Small Projector Array System

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***Abstract*— The objective of this project is to determine a solution to alleviate the high cost of flight simulation systems. The solution is to use an array of four small pico projectors in a projector box and use this array to combine a single image onto a curved back projection (BP) dome using warping and edge blending software. This setup will yield the same image quality as expensive simulation systems at a fraction of the cost.**

***Index Terms* — Analog to digital conversion, hybrid integrated circuits,microcontrollers, photodiodes, sensor arrays.**

I. INTRODUCTION

Today's flight simulators have benefited greatly from recent technological advances. High resolution projectors have brought bright, high quality images to military flight simulators. New display technologies such as the collimated and dome display screens have allowed for a depth and realism previously never seen from a video image. However, the combination of these technologies has brought about new issues in the simulator world.

Simulators can come with any number of projector channels, some common configurations being 3, 5, 7, and 10 channel systems. Single input projectors are limited in picture quality, by the ability of the projector to spread these millions of pixels across a screen. Even the high resolution projectors we see today are limited by this lens deficiency. Slight changes in the geometry and light output across the viewing area have proven to cause significant problems for many simulator companies. The collimated and dome display units only stand to intensify this deficiency. Both display systems utilize curved and spherical display systems and therefore warp the original image. This distorts pixels and greatly decreases the light intensity at the edges of our image. This requires the need for warping hardware, software or a combination of the two. The greater the distortion require more man hours needed to warp and align the picture once installed in the system. The warping and distorting of the image will essentially cause a "loss" of pixels, and therefore picture quality.

The use of high quality, high definition projectors also comes at a great cost. The average projector used simply for home theater systems can cost upwards of $5,000. The custom and top of the line projectors used on most flight simulators can greatly exceed this, reaching the $20,000+ range. If you multiply this across a standard five or seven channel system, the cost of the projector system alone can approach $150,000, not including any cost and labor put into the system on installs. A lower cost solution that can be implemented simply with existing setups can yield hundreds of thousands of dollars of savings, especially for sites with multiple simulator setups.

Our immediate idea to alleviate these issues is to look for a different kind of imaging system. Projectors are clearly still the solution to placing our image on the screen, however a different projector or projector setup may allow us to eliminate or at least lessen the effect of these problems.

To combat the degradation in image quality we propose to simply use more projectors. As more projectors are introduced to the system their required coverage of the screen is decreased. Geometry tells us that if we decrease the area of any one spot of a spherical surface to an infinitesimal level, we eventually are left with a planar surface. Therefore if we introduce more projectors we can approach a more planar surface and limit the amount of warping and distorting of pixels. Figure 1 below shows the effect of using multiple projectors as opposed to a single one:

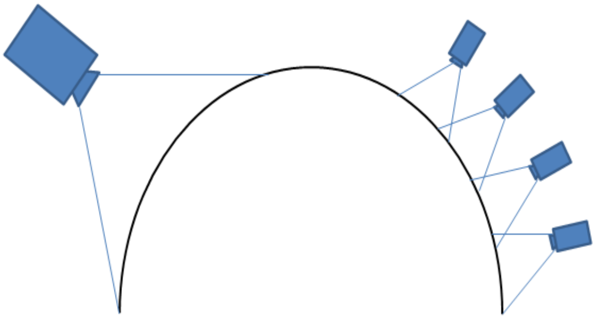


Fig. 1 Shows the spread of a single projector on the left and a projector array covering the same area on the right.

Using more projectors will also eliminate some of the lens issues facing the larger more powerful projectors. Instead of using one say 4 inch diameter lens to display an image, we will now be using five or six 3 inch diameter lens to display the exact same image. This gives more area to spread our pixels around and small minute discrepancies in the geometry of each lens will be rendered negligible to the overall quality of our image.

An array of projectors may sound costly considering most quality projectors can cost thousands of dollars; however the emerging pico projector market offers a suitable alternative to their larger counterparts. Coupling a pico-projector array to the back-projection-screen (BPS) of a WIDE display is highly efficient in terms of physical space and display performance. The individual projectors of the array will shine directly onto the section of BPS in front of them, which means there will be no cross-reflections. This design also allows baffles to be placed between individual projectors to further prevent secondary reflections and stray light from washing out native image contrast. The number of pico-projectors needed to fill up a field-of-view is more than needed using traditional projectors; however the pico-projectors will be far less expensive on a unit basis, at a cost of only a few hundred dollars each. They will also be essentially maintenance-free with excellent color and brightness uniformity over their life cycle, particularly when controlled by an auto-alignment system. These projectors have low power and heat output and will not require any special cooling systems.

Our overall system will encompass a box representing a single projector. However, inside of our box we will implement an array of fourpico projectors.

II. INDIVIDUAL SYSTEM ELEMENTS

The overall system can be divided into different individual elements when integrated together create our final project. These elements areare listed below.

A. Projectors/Projector Array Setup

The pico projector we have decided to utilize is the Acer K330 for our projector array design.The main aspect of the Acer K330 that won us over was that it is capable of outputting 500 lumens which added to the image quality greatly.

Based on the 16:10 aspect ratio of Acer K330 selected, we plan to place two projectors together, one on top of the other to create a square format image (1:1 ratio) that will be easily scalable.

The 4 projector layout (projector 1 , 2, 3 and 4 = 1:1) in Figure 2, given below, would give a format of 2600x1600 for a total of over 4.5M pixels and almost identical to the latest WQXGA format at a fraction of the cost. The 4 projector layout with an aspect ratio of 1:1 will make the most use out of the usable area of the screen that our projector array will be projecting onto.

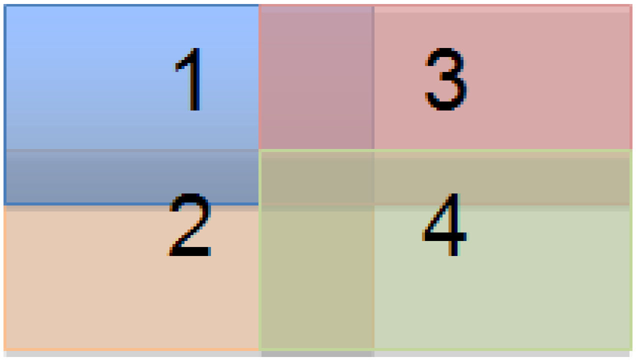


Fig. 2 Four projector layout from projector array

We will place the projector array into a “projector box” which will house the projectors as well as essential microcontrollers used for this project. The box will be made out of aluminum and silk screened red where the box will be visible. Figure 3 given below shows the overall layout that will be used for the projectors when placed into the projector box. An alignment camera will not be used for our final presentation. Q4 will add an alignment camera later in the design process of the Navy SBIR grant. Figure 4 shows the frontal view of the actual projector box which shows off the 1:1 ratio described earlier.

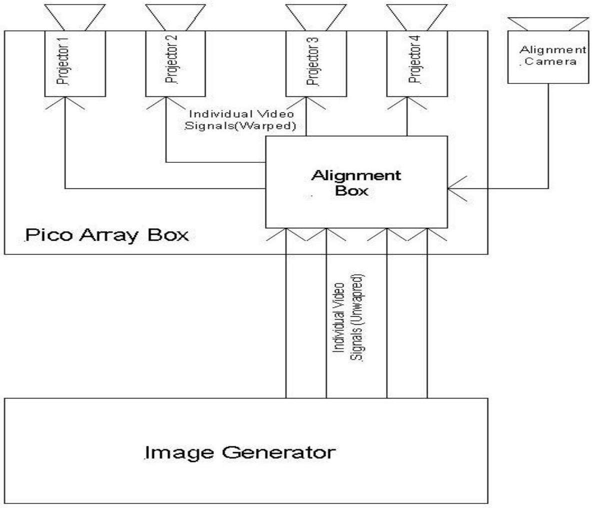


Fig. 3 Overall system layout

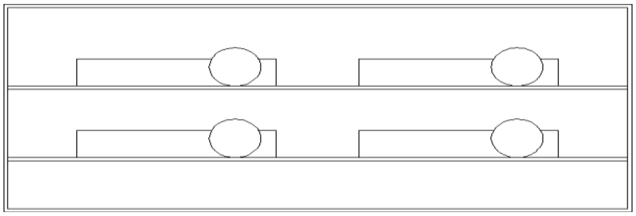


Fig. 4 Frontal view of projector box with 1:1 ratio

B. Interface/Control

The interfacing and control of our system will require synchronization of 3 separate components. A PCB with a microcontroller will be used on our light sensor array to input the analog data from our light sensors and transfer that data to our box. A PCB with a microcontroller will be used inside of our projector box to input the serial data from the light sensor array PCB and transmit this data to the computer. The user interface will be implemented on the host computer system. Each component will be independent and require independent circuit design and/or programming to work properly.

C. Analog Sensors

We will be using the Osram SFH 5711 ambient light sensor. Due to its unique characteristics, the SFH 5711 is able to almost perfectly mimic how the human eye detects light. The human eye is most sensitive to the 550 nm wavelength, and the SFH 5711 is most sensitive at 555 nm. This is only a tiny deviation, which should not have much effect, if any, at all. With the range of the sensor, 475 – 650 nm, within the range of the human eye's sensitivity, 400 – 700 nm, we will be sure to get an accurate reading that is easily compared to our own vision. Figure 5 below shows the range of spectrums different light sensors can detect. From the figure it is seen that both the ambient light sensor and a standard Si detector cover a wide range but the SFH 5711 closely mimics what the human eye can see.

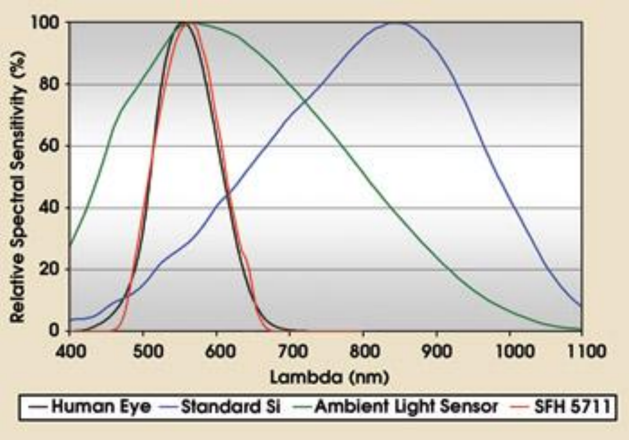


Fig. 5 Relative spectral sensitivity of a standard Si-detector and the SFH 5711 compared to the human eye

D. Analog Sensor Array

The American National Standards Institute or ANSI for short, has issued a standardized way for measuring the brightness of a projector. This method is called the ANSI Lumen Method.

The ANSI Lumen Method requires us to have the image being projected from our projector array to have an aspect ratio of 4:3. Being that our setup uses a 16:9 this will work fine. Then the area of the image needs to be divided into nine equal blocks as shown in the figure below. Then measurements must be taken at the center of each of the nine blocks. When all the measurements are taken, they are all added to together and divided by 9 to get an average reading. Then this average is multiplied by the total area of the image to give the lumens reading in ANSI Lumens.

Figure 6 below shows us the actual setup we will use to test the brightness of our projector array. We will use a PVC structure in front of our BP screen with the Osram light sensors attached to the structure. This is setup in the same way as the ANSI lumens test describes it.

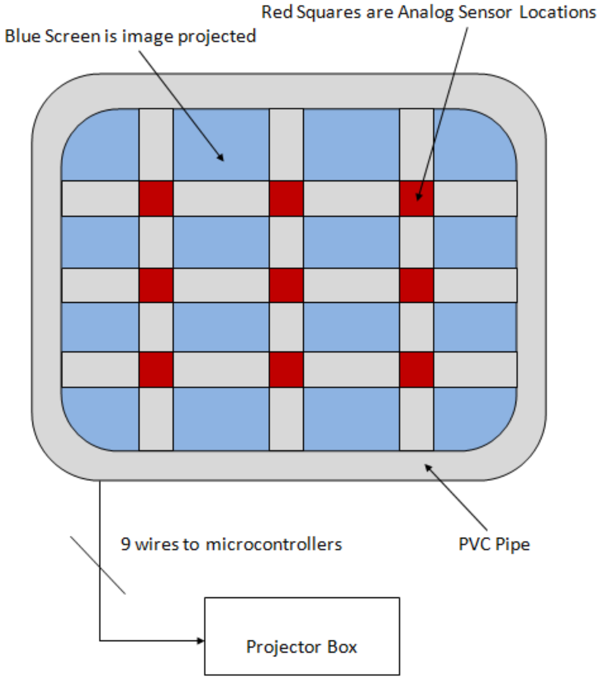


Figure 6: Diagram of light sensor array

E. Software Alignment/Warping

Most auto-alignment systems are still solely research based and done at major universities. We have identified four different systems of auto alignment outside of university research teams: Dome Projection, BSM Auto Alignment, Scalable Easyblend, and Warpalizer. Warpalizer, was identified as the only system cost effective for use in this project. We were able to negotiate a proof of concept fee of 150 Euro or approximately $180 per channel.

Warpalizer will handle both the edge blending and warping of our image onto our spherical BP screen. The edge blending is handled by way of a configuration file where the user can input the degree measurements that each projector occupies in the horizontal field of view (FOV). The warping is does similarly with the addition of user entered dimensions of the screen. Once the values are entered by the user the software can automatically warp, edge blend, and align our image onto the screen.

F. Host Computer System

Our host computer system will be designed as a graphics workhorse. The ideal setup will have the ability to drive a large number of projectors with extremely high quality graphics. This computer will handle all of the graphical processing including the warping and alignment of the image, which will require an immense amount of graphics processing. We have identified the AMD FirePro W600 graphics card for use with our system. This gives us an ideal mixture of high quality graphics, a large number of output ports, and native compatibility with multi-projector display setups. This will be placed into our host computer system to drive our projector array via a PCI express bus.

The host computer system will be a Windows based desktop computer. It will be powered by an Intel i7 processor to ensure maximum computational abilities and to remove any system bottlenecks that could limit the graphical output of the system. We will install the Warpalizer alignment software onto this computer. The Warpalizer software requires Windows 7 to operate correctly, as it utilizes Windows proprietary AeroGlass technology. Many simulators run on customized Linux operating systems, however due to cost restrictions in the alignment technology a Windows based solution was necessary for this project. The AMD graphics card will require the latest drivers to be installed to ensure maximum compatibility with multi-projector setups, as new updates are expected in Q4 of this year. A quality video player will also be required for testing purposes. Windows Media Player, which is factory installed on all Windows based systems, should provide sufficient video capabilities for this purpose.

Video Signals: From our host computer system we will run four video cables to our box to supply imagery to the projectors. The AMD FirePro W600 supplies us with 6 mini display ports, which follow the DisplayPort1.2 formatting, for this purpose. We will acquire mini display port to HDMI conversion cables, to convert the formatting of the signals to a format accepted by our projectors. These cables will plug into the back of our projector box and additional HDMI cables, contained within our box, will then supply the signal to our projectors.

The video signals will be warped and aligned using the Warpilizer alignment software. Warpilizer allows the user to save any configuration once aligned. This will allow us to warp and edge blend our image before any presentation of the system. Once a configuration is saved, the user can easily upload this configuration with one button press. This gives us the ability to show both our warped and un-warped images for the purposes of comparison, without any lengthy setups.

A serial communication interface will be used to transmit data to and from our PCB within our box. Our microcontrollers will supply TTL serial data that will be converted to RS-232 data which can be accepted by our host system. After conversion, the signal will be routed to a Db9 connector on the back of our projector box.

G. General User Interface

To ensure user friendliness, a simple Graphical User Interface (GUI) will be created to display information to the screen. This will be created using the GUI toolkit, Fox. A toolkit such as fox takes out the lengthy programming required to make simple GUI's, with a simple API to create windows, buttons, texts, and other elements required in GUI's.

Our GUI will ensure maximum user friendliness. There will be only one window with two buttons placed within it. One button will be used to get light levels measured by our light sensor array, while another button will be used to exit the program. When the user presses the button to acquire light levels, a command will be sent from our host computer via RS-232 serial data to our microcontroller inside of our projector box. This data will be converted to TTL serial data which is accepted by our microcontrollers. The microcontroller inside of the box will then retrieve the data from our light sensor array PCB and transmit this data back to our host computer system. The GUI will then display this data onto the screen for the user. The data will be displayed in an array showing the light intensity (in lumens) measured by each sensor, as well as the total lumen measurement of the image as a whole. This total measurement is calculated by averaging the measurement from each sensor and will be calculated by the host computer system, as the computers computational abilities will greatly outweigh the microcontrollers computational abilities.

The GUI will be designed using Microsoft Visual Studio. Once a solution file (.sln) is created via Visual studio, we will create a Windows installer using the NSIS program. An installer allows any user to easily install the program onto their system. It also ensures that the program, and all of its dependencies, is correctly installed and used by the Windows operating system. The installer will also create a executable file to uninstall the program, ensuring accurate and correct removal of the program from the system.

III. SCHEMATICS AND PCB CIRCUITRY DESIGN

A. Light Sensor Control PCB

A PCB will be designed to hold all of the circuitry for our Light Sensor Array. A 9 pin header will be used to attach the individual light sensors to our PCB. A Db9 connector will be used to send power to the board from our projector box, to transmit the TTL serial data to and from our projector box, and carry a single control signal from our box to initiate the program. A low pass filter will be designed to filter out any noise that may come through from our light sensors before the signal reaches our microcontroller. All 9 different light sensor signals will need to pass through this filter before being sent to the microcontroller for processing. Instead of building 9 filters we will implement a 9 to 1 multiplexer to switch between each of our signals and allowing them to pass through our single low pass filter. The multiplexer will be controlled via our digital outputs from our microcontroller. The output from the multiplexer will be attached to one of the analog inputs on our microcontroller. The circuitry for our light sensor PCB is given below in Figure 7 and Figure 8.

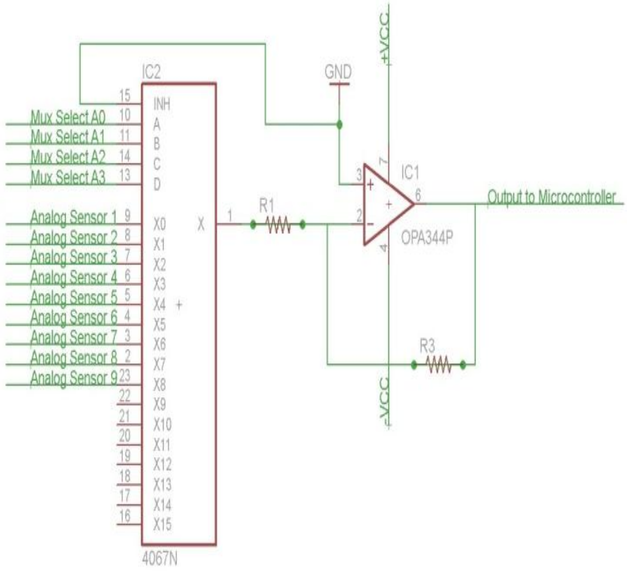


Fig. 7 Light sensor filter and mux schematic

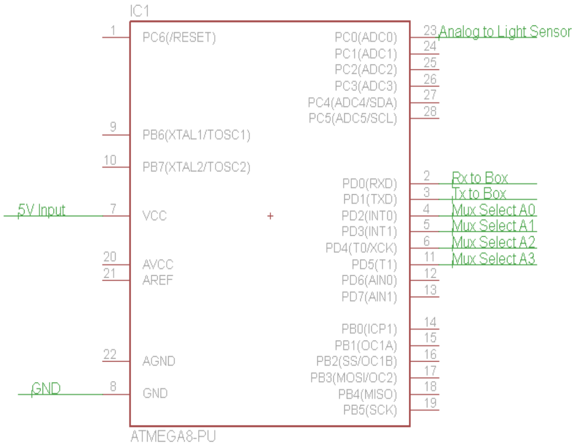


Fig. 8 Light Sensor Microcontroller Schematic

B. Projector Box PCB

A PCB will be design to hold all of the circuitry for the interface will the host computer system as well as the Power source. A two pin header will take the RS-232 serial data from the back of our box to the PCB. A 4 pin header will take TTL serial data, power, and a control signal to a Db9 connector to route up to the light sensor array PCB. The RS-232 serial data will need to be inverted to TTL signals that are accepted by our microcontroller. This inverting will be done by a MAX 232 chip. Both the serial data links will be connected to a 2 to 1 multiplexer that will be controlled by a digital output from our microcontroller. Power will be supplied to the controller from the power source circuitry on this board. The schematics for the Controllers circuitry only is given below in Figure 9 and Figure 10.

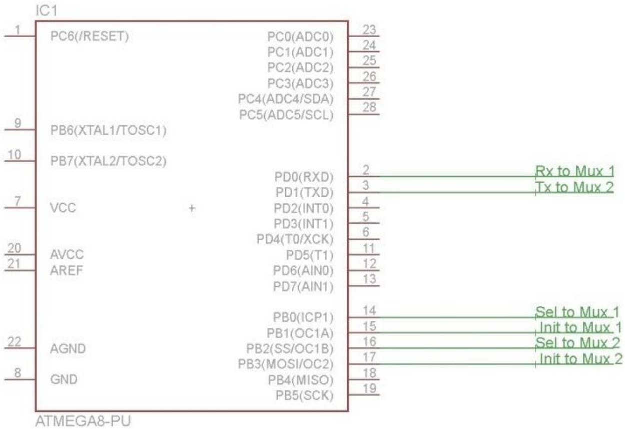


Fig. 9 Projector box microcontroller schematic

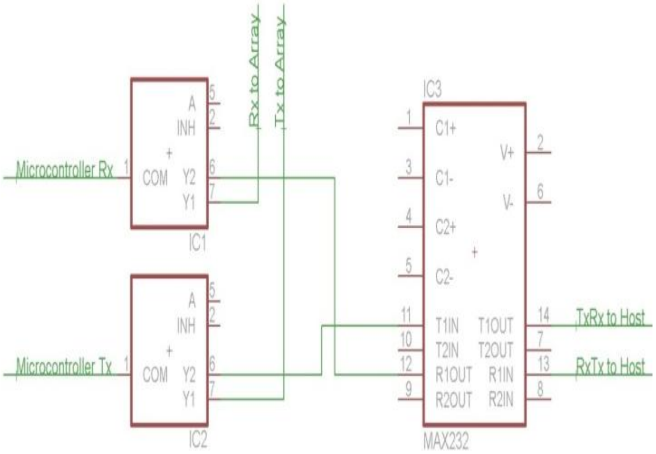


Fig. 10 Projector box mux and Max232 schematic

C. SFH 5711 PCB

A general schematic diagram for the SFH 5711 is shown below in Figure 11. This design does not offer any control of the maximum illuminance that can be detected, and the output will be a current. By using a load resistor connected from the I_{out} output to ground we are able to fix both problems. The load resistor can be seen in Figure 12 given below. This load resistor allows the current to be transformed into a voltage that can easily be processed later, and the load resistor also sets a maximum for the illuminance that can be detected.

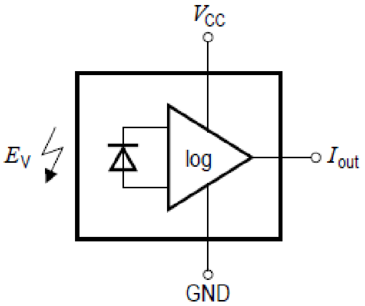


Fig. 11 Typical circuit diagram for SFH 5711

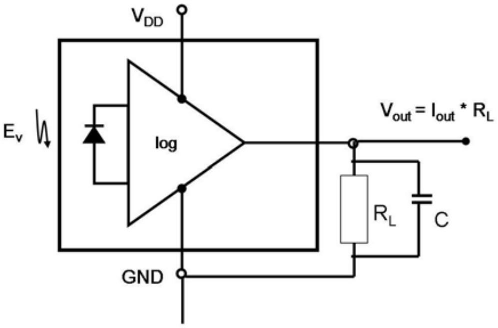


Fig. 12 Modified SFH 5711 circuit

Due to the projectors not putting out a great deal of light, meaning around 10k lx and above, we do not have to necessarily have the sensor setup to detect an illuminance above 10k lx. If we select our peak illuminance to be 10k lx then we can then solve for the output current. The equation as well as solution is provided below.

$$I_{out} = S * \log\left(\frac{E_V}{E_0}\right) where S = sensitivity = 10\mu A;\ E_0 = 1\ lx; and E_V = 10{,}000\ l \tag{1}$$

Therefore

$$I_{out} = 10\mu A * \log\left(\frac{10{,}000 lx}{1 lx}\right) = 100\mu A * \log(10{,}000) = 10\mu A * 4 = 40\mu A \tag{2}$$

As seen from the above equations I_{out} is equal to 40μA for a value of 10,000 lx. If use an input voltage of V_{CC}= 5 V, and V_{out}can not be greater than V_{CC} then we must select a resistance value for the load resistor that will not violate this rule.By using Figure 12 we can get an idea for the resistance value we should choose for the load resistor. By looking at the far right curve for V_{CC}= 5 V in Figure 13 we can see that for a peak value of 10,000 lx of illumination we should use a load resistor equal to about 75k Ω

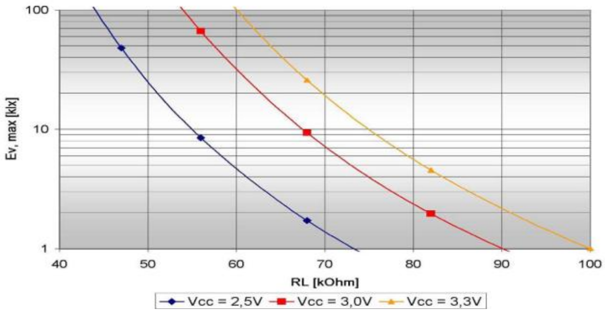


Fig. 13 Max detectable light level vs. load resistance

We can now solve for V_{out} to make sure the resistance value of 75k Ω will be sufficient for this design or not.

$$V_{out} = I_{out} * R_L = 40\mu\text{A} * 75\text{k}\,\Omega = 3\text{ V} \tag{3}$$

Since V_{out}= 3.0 V and V_{CC}= 5 V we can see that V_{out} is indeed less than V_{CC}. Therefore this would be a viable solution for this design; however, once we obtain the SFH 5711 chip we will have to test and verify that our design remains within our specifications for this project. If any adjustments are needed we can adjust our detection range of the circuit shown in Figure 14 by adjusting the value of the load resistor, or the value of V_{CC}.

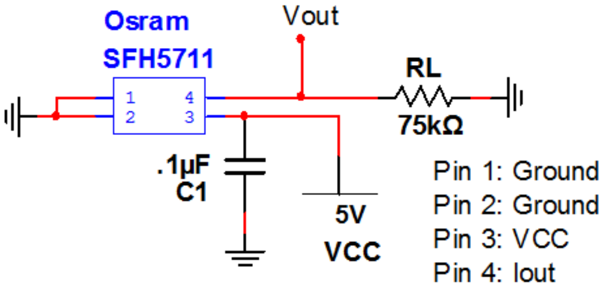


Fig. 14 Final SFH 5711 Circuit

IV. POWER IMPLEMENTATION

Although there have been multiple changes since the initial design specifications were created, none of the changes affect our decision on the design that we have chosen.The decision to use the AC to DC conversion circuitry that comes with the pico projectors also greatly reduces our design efforts. The power flow block diagram is given in Figure 15 below.

Going back to the fact that the pico projectors contain their own AC to DC conversion circuitry, this greatly reduces the design complication of the power system. This allows us to create a power block that can be placed in close proximity within the projector box.

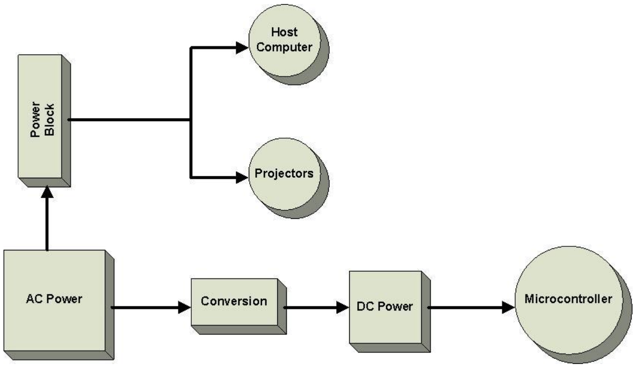


Fig. 15 Power flow diagram

V. PROGRAMMING SPECIFICS

A. Light Sensor PCB

The light sensor PCB will be controlled by the ATmega 328 microcontroller. Once a command via the TTL serial data link to the projector box is received the microcontroller will then poll the light sensors for data regarding the light intensity of our projector's image. The microcontroller will then convert the analog signals data to the corresponding lumen values and transmit this data via the TTL serial data link back to the projector box. No conversion of the serial data will be needed as both microcontrollers accept and transmit TTL serial data.

The programming for this microcontroller will be developed using the Arduino development environment available via Arduino's website. This environment accepts high level languages such as C and C++, as well as object oriented design. There are some proprietary API's that will also be implemented.

The program will utilize four custom functions and one main function outside of the proprietary API. The four functions will include:

- TTL Serial data receive (Serial_receive())
- TTL Serial data transmit (Serial_transmit())
- Analog signal receive (Analog_receive())
- Data conversion (Data_Convert())

Serial_receive() and Serial_transmit() will be used to send and receive the TTL serial data to and from the projector box. Analog_receive() will be used to poll the light sensors and input it's corresponding analog signal. Data_Convert() will be used to convert the analog signals to their corresponding lumen values.

The program will sit in a loop waiting for a digital signal to come from the projector box requesting data. Once this signal is received, the program will we use the analog_receive function to poll the light sensors and receive their corresponding analog signals. Once it has received these signals it will call data_convert to convert the signals to the respected lumen values. Once all the conversion is completed the microcontroller will use Serial_transmit to send the data down to the box.

B. Projector Box PCB

The projector Box PCB will include an ATmega 328 microcontroller for control and interfacing purposes. This PCB will also contain the power source for our entire system but that will be covered in another section of this report. This controller will be connected to our host computer system via a RS-232 serial data link for displaying information to the end user. Our host computer will send a command to this controller asking for data. The controller will interpret this command and then poll the light sensor array for information via a TTL serial data link. It will then receive this data via the same serial data link and then transmit this information out to the host computer system.

The programming for this microcontroller will be developed using the Arduino development environment available via Arduino's website. This environment accepts high level languages such as C and C++, as well as object oriented design. There are some proprietary API's that will also be implemented.

This program will implement two custom functions and one main function outside of the proprietary API's. The functions will include:

RS-232 Data Receive	Serial_receive()
TTL Data Transmit	Serial_transmit()

Serial_receieve will input the RS-232 Serial data from the Host computer system. Serial_transmit will output TTL serial data up to the Light Sensor Array. Our microcontroller can only receive and transmit TTL serial data but our circuitry will invert the RS-232 signals from our host computer to TTL signals that can be accepted by our microcontrollers.

The program will sit in a loop waiting for a digital signal from the host computer system requesting data. A digital signal will then be sent out to a multiplexer to switch the path of the serial data away from the computer system to the light sensor array. It will then send a digital signal up to our microcontroller on our light sensor array requesting the data needed by the host system. Once the light sensor array sends the data the program will receive the data, change the digital signal to the multiplexer rerouting the signal to the host computer system, and then send that data on to the host computer system.

V. CONCLUSION

Current simulators of today face an enormous challenge of creating highly realistic images for training purposes. Current projectors can cost tens and thousands of dollars and require immense amounts of adjustments in order to create a realistic image. We chose to investigate a solution to this problem by introducing a high quantity of low cost pico projectors to produce a higher quality, self-adjusting image.

By implementing an array of 4 pico projectors, we are capable of producing that supplies more pixels and higher resolutions at a fraction of the cost of standard simulation projectors. We are able to confirm these results through our light sensor array that calculates the brightness of our images.

The simulation industry could benefit greatly from the design of our project. Removing the alignment labor the alignment system can save countless man hours during installations. A low cost projector system will cut the cost of multiple projector setups down to an all time low.

VI. ACKNOWLEDGEMENTS

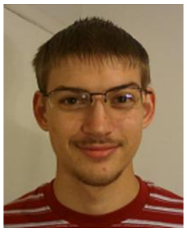
The authors would like to acknowledge Dr. Samuel Richie for his guidance throughout this course. We would also like to thank Q4 Services for sponsoring this project.

VII. GROUP MEMBERS

Gilbert Duverglas is currently a senior at the University of Central Florida. He plans to get his Bachelor of Science in Electrical Engineering in December of 2012. Career goals include managing own engineering firm.

Nicholas Futch is a current employee of Q4 Services. He has the greatest knowledge of simulator design and implementation, thus he assumedthe role of project manager and assisted in all aspects of the project.

Ryan Gallo is currently, and has been an employee, of Siemens Energy Inc. for over 2 years and has developed a good working knowledge of power systems and power system design.



Chris Rowe has worked at Walt Disney World where he worked at Architectural and Facilities Engineering department. While in this position he worked in power system, distribution simulation, architectural / electrical / mechanical drafting, and also power control systems.