of the Array was performed in three stages, first the solve algorithm was modeled using a series of spreadsheets to provide an analytic basis on which to judge the performance of the Array. In these spreadsheets the effects of using random, sinusoidal, stepped, bell curved, linear and flat spectral curves was examined. Also examined was the effect of using various numbers of illumination spectra. Then the uncelebrated array was tested on its ability to differentiate objects based on color. For this test a version of the code plotted the relative intensities of each illumination spectra on a graph, and produced an image showing only pixels which matched each point on that graph to within a threshold. This test was intended to identify objects with extremely similar color. The final test utilized the calibrated data from spectrometer measurements of the filtered light sources to attempt to produce similar quality spectral solves to the spreadsheet tests.

System Performance

The first test using spreadsheets to simulate the solution did not return the expected perfect results. Further analysis indicated a fundamental flaw in the solve which must be rectified before the Array will be able to produce usable graphs. The problem is that while impulses, steep bell curves and other highly correlated spectra will produce approximately usable graphs, all secondary peaks cause an inflation in the values associated with the primary. For random or multi-peaked spectra this problem tends to inflate the error to over 78% essentially an output graph which is almost but not entirely unrelated to the actual spectra of the sample. Figure performance 1 shows the most closely correlated graph which was achieved using output spectra from actual measurements of the filters during calibration. For this test an imaginary subject with a linear spectrum was used as it would be extremely clear if the output graph was accurate. Unfortunately, this closest matching spectrum still had an average error of 36%.

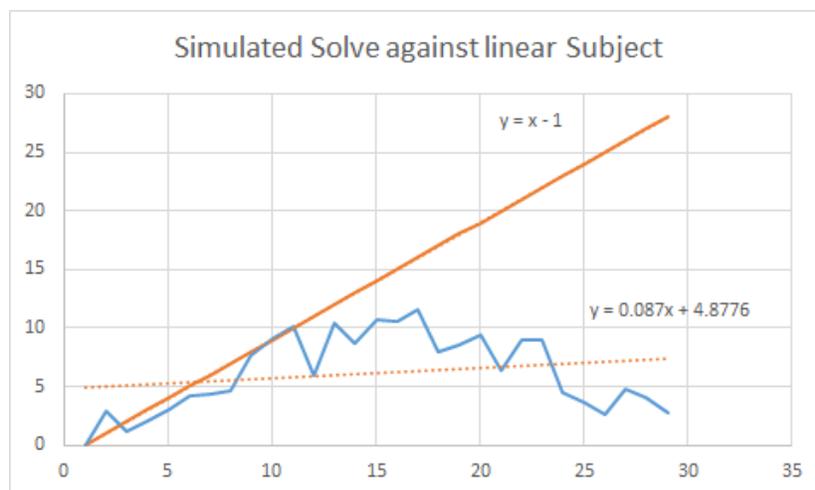


Figure 8: The orange line indicates spectra under test while blue indicates the computed curve

Further research since Senior Project Expo has located two research papers which describe

both the mathematical error for similar systems and solutions for producing accurate curves. One notable paper from 1977 presents a methodology remarkably similar to this project including simulations which indicate effectiveness of the method. Though there has not been time to include this new research into an updated version it indicates future work is merited.

The second tests however, which focused on the system's ability to differentiate objects were much more successful. These tests were performed informally in a dark room. Under these conditions the array was able to consistently locate objects within the room. Subjects included a roll of yellow tape a blue backpack a blue highlighter, a cardboard box, and a whiteboard. The array was able to locate each object with the exception of the whiteboard. When directed to locate the whiteboard the array also identified the walls as sufficiently similar. However, the array was able to differentiate the pen even when placed on the blue backpack.

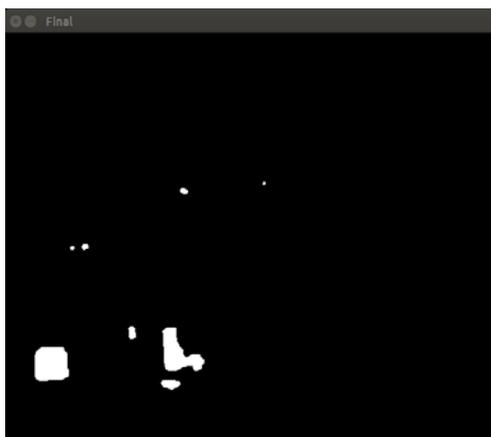


Figure 9: Test to locate cardboard objects within image, several were missed however all white sections do correspond to cardboard objects

The third test an example of which is shown in *Figure 10* produced graphs of similarly poor quality to the first test and was abandoned quickly in favor of further tests of object differentiation.

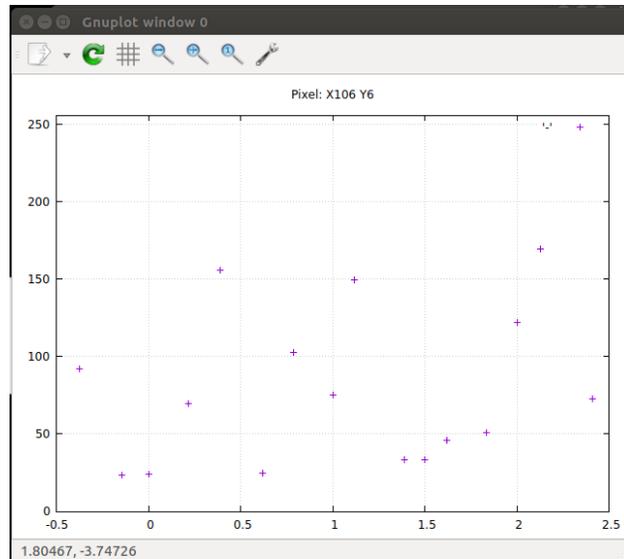


Figure 10: Generated graph with low correlation to actual spectra

Conclusion and Future Work

Though the Multispectral Imaging Array still requires development, preliminary testing suggests it is already capable of dramatically increasing object detection based on color in machine vision applications. More precise spectrographic approximations still present significant challenges of decoupling and digital signal filtering, however most evidence so far suggests usable analysis of foreign materials can be accomplished through illumination only, without the use of a diffracting spectrometer. Further developments include; reselection of filters based on experience gained with the first version, redesign of the array geometry for portability and robustness, and further development of the spectral solve and machine vision applications.

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Appendix A (ABET Senior Project Analysis)

Summary of Functional Requirements

The MultiSpectral Identification Array (MIA) is a combination of multiple filtered light sources with a camera and computer. The Array is designed to illuminate a subject with a series of up to sixty-four filtered light sources, take a picture in each lighting environment, then analyse the captured frames to produce a spectroscopy style graph for each pixel. The array, has extremely limited accuracy as a spectrometer however has shown capable of differentiating objects and thus has applications in machine vision.

Primary Constraints

The primary constraints for the project were, cost, mobility, and manufacturability. Since this device was intended to be useful for amateur data collection, ideally in marine environments, the cost, and difficulty of acquiring materials could not be prohibitive for a single individual. The total array, including camera and controlling computer also had to be sufficiently small to fit in a mobile enclosure. Finally, the array must be easy to manufacture, if necessary by hand but ideally with chemical etching or milling of surface mount circuit boards. While the software is not designed to be portable it is primarily based on the cross platform openCV library which will allow portability with relatively minor modifications.

Economic

Initial estimates of the materials costs for the project where between \$142 and \$712. This wide range was due to uncertainty about what primary components would be used and what the final manufacturing process would be. The main factors in the cost as estimated at the beginning of the project were the LED's, the Camera, and the main computer. At the time the most expensive approach utilized high end colored LED's with a DSLR camera and Nvidia Jetson TK1 stand-alone graphics board for the main computer.

The actual cost of producing an exact copy of MIA using off the shelf components is \$376.11 as detailed in the Bill of Materials. However, many of the components may be obtained with little effort by recycling from other electronics. This simultaneously reduces costs and is far more environmentally friendly. The attached BOM identifies which components of the final array were recycled either from other projects, discarded electronics, or which were simply appropriated from personal supplies. Additionally, project development required roughly one and a half times as many LED's as are listed in the final BOM so actual the per unit cost may be slightly higher to reflect price breaks.

Part Category	Part Type	Selected Part	Vendor	Qty	Unit Cost	Cost	Purchased ?	Received ?	Details	Link
---------------	-----------	---------------	--------	-----	-----------	------	-------------	------------	---------	------

Central Control	Main Computer	hp Celeron Stream	Amazon	1	\$220	\$220.00	Yes	Yes	(Recycled, personal laptop was refitted to run openCV under a linux environment)	https://www.amazon.com/HP-Stream-14-ax010nr-Celeron-Personal/dp/B01JLCKP34/ref=sr_1_3?ie=UTF8&qid=1497308449&sr=8-3&keywords=hp+celeron+laptop
	Camera	Logitech C920	Amazon	1	\$62	\$61.99	No	Yes	(Borrowed From CalPoly)	https://www.amazon.com/Logitech-Widescreen-Calling-Recording-Desktop/dp/B006JH8T3S/ref=sr_1_1?s=pc&ie=UTF8&qid=1497308789&sr=1-1&keywords=Logitech+C920
	Array Controller	Arduino Mega1280	Amazon	1	\$9.99	\$9.99	Yes	Yes	(Recycled && Obsolete use Mega2560 for future versions)	https://www.amazon.com/dp/B0711F2ZHX/ref=sr_pa_click_within_right_1?pf_rd_m=ATVPDKIKX0DER&pf_rd_p=3008539542&pf_rd_r=C569VAZHY5YDBDR37XEG&pd_rd_wg=35Em1&

										pf_rd_s=desktop-rhs-carousels&pf_rd_t=301&pf_rd_w=qzqKQ&pf_rd_i=ARduino+Mega+1280&pf_rd_r=YBVQBWVQ5CJPDGGAE01&psc=1
LED Array	LED's	Luxeon White Warm 3000K SMD	Digikey	64	\$0.75	\$48.15	Yes	Yes		https://www.digikey.com/product-detail/en/lumileds/L150-309050240000/1416-1965-1-ND/6196411
	Resistor Current Limiting	100 Ohm 1/2W	IEEE	64	\$0.10	\$6.40	Yes	Yes		
	Copper Clad Blanks	FR1 Double Sided 4"X5"	OtherMachine	4	\$1.28	\$5.12	Yes	Yes		https://othermachine.com/store/materials/pcb/
	Filters	RoscoLux Swatchbook	Adorama	1	\$1.75	\$1.75	Yes	Yes		https://www.adorama.com/rosb.html?gclid=CMmpl6q3udQCFYF-fgodlyAIGA
Array Power	Wires	24 Awg stranded		20	\$0.01	\$0.20	No	Yes	(Recycled)	
	Pins	Male Pin Header		2	\$0.02	\$0.04	Yes	Yes	(Recycled)	

Power Suply	HP 24V 132mA Printer supply	Ebay	1	\$9.99	\$9.99	Yes	Yes	(Recycled)	https://www.ebay.com/i/122527241730?chn=ps&di spltem=1
Power Switch	Toggle Switch	SparkFun	1	\$1.75	\$1.75	Yes	Yes	(Recycled)	https://www.sparkfun.com/products/9276
MOSFET	IRFZ44N	Amazon	16	\$0.27	\$4.26	Yes	Yes		https://www.amazon.com/SODIAL-IRFZ44N-IRFZ44-Transistor-N-Channel/dp/B00L8VC9TK/ref=sr_1_1?s=electronics&ie=UTF8&qid=1497310427&sr=1-1&keywords=IRFz44N
NPN Transistor	2N3904	IEEE	8	\$0.06	\$0.47	Yes	Yes		
Pullup Resistor	4.7KOhm 1/4W	IEEE	8	\$0.10	\$0.80	Yes	Yes		
Pull Down Resistor	1KOhm 1/4W	IEEE	8	\$0.10	\$0.80	Yes	Yes		
ProtoBoard	universal copper rectangle	Amazon	1	\$4.40	\$4.40	Yes	Yes		https://www.amazon.com/Prototyping-Universal-Copper-Rectangle-Circuit/dp/B00EDJZ7Z2/ref=sr_1_6?s=electronics&ie=UTF8&q

Given an appropriate waterproof enclosure, users should expect approximately one noncritical component failure every two months. This is based on experience working with the present version of the array and could be dramatically improved by increasing safety tolerances and heatsinking. The array can be left on unattended for significant lengths of time, primarily depending on available storage for collected data streams. The cost to operate on a remote buoy as suggested would primarily be in terms of power and data storage. The Array requires approximately 3GB of storage per hour of runtime and uses roughly 73 watts of power. Combined this would allow the array to be used only sparingly on most conventional buoys. When attached to the California power grid at approximately 12 cents per kilowatt hour the Array requires only 20.73 cents per day of operation.

Environmental

Environmental impacts of the manufacture is primarily in the rosin core lead solder and the electricity usage of the soldering iron. The cellulose and resin based FR1 copper clad blanks are non-toxic and utilizing a CNC mill instead of chemical etching significantly reduces manufacturing impact on the environment. This analysis ignores the high environmental cost of manufacturing the stock integrated circuits used as well as the impact of the entire laptop which is no doubt significant but is largely a proprietary secret.

Manufacturability

Describe any issues or challenges associated with manufacturing.

The most complex aspect of the project, the Array control circuit was assembled by hand using a proto-board. This aspect required approximately three hours to complete and due to a mix-up with labeling on the NPN and PNP transistors had to be redone requiring an additional half hour. This aspect of the project however could be made significantly easier and less time consuming by utilizing a milled circuit board similar to the main LED Array.

Sustainability

The hardest part of maintaining the completed system is ensuring that a control failure never occurs. In the event that a single LED is left on longer than a few minutes it will overheat and the limiting resistor will burn out. A simple watchdog timer could be added to prevent this event however this version of the Array does not include such a safety feature. Otherwise maintaining the device is a simple matter of wiping down the filters or camera lenses if they get too dusty, and ensuring that the main computer always has sufficient memory to store the video stream.

The Project is designed in part to increase collected data about water quality and marine ecosystems. If adopted it could have a positive effect against the use of harsh chemicals close to shore. However, as a one off device the manufacture and use of this device must be considered to be detrimental to the environment until such time as it is proven useful.

Improvements.

Upgrades to the system which would cause a dramatic improvement are as follows.

- First redesign of the array from a hollow circle to a more maintainable standalone rectangle. The hollow circle design was intended to minimize shadows and provide a consistent incidence angle for the light however given the effective range of use this turned out to be unnecessary so long as the LED's are within a few centimeters of each other.
- An improved casing and battery based power supply would allow the array to become mobile enough for field tests.
- Reselection of the filters used could provide more consistent results. A lot of data has been gathered on the effectiveness of the current filters and trends are clear which could advise future selection. Namely, filters which produce a thin bell curve are significantly more useful and these are most often produced by higher absorption filters.
- Additional heat sinking and safety tolerances are a high priority improvement. Full watt resistors and aluminum slinked PCB would allow the use of the Array to expand into the theatre lighting industry.
- A faster main computer would be much less frustrating to operate. The current model often struggles with heavy image processing algorithms and has low available storage for the video stream.

The primary challenge with upgrading the design is utility. More theoretical research and analysis of the project must be done to determine if further upgrades are warranted. Given that they are warranted there is very little to cost to further upgrades in either time or money with the exception of upgrading the main computer.

Ethical

Misuse of the device could be as simple as utilizing it as the sole measurement of surface spectra or as sophisticated as using it for machine vision applications in a targeting system. While the device is not sophisticated enough for such endeavors it is nonetheless conceivable. Use of the Multispectral Array outside of preliminary sample filtering and data collection is not intended. If used as more than such a preliminary filter would be placing undue credibility in the device when other more accurate systems already exist. If the margin of error is then not properly reported and results taken as factual the harm to the scientific community could be significant.

Health and Safety

The primary health and safety concern with the Multispectral Array is the risk of triggering Photosensitive Epileptic Seizures. The flashing multicolored lights of the array closely match descriptions of common triggers of PSE seizures. This can affect many animals as well as humans. A less dangerous side effect of viewing the device in operation is a mild headache and temporary spots in the vision. The lights used are extremely bright and absolutely should not be used around species known to be sensitive to light.

Social and Political

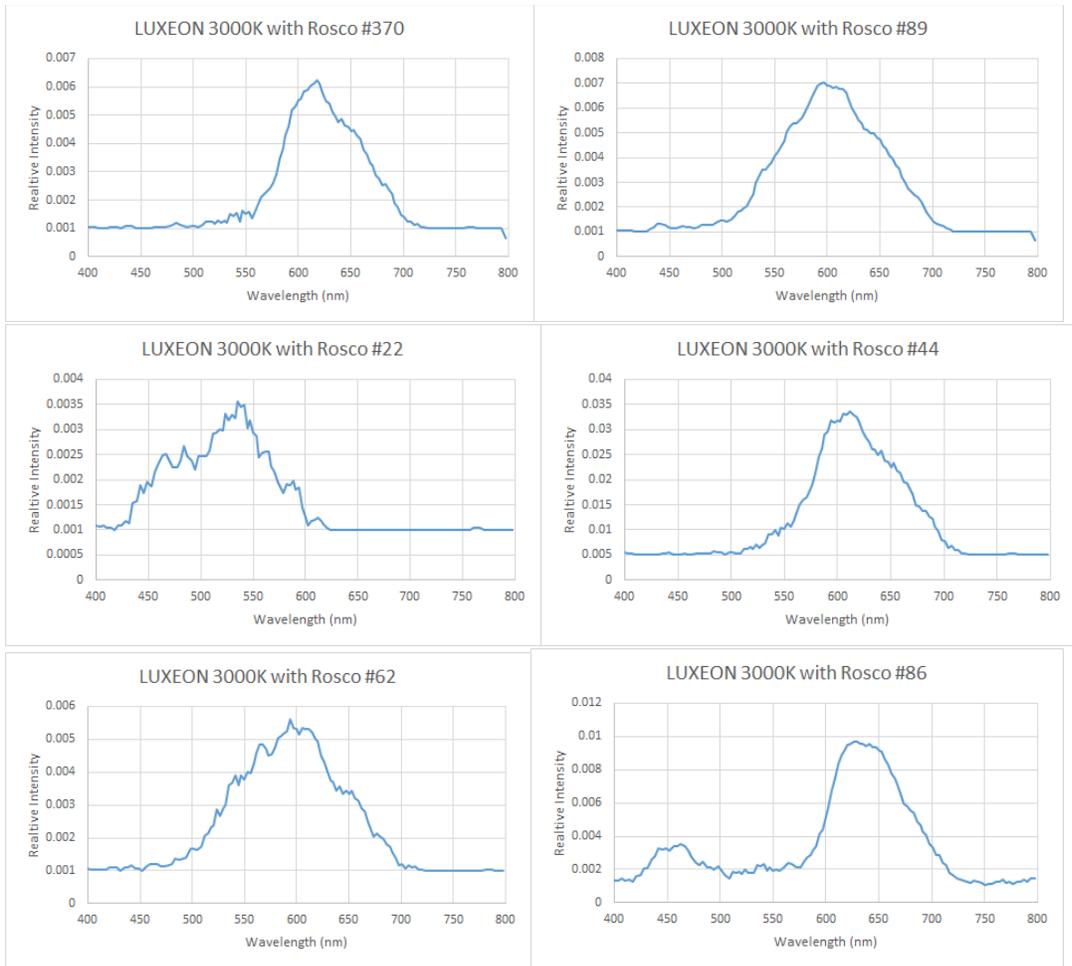
The array is intended to be used in environmental research. As such it is potentially a politically controversial device. There is also the potential for use in cataloging or differentiating humans based on otherwise imperceptible skin coloration. This would be the absolute worst use of the device currently imaginable and is not intended in any way.

Development

During the development of this project, I learned and became proficient at surface mount soldering, eagleCad component design, image processing techniques, and medium size project organization including the use of the git version management system. Most importantly I learned how to log nearly every hour spent on a project, to write everything down, and to keep track of all my work in an organized fashion.

Appendix B (Spectra of Selected Filters)





Appendix D (Electronics Schematics)

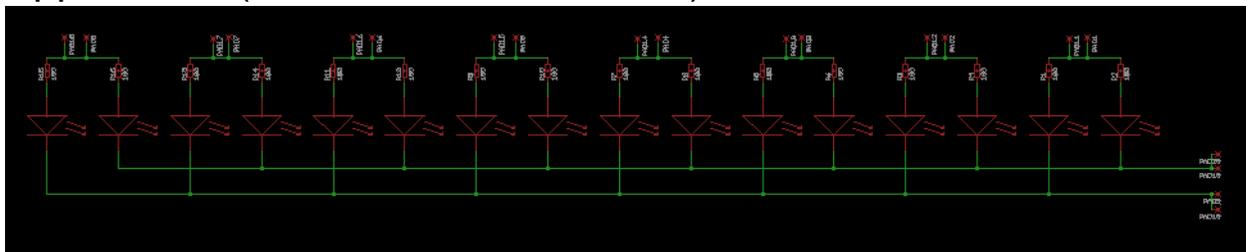


Figure D1 shows the total electronics schematic for one quarter of the LED Array. External connections are connected by wire to the control circuit below.

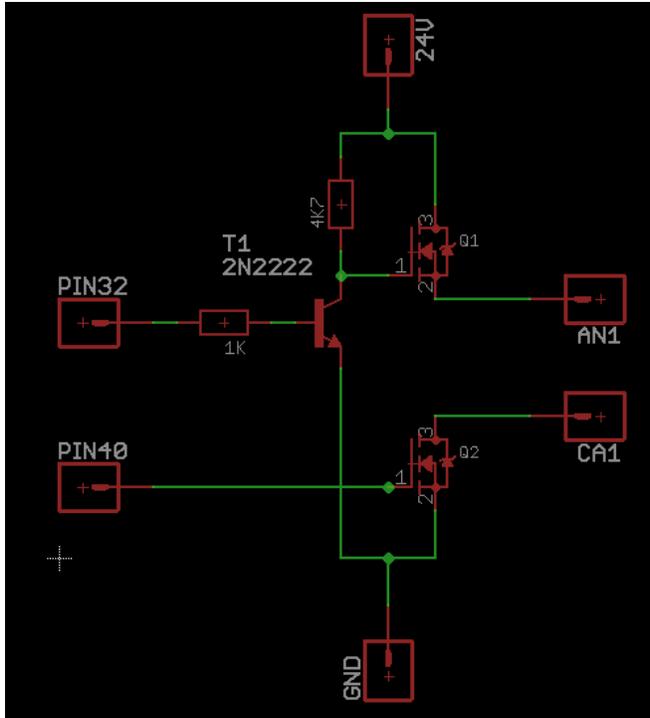
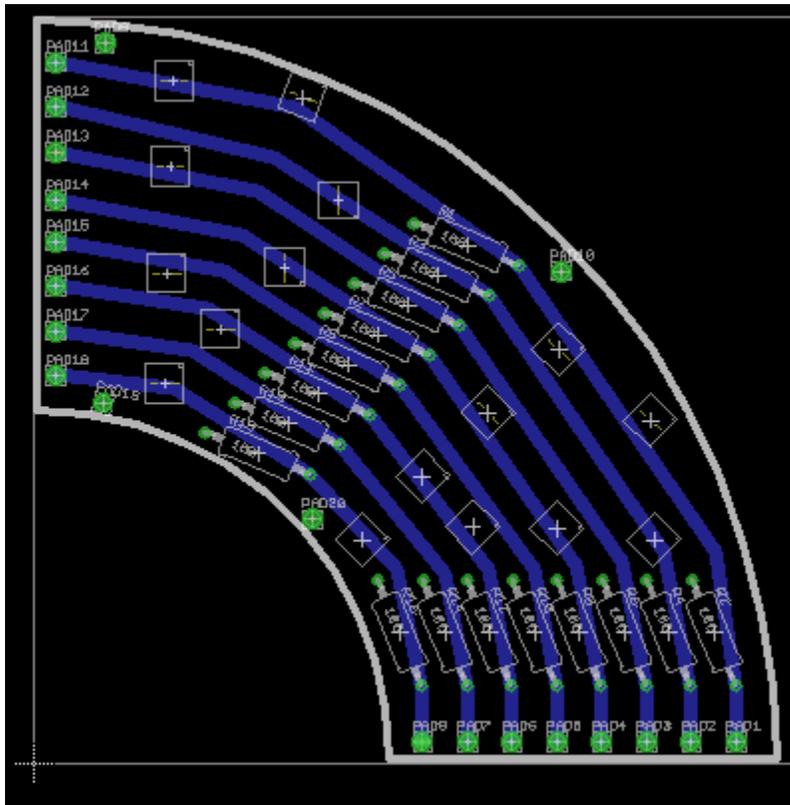


Figure D2 shows a circuit containing one anode supply and one cathode supply. The total array control circuit consists of eight copies of this circuit.



MIA

Figure D3 shows the backside of the LED array board. This side is primarily used to conduct current to the anodes of the LED's. Components shown are mounted on the A side.

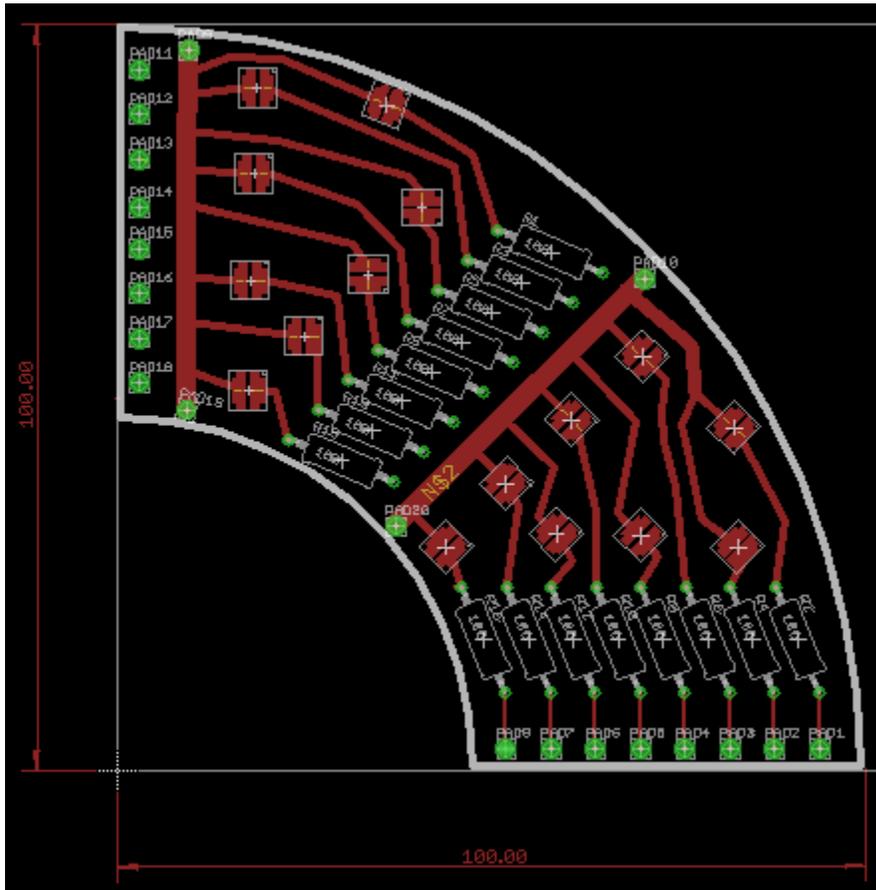


Figure D4 shows the front side of the LED array board. This side provides the mountings for components shown. Pads for the LED's are SMD5050 compatible. Scale shown is in Millimeters.

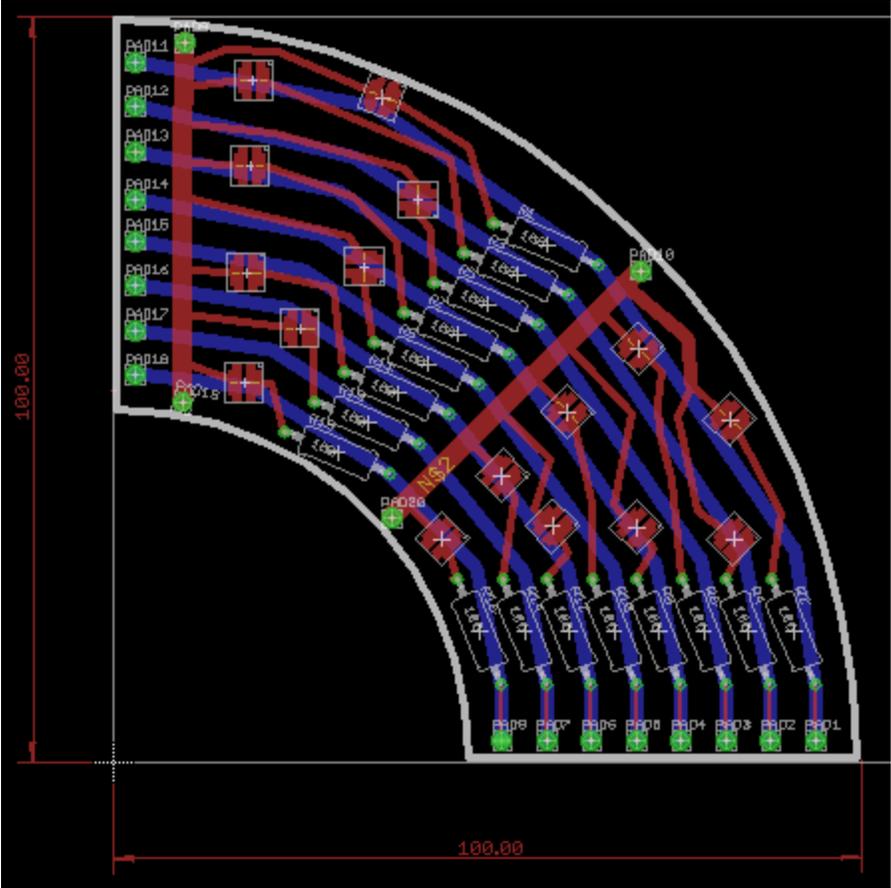
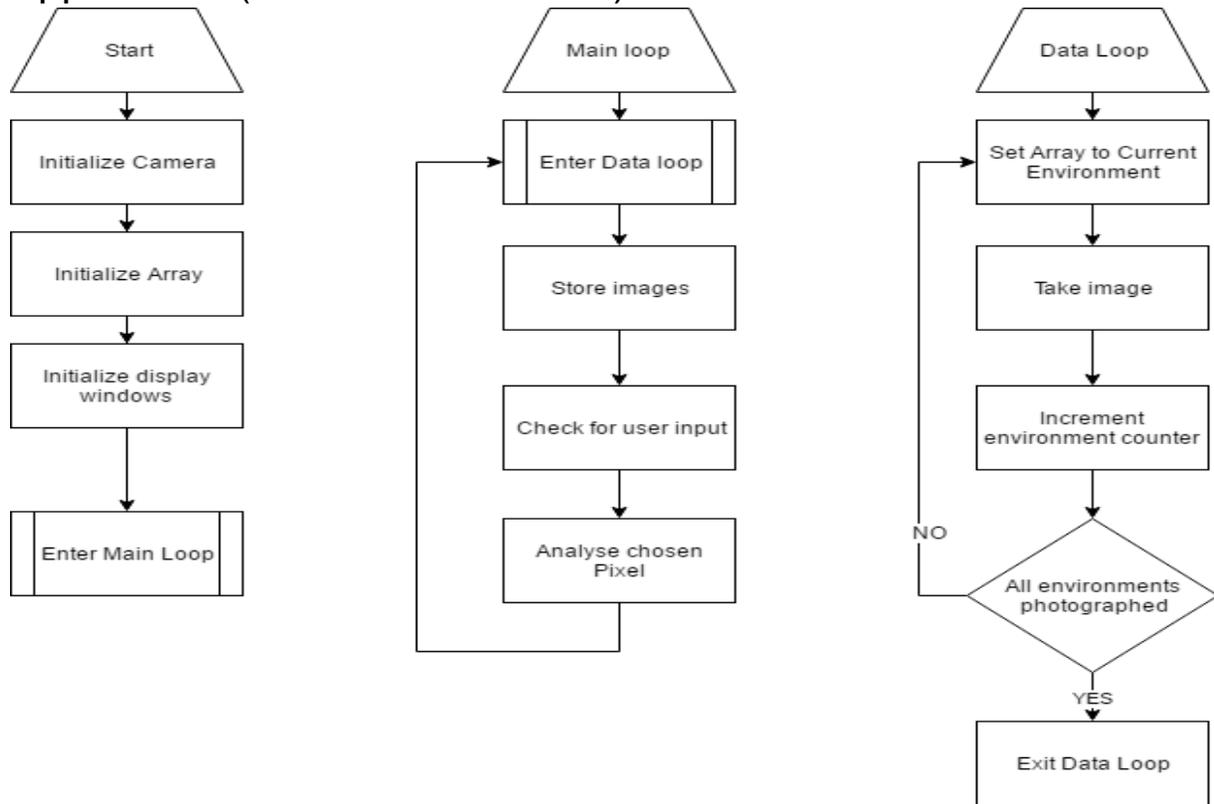


Figure D5 shows the overlay of the front and back side of the LED array board. Scale shown is in millimeters.

Appendix F (Software Flowchart)



Appendix G (Array Firmware)

```
#define NUM_AN 8
```

```
#define NUM_CA 2
```

```
#define NUM_LED 16
```

```
#define ANOD_START 30
```

```
#define CATH_START 38
```

```
void setup() {
    for (int i = 0; i < NUM_AN; i++) {
        pinMode(i + ANOD_START, OUTPUT);
        digitalWrite(i + ANOD_START, LOW);
    }
}
```

MIA

```
for (int i = 0; i < NUM_CA; i++) {
    pinMode(i + CATH_START, OUTPUT);
    digitalWrite(i + CATH_START, LOW);
}

Serial.begin(115200, SERIAL_8E2);
}
boolean refresh;
char cur_led = 0;
char cur_an = 0;
char cur_ca = 0;

void loop() {
    while (!Serial.available());
    refresh = false;
    switch(Serial.read()) {
        case 'I':
            cur_led = NUM_LED; // default state is all LED off
            refresh = true;
            break;          //For other Arrays may be white

        case 'N':
            cur_led++;
            cur_led %= NUM_LED ;
            break;

        case 'R': refresh = true;
            break;
    }
}
```

```
        default : refresh = false;
                break;          //Other options NULL
    }

//Set the LED array to correct value if a refresh instruction received
if (refresh) {
if (cur_led < NUM_LED) {
    cur_an = cur_led % NUM_AN;
    cur_ca = cur_led / (NUM_AN + 1);
} else {
    cur_an = NUM_AN + 1;
    cur_ca = NUM_CA + 1;
}
for (int i = 0; i < NUM_CA; i++) {
    if (i != cur_ca) {
        digitalWrite(i + CATH_START, LOW);
    } else {
        digitalWrite(i + CATH_START, HIGH);
    }
}
for (int i = 0; i < NUM_AN; i++) {
    if (i != cur_an) {
        digitalWrite(i + ANOD_START, HIGH);
    } else {
        digitalWrite(i + ANOD_START, LOW);
    }
}
}
```

MIA

```
    }  
    //clear buffer, only one command at a time please  
    while(Serial.available()  
    Serial.read();  
  
    if (refresh)  
    delayMicroseconds(1); //Delay to ensure all states have set  
    Serial.write(cur_led);  
    Serial.write(cur_led);  
    Serial.print("e");  
  
    //Serial.println(cur_led + 0);  
}
```

Appendix H (Software)

For full Software please see the git repository at:

<https://github.com/ZacharyEagan/IMGPROC/tree/master/MultiSpectral/MIA>