A Design of Interactive LED Cube with Music Synchronization

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Abstract

Electrical and Computer Engineering departments always look for ideas and projects to attract and recruit students to the field. The ECCS department at Ohio Northern University is no different. It would like a new, modern design project that can showcase the talents of the students, attract positive attention to the department, and be transported to on-campus events.

The objective of this project is to design and build a portable 3D LED display. This project will display different words, pictures, and objects while synchronized with music. This design will include a colored light display to entertain the audience. The size of this display should be big enough so that it can be easily seen from a reasonable distance. This design will use a standard power outlet and will perform pre-programmed visual effects based on a given command from the external navigation buttons. During the light show, music will be played from external speakers.

The design utilizes a Raspberry Pi microcomputer to control the LED display and its animations as well as controlling the music playback.

The LED structure design is built in a modular fashion so that the project can easily be taken apart in sections if any maintenance is required. The LED dimensions are 32 LEDs wide by 16 LEDs high by 8 LEDs deep. These dimensions will make the project look like a three dimensional widescreen TV. With these dimensions, the design will be constructed in layers and then soldered together to make the final display. There will be 32 vertical sections of 16 by 8 LEDs to make it easier to maintain and to minimize power.

To power the LED display, the cathodes will be connected in parallel to ground one particular layer. This will allow for voltages to be set for each LED in the layer and only that layer will light up with the desired image. The layers consist of each of the 32 LED by 8 LED planes. The cathodes for each layer will have one ground output.

The full paper will explain the project in details.

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Problem Statement

A Senior Design Team has built a prototype of a smart home in 2010. This project is meant to wirelessly control different objects around a residential home. The design would control things like a garage door, lights in the house, unlock doors, etc. It is a respectable project; however, it is not portable. The ECCS department would like a new, modern design that can showcase the talents of the students and to attract positive attention to the department. The project must be portable for transportation to on-campus events.

Project Objective

The objective of this product is to design and build a portable 3D LED display. This product will display different words, pictures, and objects while synchronized with music. This design will be a colored light display so that the product will please the audience. The size of this display should be big enough so that it can be easily seen from far away. This design will use a standard power outlet and will perform all the pre-programmed visual effects until it is given a different command. This product will include external navigation buttons. During the light show music will be played from external speakers.

Literature Survey

There are many different technologies that go into a 3D LED cube. Our literature survey addresses different technologies used in most available designs.

A light-emitting (LED) diode is a semiconductor light source. LEDs are used extensively in everyday life. There are LEDs in TVs, Computer Monitors, traffic lights, signs, electronic gadgets, etc.

LEDs contain no filament nor do they get particularly hot. They are illuminated solely by electrons moving through a semiconducting material. [13] The lifespan of LEDs surpass incandescent lights by thousands of hours. LEDs are also very efficient because they have a high luminous efficacy, which is the level of efficiency electricity is converted into visible light. [13]

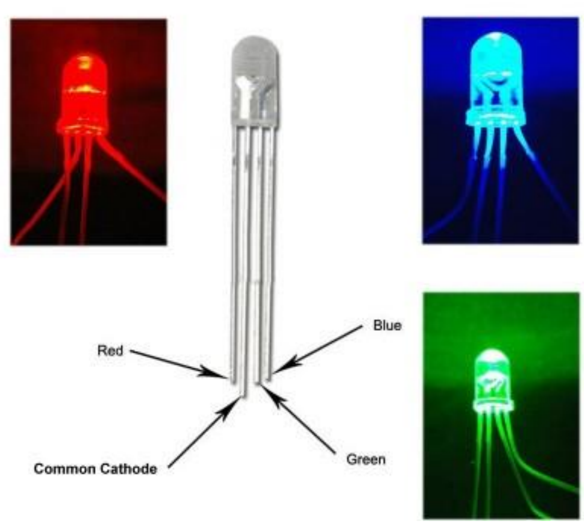

Figure 1: RGB Common Cathode LED

LEDs are constructed to release the light from the diode outward. [13] The diode is encased in a plastic bulb, which makes the light more efficient. There is an issue with LEDs that needs to be considered in all designs using LEDS: “LED meltdown” occurs when too much current is passed through the LED. A way to circumvent this is to use a resistor to control the current.

Red Green Blue (RGB) LEDs use the three primary colors to form most perceivable colors. One type of RGB LED is a common cathode LED. This type of LED has four pins; three anode pins and one cathode. [8] The cathode is connected to ground while the three anodes are connected to a power supply (through a resistor). [8] Varying the voltage levels will vary the color for each primary color. There are 256 different possible voltage levels for each primary color (RGB). The current will control the brightness of the LEDs. [1]

A vital part of any LED design is the central control system. This is what communicates to the LED grid what animations to execute and what music to play. Below, we discuss a few of the options we looked into.

Arduino

An Arduino is a microcontroller that offers access to an open-source platform and development environment. This system is based on the Atmel ATMega chip and offers a number of additional breakouts and features. [3] These boards are designed to be inexpensive compared to other top microcontrollers or computer platforms. Arduino can also run cross platform allowing for development on Windows, Macintosh, or Linux operating systems. [3] This microcontroller is programmed through an AVR C based environment that includes large libraries of helpful functions. The board can be directly programmed through AVR C or used by expanding through C++ libraries. Arduino is known for its vast development community that makes learning and getting started easy.

Raspberry Pi

Raspberry Pi is a credit-card sized computer that can perform many standard desktop PC functions. This system was originally designed to offer low cost computers for education purposes and is also a perfect research tool for many electronic projects. The Raspberry Pi is built around an ARM 11 processor.[5] The microcomputer also includes standard USB 2.0 ports, the option of AV or HDMI video, standard 3.5mm audio output jack, Ethernet, several general purpose IO ports, and an I2C communication bus.[5] The Raspberry Pi runs a standard Debian Linux distribution. The system is programmed using Python by default, but can compile several other programming languages that support ARMv6 assembly.

Standard PC

A standard PC offers an abundance of processing power and memory compared to a typical microcontroller. It also offers the flexibility to use a wide range of well-developed programming languages and operating systems. However, the ability to interface with hardware through the typical general purpose input and output pins is not available. The cost of a machine is also much greater than that of a microcontroller, which is solely designed for integrated electronics projects.

Custom Microcontroller

A custom microcontroller includes the selection of individual hardware parts to create a microcontroller specific to an electronics project. The use of a custom microcontroller offers the ability to meet exact requirements and is often ideal for mass-production projects in which the cost can be significantly lowered. However, in single applications you can often get more for your money by purchasing a prebuilt system. The custom microcontroller approach will offer the advantage of working items such as the required voltages and number of output pins directly into the board itself. This prevents the need for workarounds or circuit modifications down the line. This approach also lacks the community examples and troubleshooting that many common microcontrollers have to offer.

Without a shift register and demultiplexers, building an LED cube would be very difficult and very costly. Each LED would need a wire connecting it from the controller. Below, we discuss the technology behind each.

Shift Registers

A shift register is a sequential logic system that uses past inputs in addition to current inputs to create a specific output.[12] Serial-in/parallel-out shift registers shift data into internal storage elements one clock cycle at a time and can output all data values at any given clock cycle. This allows data to be sent 1 bit per clock cycle and then allows for n bits to be outputted after n clock cycles. This is one method of expanding output ports for a system while not increasing bandwidth.

Demultiplexer

A demultiplexer is a system that converts bitwise input numbers into driven control lines for each number. [4] This allows for n general purpose IO pins to be converted into 2^n output pins. These output pins are driven based on the input value. For example, 2 input pins could be set to binary 2 which would drive the 3rd of the 4 output pins high. The downside of demultiplexers is that only one output can be set at any given time. This makes that transition rate an important factor for the overall bandwidth of the end system.

Marketing Requirements

The marketing requirements listed below highlight the needs of the ECCS department at Ohio Northern University. They help to ensure the final project follows the specifications assigned.

- The LED cube should be large enough to attract attention and be clearly visible.
- The cube should showcase the talents of students in the ECCS department to increase positive attention toward the department and recruit prospective students.
- The system should have high quality LEDs and audio.
- The system should be synchronized to several songs including the ONU fight song and the ONU Engineering rap.
- A case should be designed to house the LED cube and easy to transport.
- The budget for the project is $2,500.

Realistic Constraints

Constraints are restrictions that can limit a design process. These can range from economic to maintainability. Listed below are the realistic constraints considered for our project.

Functionality

- The system will synchronize lights and music in real time.
- I/O interface will allow for users to cycle through various routines.

Economic

- The cost for developing the system (labor and parts) should not exceed $2,500.

Health and Safety

- The system should not expose users to any dangers.

Legal

- An intellectual property search will be conducted to ensure there is no infringement on prior patents.
- There are copyright laws and regulations in regards to using copyrighted music. When determining musical selections, these regulations must not be violated.

Maintainability

- The system will have a modular layer design for layer LED replacement.

Manufacturability

- The system must be manufactured to fit within a cabinet in Biggs 240, the Power Lab.

Operational

- The system should be easily transportable and work in various locations across campus.

Reliability

- The system is expected to operate under normal conditions.

Availability

- The system will be available as long as Biggs College of Engineering is open and access is granted to the Power Lab, room number Biggs 240.
- The system will be available to be used in University events such as homecoming or prospective student events.

Objective Tree

Figure 2 shows the objective tree, which gives a visual representation of criteria for selecting the optimal LED cube design. We have weighted the "High Quality Output" as one of the more important requirements of our design. It is important because the LED Cube is, by default, an audio and visual entertainment device. "Easy to Use" and "Transportable" are weighted the same but are still important.

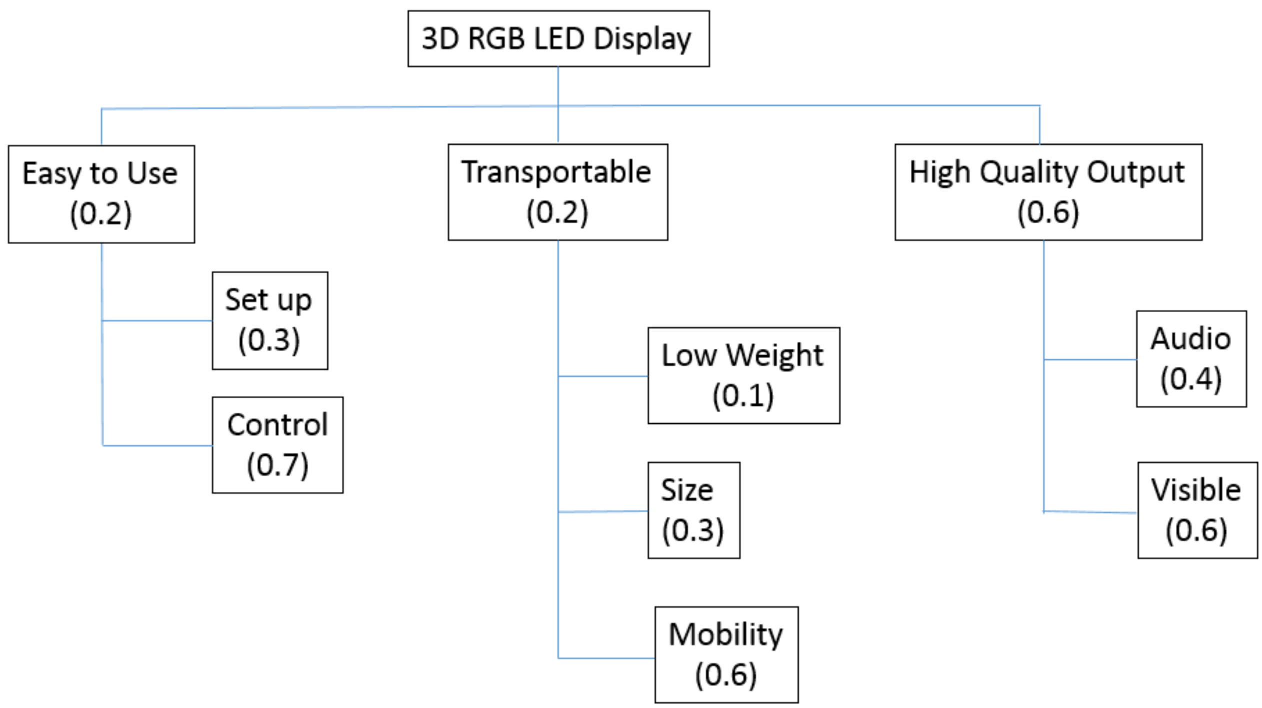

Figure 2: Objective Tree

Detailed Solutions

Buy Prebuilt Designs

The first design under consideration was a pre-built cube from a company called Seekway. This company specializes in designing and creating LED lighting effects for different environments. They are most famous for their 3D LED cube displays and how they program complex and amazing objects in their design. This project could have involved taking Seekway's design and modifying it so as to improve it. Some of Seekway's designs run close to 4000 Watts. This project could have been taking their design and changing it so that the power was more reasonable, while still keeping the same big size that they designed. This would have solved the problem statement for this project. This solution scored second in the decision matrix.

Buy Do-It-Yourself Kits

The second design that could have been done, would have been to buy a "Do-It-Yourself Kit" that included most of the parts for the project but are limited to how many LEDs that came with it. This option would have involved the team analyzing how the circuit would work and then building it based on the instructions already given with the purchased product. This solution resulted with the lowest score in the decision matrix.

Custom Build-Single LED Color

The next design that was considered was a custom built 3D LED display constructed with LEDs of a single color. This design ranked second best on the decision matrix. The design would be easier to create because the LEDs would only have a cathode and an anode. This would make it simpler to connect a power supply and run the design more efficiently. The design would also lower the amount of wires to deal with and make the circuit easier to understand and maintain if repairs would be necessary. Ultimately, the desire for greater visual appeal trumped the simplicity of design.

Custom Build-RGB LEDs (Our Design)

The design selected by our team includes a 32 x 16 x 8 RGB LED matrix that will synchronize visual routines to corresponding music.

This device will be controlled by a Raspberry Pi microcomputer. This control unit was selected because it has several key advantages that directly impact this project. The first is the built in audio output which will make playing music relatively easy. The built in SD card reader also gives us the ability to easily store larger music and program files. The I2C bus will allow for the expansion to an increased number of output pins, through I2C compatible I/O expander chips.

This device will also take inputs from a control panel that can be used to select sounds and routines for the cube to run. There will be pre-programmed routines saved for the project to use. These routines will be custom designed for each individual song. This will allow for more advanced animation that makes for a more entertaining presentation.

The LED structure design is built in a modular fashion so that the project can easily be taken apart by sections, so it can be easily powered and maintained. The LED dimensions are 32 LEDs wide by 16 LEDs high by 8 LEDs deep. These dimensions will make the project look like a widescreen TV. The only difference is how the design has LEDs for depth to give objects their 3D effect. With these dimensions, the design will be constructed in sections and then soldered together to make the final display. There will be 32 sections of 16 by 8 LEDs to make it easier to supply power and maintain.

The RGB LEDs that will be used have a total of four "legs", one cathode and three anodes. This type of LED is known as a common cathode LED. Each anode is for a single color showing Red, Green, or Blue. The cathode needs to be connected to ground to complete the circuit. To connect all of these LEDs and supply power to the final project, the anodes will have to be connected in parallel, so that the same voltage can be applied to all anodes, this will effectively illuminate each LED. This is done by wiring each of the 8 columns of 16 parallel LEDs to an individual control line. The grounds will then be connected in horizontal fashion across the entire device for a total of 16 ground outputs. The combination of a positive voltage and ground will light each individual LED. This design will include all the necessary hardware to create an attention grabbing 3D display. The hardware will then allow for the programming of numerous visual routines. These visuals will also be cued to music in order to create the desired end effect.

This design was chosen over the other solutions based on six main criteria; visual appeal, size, ease of construction, cost, transportation, and maintainability. (See Appendix C for our decision matrix)

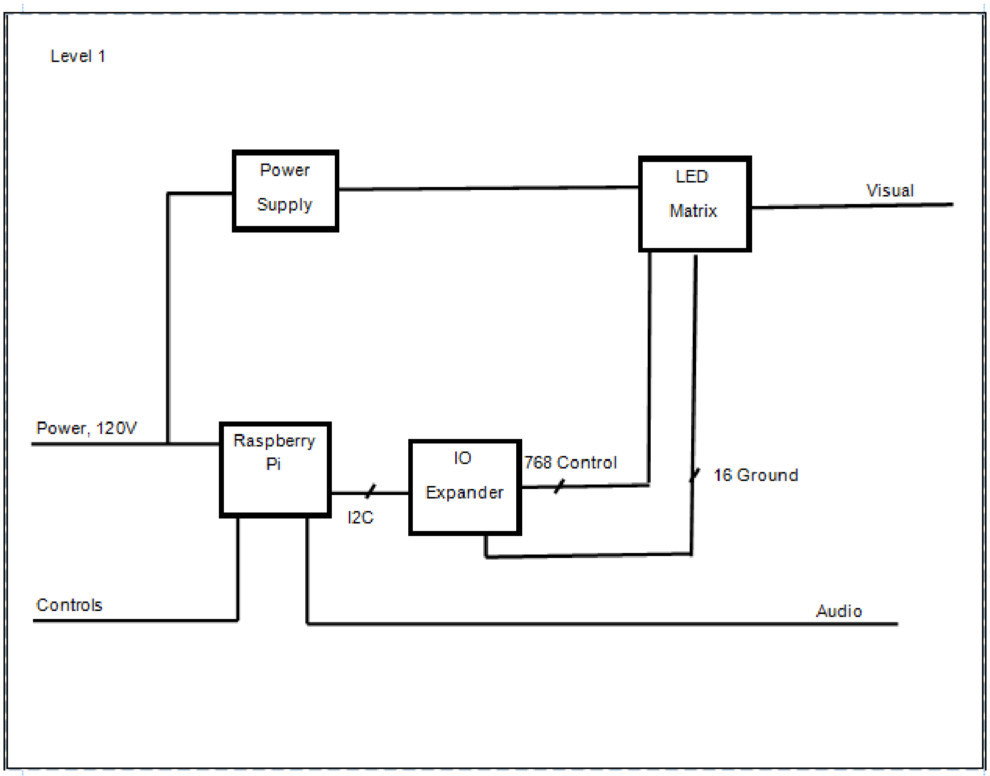

Figure 3: Level 1 Block Diagram of 3D LED Cube

Construction Plan

When the team starts construction, we must make sure the cube is sturdy, straight, and no harm comes to the LED bulbs. The best idea that will keep LEDs in a uniform position is a "jig". This jig will be a grid of holes in dimensions of 32 x 16. These holes will be about 7/8 inches away from each other. This tool allows for an easy way to solder LEDs and keeps them at a set distance for a neat, uniform cube.

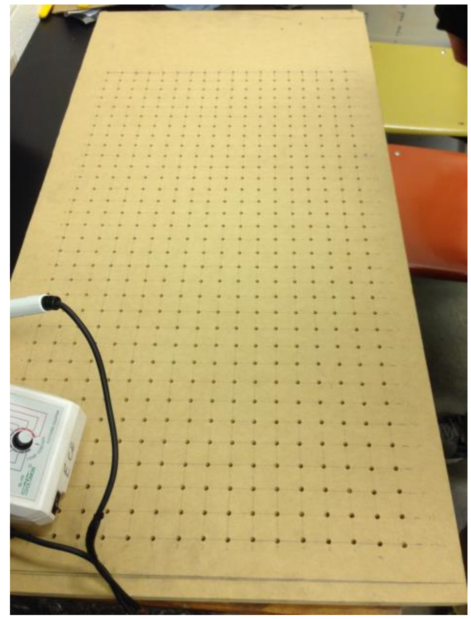

Figure 4: Jig used for construction

All LED bulbs will be placed with the bulb facing down into the jig. This will allow the legs to bend all in one direction for set LED legs to connect. Red, Blue, and Green LEDs will be connected in parallel. So it will look like three wired lines running from top to bottom. The ground wire will bend over the red wire and reach to the next ground immediately to the left of the current bulb. This will connect all the grounds together so that the Raspberry Pi will be able to communicate throughout the LEDs and create a visual display.

After a 32 x 16 layer of LEDs has been soldered together, it will be removed from the jig so that the next layer can be built. This method will help to create 8 different layers. With 8 sections of 32 x 16 LEDs, we will combine them to create the final design.

As we move forward with our project, we will be adhering to our project schedule, which can be viewed in Appendix A.

Digital Design

The programming language Python will be used on a Raspberry Pi to control the music and synchronize the LEDs accordingly. The Raspberry Pi will use its built in I2C bus to communicate with IO expanders chips creating an increased number of IO ports. These IO ports will be used to drive a series of shift registers that are uses to control which LEDs are lit. One of the first steps in our design will be to create simple functions to turn on specific LEDs and then build off of those to create animation functions which can be used in different sequences for different songs.

Test Plan

Testing will be a vital part of the entire process. Tests will occur at various stages of the entire project. Testing will be useful in ensuring all LEDs are functional before construction is completed. Testing will also ensure that programming progress is having the desired effect operating smoothly.

Instead of building a prototype, the team will start the construction of the final project and will pause construction when each 32 x 16 layer is complete. This will allow the team to test the programming and to find any unforeseen problems. If no problems occur, the team will continue building until the final product is complete.

During the construction, each LED in a layer will be tested on the completion of each layer. To test an LED, a DC voltage source will be applied to each cathode, through a resistor. Upon completion of the LED cube, another round of LED testing will take place.

For testing the final product, the following tests will occur:

- All songs and animations will be viewed to verify music is in synchronization with the animations.
- All songs and animations will be run through to verify there are no bugs.
- The songs and animations will be run continuously to verify the system can handle a long time period of playing.
- The system input will have all combinations of inputs tested to verify the system does not break.

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Cost of Project

Table 1 describes the estimated project cost. It summarizes how funds will be spent to ensure the project can be completed within the budget. These values were taken as conservative estimates and are not exact values. The total for this project still falls safely under the project allocation of $2,500.

Table 1: **Summary of Estimated Total Project Cost**

Item	Amount	Price
Raspberry Pi MC	2	$ 75.00
16 I/O pins	2	$ 6.00
RGB LED	4300	$ 430.00
Resistors	1000	$ 15.00
Cabinet	1	$ 1,000.00
Wire/Cables	1	$ 50.00
Demultiplexer	8	$ 75.00
Transistors	1000	$ 300.00
Power Supply	1	$ 50.00
Controls	1	$ 20.00
Speakers	1	$ 30.00
Construction Materials	1	$ 100.00
Total		$ 2,151.00

Conclusion

The detailed outline of our senior design project can be seen in this proposal. This gives a current overview of how our team will create a visual display that can be used across campus to showcase the talents of the ECCS department. The detailed background search relevant to this topic will help to ensure that our team possesses the necessary knowledge to effectively tackle this problem. The restraints and objectives of this project allowed for several potential solutions highlighted above. The best solution was selected using a decision matrix and discussed in great detail above. This was determined to best meet the economic and qualitative requirements for this project. The costs show that this is a reasonable financial conclusion. The testing plan will help ensure that this design meets all the desired requirements. Overall, this plan will help guide the creation of a 3D LED display that will be readily available and used for years to come.

References

[1] "3D LED Hanging Cube 130x122x135cms Inc Flightcase." MADeffects.com Disco Dj Gear and Special Effects. N.p., n.d. Web. Sept. 2013.

[2] "Aerosphere." 3d LED Cube with Arduino at. N.p., n.d. Web. Sept. 2013.

[3] "Arduino - HomePage." Arduino - HomePage. N.p., n.d. Web. Sept. 2013.

[4] "Big Data Home." Techopedia.com. N.p., n.d. Web. Sept. 2013.

[5] "Broadcom MASTERS." Raspberry Pi. N.p., n.d. Web. Sept. 2013.

[6] "Generic System Error." Test JSP (Item). N.p., n.d. Web. Sept. 2013.

[7] "Hypnocube." Hypnocube. N.p., n.d. Web. Sept. 2013.

[8] "LED Cube 8x8x8." Instructables.com. N.p., n.d. Web. Sept. 2013.

[9] "Main Menu." HNTE. N.p., n.d. Web. Sept. 2013.

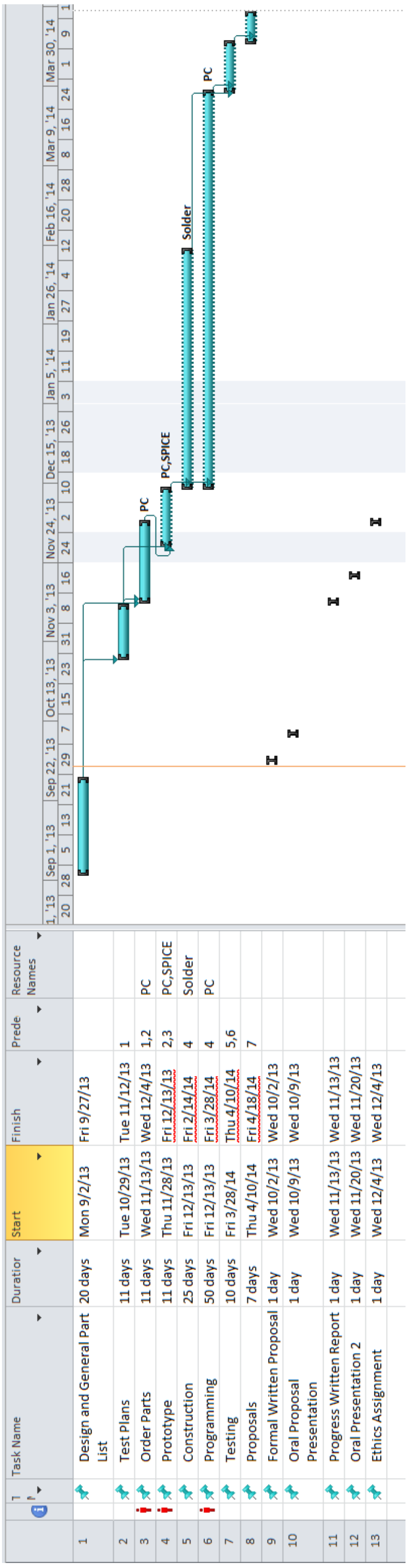
[10] "FAQs | Raspberry Pi." RaspberryPi.org. Raspberry Pi. Sept. 2013 <http://www.raspberrypi.org/faqs>.

[11] "Quick2Wire." Quick2Wire. N.p., n.d. Web. Sept. 2013.

[12] "Welcome to All About Circuits!" All About Circuits Forum RSS. N.p., n.d. Web. Sept. 2013.

[13] Harris, Tom. "How Light Emitting Diodes Work." HowStuffWorks. HowStuffWorks. 28 Oct. 2013 <http://electronics.howstuffworks.com/led.htm>

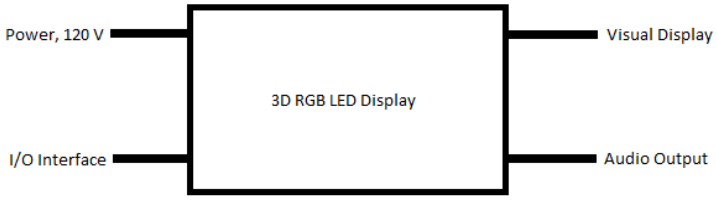
Appendix A: Gantt Chart

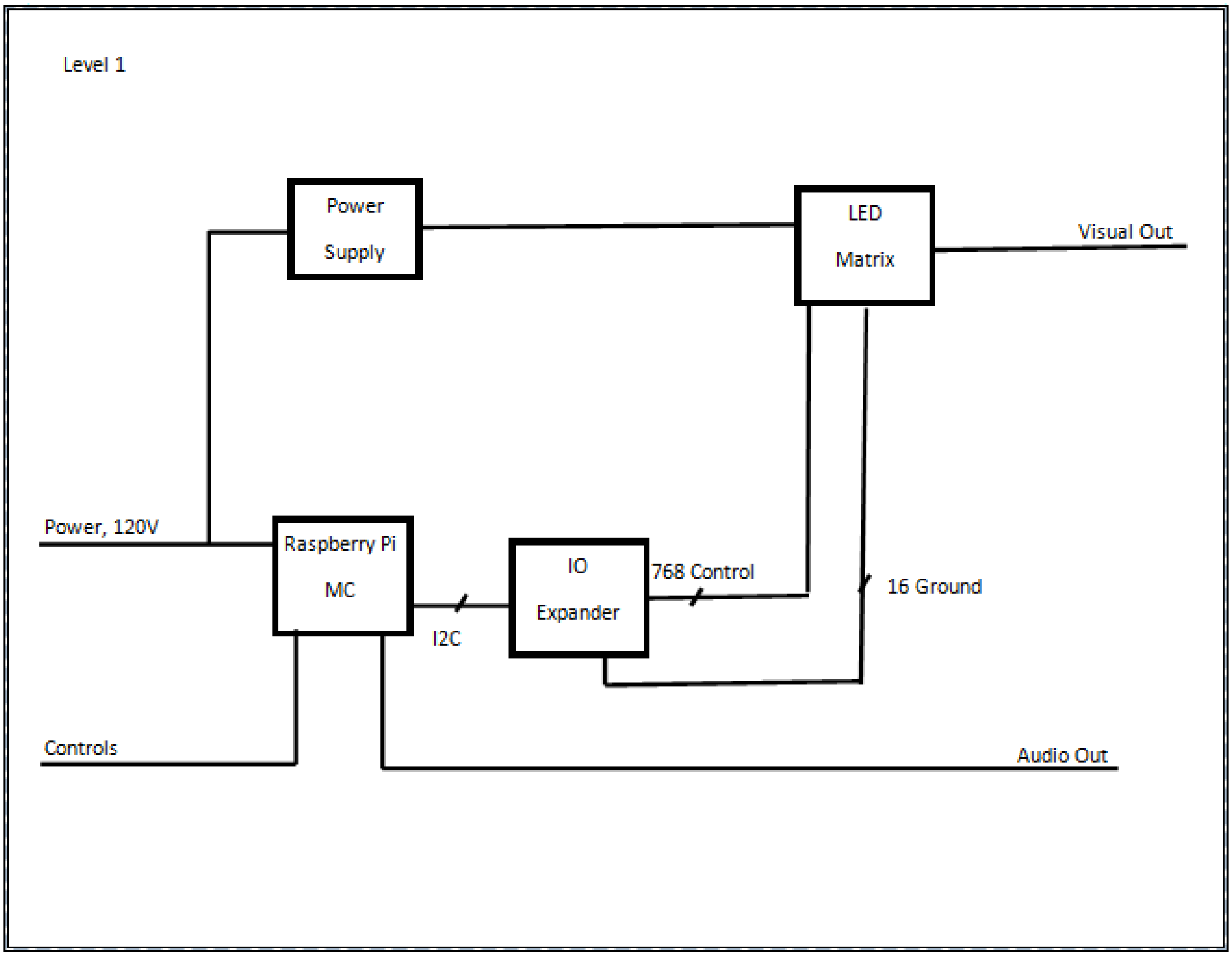


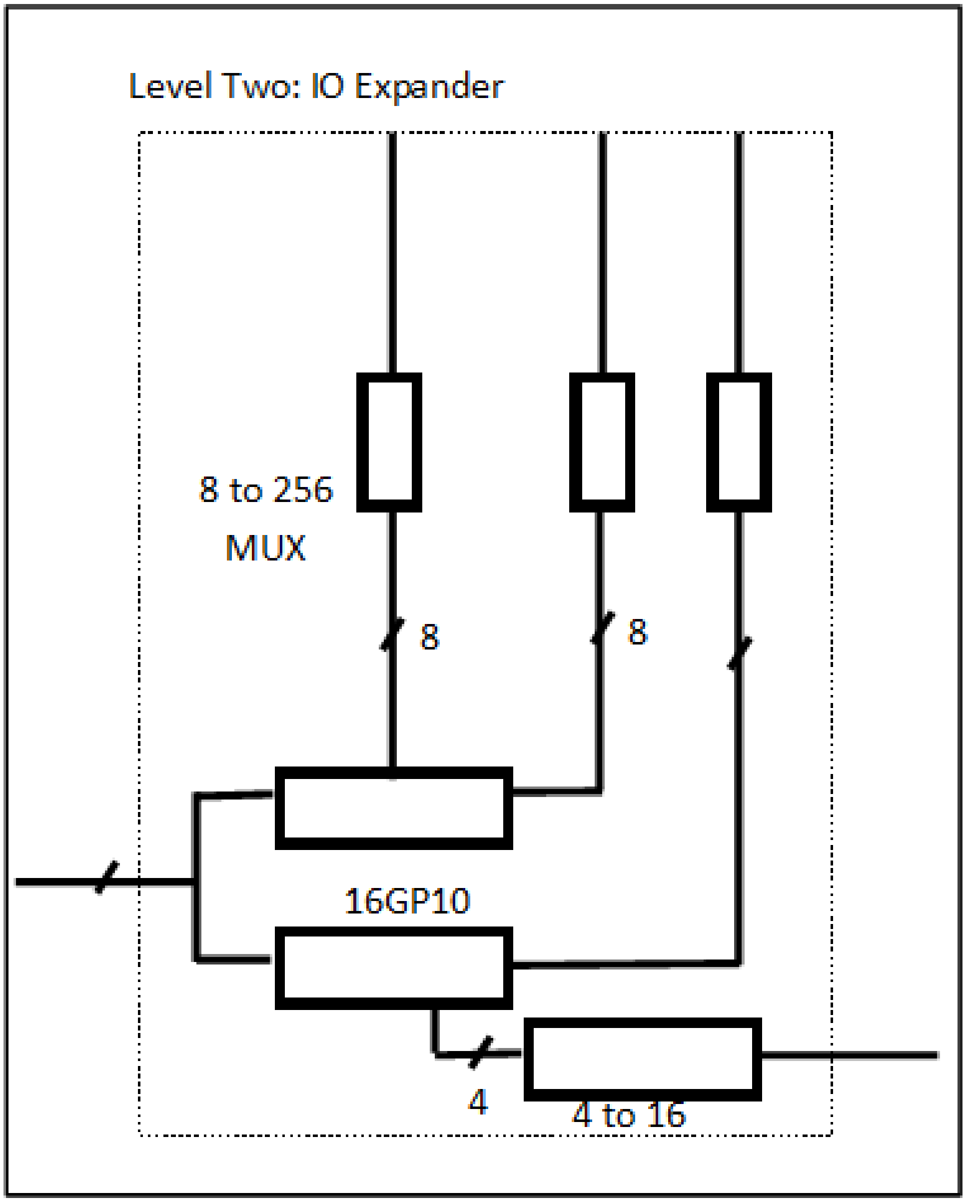
	Task Name	Duratior	Start	Finish	Prede	Resource Names
1	Design and General Part List	20 days	Mon 9/2/13	Fri 9/27/13		
2	Test Plans	11 days	Tue 10/29/13	Tue 11/12/13	1	
3	Order Parts	11 days	Wed 11/13/13	Wed 12/4/13	1,2	PC
4	Prototype	11 days	Thu 11/28/13	Fri 12/13/13	2,3	PC,SPICE
5	Construction	25 days	Fri 12/13/13	Fri 2/14/14	4	Solder
6	Programming	50 days	Fri 12/13/13	Fri 3/28/14	4	PC
7	Testing	10 days	Fri 3/28/14	Thu 4/10/14	5,6	
8	Proposals	7 days	Thu 4/10/14	Fri 4/18/14	7	
9	Formal Written Proposal	1 day	Wed 10/2/13	Wed 10/2/13		
10	Oral Proposal Presentation	1 day	Wed 10/9/13	Wed 10/9/13		
11	Progress Written Report	1 day	Wed 11/13/13	Wed 11/13/13		
12	Oral Presentation 2	1 day	Wed 11/20/13	Wed 11/20/13		
13	Ethics Assignment	1 day	Wed 12/4/13	Wed 12/4/13		

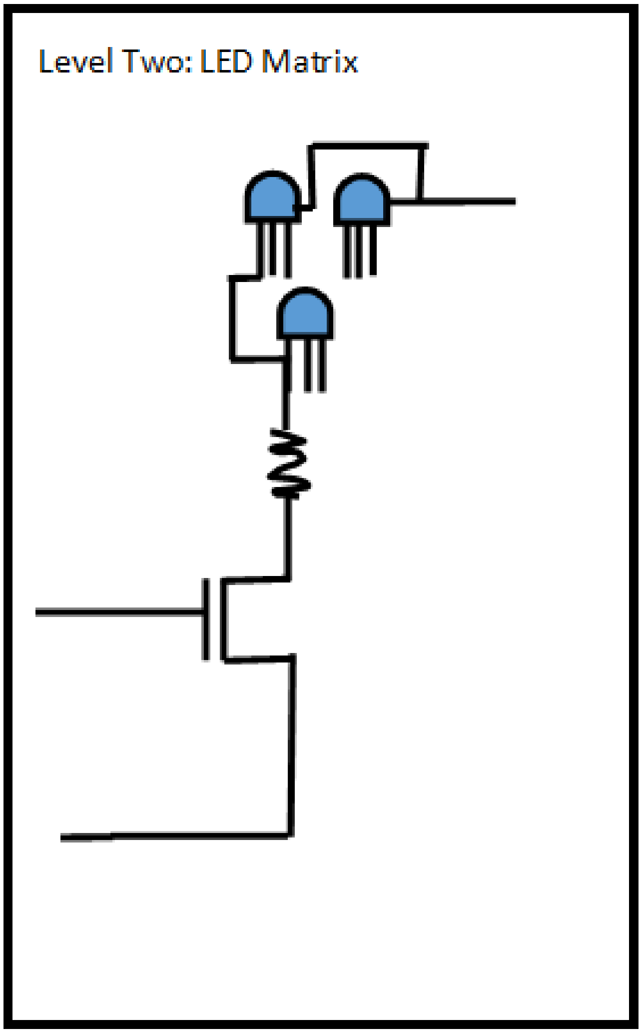
Appendix B: Block Diagrams

Level 0






Level Two: IO Expander
8 to 256
MUX
8
8
16GP10
4
4 to 16



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Appendix C: Decision Matrix

Decision Matrix Criteria		Pre Built Cube		Do It Yourself Kit		Custom White Design		Custom RGB Design	
	Importance	Rating	Score	Rating	Score	Rating	Score	Rating	Score
Vsual Appeal	25%	7	1.75	5	1.25	4	1	9	2.25
Size	25%	8	2	5	1.25	9	2.25	9	2.25
Ease of Construction	10%	9	0.9	7	0.7	5	0.5	3	0.3
Cost	5%	1	0.05	9	0.45	7	0.35	5	0.25
Transportation	25%	6	1.5	8	2	7	1.75	7	1.75
Maintainability	10%	6	0.6	4	0.4	8	0.8	7	0.7
Total	100%	**6.8**		**6.05**		**6.65**		**7.5**	