# Innovative Connectivity Ensuring Education (I.-C.E.E.)

by

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California Polytechnic State University
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Instructor's Grade: _____
Date: _____

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# Executive Summary

This is the critical design review for the Telepresence/Telerobotic Technology for Children with Disabilities Project by team I.- C.E.E. (Innovative Connectivity Ensuring Education). This report details our telepresence system design for our client (Nathan Stilts) including design choices/justification, testing verification and procedures, and chosen components for implementation. There are seven chapters in total starting with introductory/background information followed by hardware and software design, verification, and testing and concludes with the current status of the project and what future work may need to be included.

# Chapter 1: Introduction

## Sponsor Background and Needs

The Stilts-Cooper family is the client in this product. This project is about restoring Nathan Stilts's ability to participate in the same education program as his peers. To meet this end, the team of Margot Allen, Nicholas Ross, Andrew Ma, Luke Cole, and Daniel Williams will be working to create a telepresence module to enable Nathan to receive an improved education and interaction experience between his classmates and his school.

Nathan Stilts has a genetic disorder called Spinal Muscular Atrophy that affects his muscular development. A side effect of this disorder is a compromised immune system that makes it very difficult for Nathan to work amongst his fellow students in the classroom. The potential illnesses that are carried around by Nathan's classmates could have a very harmful effect on Nathan if he were to be exposed. For this reason, Nathan spends his school day in a classroom shared only with a teacher's aid and he receives his lessons via Skype whenever possible.

## Formal Problem Definition

Team I.-C.E.E. is improving the quality of the current method that Nathan uses to participate in class remotely. Skype between two laptops has very poor audio and video quality which makes it very hard for Nathan to receive a clear view of the teacher's daily lessons. Also, Skype provides no method for Nathan to interact with the teacher and other classmates, which makes the learning experience very limited.

## Objective/Specification Development

Nathan needs a device that can have the following features: uninterrupted clear audio, continuous video streaming with zoom capabilities, camera pan/tilt motion control, and a method for queuing the instructor for a question. Given these capabilities, Nathan's educational experience will be dramatically improved.

The audio that Skype provides is very muffled and has a hard time picking up the teacher's voice over other ambient noise created by the classmates and other electronics. The microphone needs to be sensitive enough to clearly pick up a lecture being given from across a classroom, while still filtering out the ambient noise.

Video streaming with Skype tends to cut in and out frequently while Nathan is observing a lecture. This causes him to miss portions of the lesson and fall behind in class. The solution to this problem will involve implementing a software that can run for the duration of a class period without dropping any footage. The teacher asked that the device preferably be placed in the rear of the classroom. That being the case, it is necessary that Nathan can still read information that is written on the board. To tackle this problem a digital zoom will be implemented to be able to view smaller objects or writing on the board. It

is estimated that a 4x zoom will be adequate in achieving the necessary image ratio on Nathan's computer screen.

For Nathan to be provided with the full educational experience there needs to be a way in which he can interact with the instructor and his fellow classmates. At the same time, however, the interaction must not distract other students during lecture time. A touch screen LCD in conjunction with a set of small desktop speakers will provide the audio and video output to the classroom. For queuing the instructor to ask a question there will be a function built into the software that causes an attached LED to flash. Nathan will have control over sending his camera video to the LCD screen. Since his audio will not be needed at all times and could be distracting for his classmates, there will a push-to-talk feature that will only send his audio when activated.

## Chapter 2: Background

There are currently many commercial telepresence devices available, with the most advanced models having telecommunication and locomotion abilities. The idea behind this trend in telepresence technologies is to connect individuals over long distances in a more physical way and with more control than what is currently available in computer programs such as Skype and Google Hangouts. These current telepresence robots are functional immediately after purchase, are finely-tuned and tested, and have a clean, easy to use control interface. There are many software and hardware options for telepresence and telecommunication. The Double Robotics Telepresence Robot was one of the hardware models that the Engineering Team researched. This robot utilizes a separate iPad Air to to provide the wi-fi connectivity and the video interface, and has built-in iPad driver applications to control the robot. The robot also has an optional integrated audio module for $100, which includes a directional microphone and an amplified speaker. However, this module comes with a hefty price tag of almost $2600 for the audio module and stand and $250 for an iPad Air, and so would be an infeasible option for Nathan's family.



*Figure 1: Two commercially available telepresence robots: Beam Telepresence Robot (left) and Double Telepresence Robot (right)*

As mentioned previously, Nathan is currently utilizing Skype to telecommunicate between classrooms; however, multiple issues regularly occur during usage, including loud microphone feedback, choppy video quality, and poor zooming capabilities. The lack of functionality and consistently poor video quality has caused Nathan to shy away from using Skype.

The technology for the ideal telepresence device exists in various forms, and will be engineered to fit our goal of providing the client with the most realistic classroom interaction possible. The I-CEE team believes that such a device can be created before the end of the academic school year. This project will

include many subsystems, which will all be tested individually and extensively before final system integration. Tests for individual parts will include stress, noise testing, electrical power consumption, heat distribution, and longevity tolerances. Component tests will include electrical logic levels, interconnectivity, and system consistency testing. In addition, structural precautions, such as mechanical connections and safety connections, will be implemented on the overall system in order to ensure module stability and student safety.

# Chapter 3: Design Development

## Conceptual Design: Hardware

There were three design choices we considered:  a completely custom design, all plug & play (devices and components that can be bought commercially), and half custom design/half plug & play.

In the custom design, we will create our own circuit board and all necessary subsystems from basic parts. This minimizes useless functions, weight, and space that might be included in the plug & play devices. Functionality, power consumption, speed, weight, cost, and shape can all be designed and controlled through the custom design process. The major drawback to this approach is that design, fabrication, and interfacing a complete system can be very time consuming. Because there are so many discrete components, troubleshooting the different subsystems for specific problems becomes very difficult. Furthermore, because each board is custom-made, a new circuit board would have to be manufactured and assembled if any subsystem fails. Consequently, it is very difficult to replace the system in case of failure. Due to the unique nature of the custom circuit board and the problems previously mentioned, this approach is unfavorable and inconvenient to the client.

The all plug & play design approach will consist of only commercial products. We considered this approach because we would need to spend minimal time on testing and verification. Consequently, we would be able to spend more time creating software necessary to the device's function. Currently, software is the most challenging aspect of this project due to the team's lack of higher-level software knowledge.  However, since these products are "off the shelf," they are more expensive and will consume the majority of our budget. Additionally, most of these products will have extra functions and surface area, which will decrease the overall efficiency of the device. Furthermore, the variety of inputs and outputs may lead to connectivity and communication issues between the components. The high cost, interfacing concerns, and limited control over the subsystem's weight, functionality, and shape makes this design choice a less than optimal one.

The final design option, half custom design and half plug & play, combines the strengths of the previous two design choices while minimizing their weaknesses.  Although the QFD table indicated that we should focus on the all-custom design due to better control over design specifications and space requirements, we decided against it due to the reasons listed above.

Our primary design was originally in favor of the half-and-half approach, as this would have interconnected both custom circuits and pre-made parts from various manufacturers. After careful consideration of the relative specialization of current market products, we have decided to move forward with a mostly plug-and-play design. While this method is more expensive, many components are modular and will not have any unneeded features in our final design. Furthermore, the reliability and overall functionality of the market components will be more effective than analogous components that the team could custom-build.

## Conceptual Design: Software

The essential functionality for the software is to be able to stream audio and video from the laptop and stream video from the Beaglebone as well as provide for pan/tilt control over the camera. This will be accomplished through the use of a Beaglebone Black microcontroller and its connected peripherals which will communicate with Nathan's laptop over the school's local area network.

*Beaglebone Black*

The Beaglebone Black will act as the controller of the overall system, and will accept commands from the desktop application. Thus, the Beaglebone Black needs to be able to interface with each of the connected peripherals, namely: the camera, servo motors, LEDs, LCD screen, wireless module, and microphone and speakers.

Several of the modules will need little specific software developed to integrate them into the overall system, and allow the Beaglebone to interface with them. The LCD screen will be interfaced through a cape for the Beaglebone, which sets up the appropriate pin connections, and will not need any specialized software drivers. When attached, a graphical interface will automatically be output to the connected screen. The microphone and speakers will be connected to a sound card that connects to the Beaglebone through USB. The Beaglebone will most likely be connected to the school network using the Ethernet port on the Beaglebone. This will simplify the network connectivity aspects and free up one USB port on the USB hub we are using.

However, for the peripherals that will be controlled by the user there will need to be custom software written. The peripherals will be connected to the GPIO pins of the Beaglebone Black, and fortunately there exists several software libraries for the Beaglebone that simplify the use of these pins. These libraries have been written in several languages, including C++ and Python. These libraries contain methods for using PWM, GPIO pins, and the internal ADC in a simple way.

The Beaglebone also needs to be able to receive commands from the desktop software. The most effective way to solve this problem is by putting a web server on the Beaglebone. There are several different web servers to choose from that will run on Linux-based operating systems, including Apache and Lighthttpd. We have chosen to use Apache due to developer familiarity with its usage.

However, the web server only provides the ability to communicate with the desktop application. There needs to be server-side software that processes the incoming requests. There are several languages to build a website in, including PHP, C, C++, Java, and Python. We chose Python as the language to write the server-side software in due to developer familiarity with the language and ease of development it provides. We also chose to use a web framework to write the server-side software, which allows us to focus on writing the functionality we need and not spend time building a working web server.

There are several mature web frameworks that exist for the Python language, the most high-profile of which are Django, Flask, and Pyramid. Django is a full-featured framework that provides a significant amount of functionality with a minimal amount of effort on the developer's part. Pyramid is another framework, that is close to Django in the functionality it offers. Flask, however, is billed as a micro framework that provides the set of features we require for this project (authentication and sessions and

RESTful request dispatching). Django and Pyramid provide significantly more features than are required and would be wasteful due to the limited space and processing power afforded on the Beaglebone (less than 4 GB).

To handle the streaming of the audio and video, we have decided to use MJPG-Streamer, which has low memory footprint, an essential requirement for decent operation on the Beaglebone. This software also includes the ability to change the streaming resolution and framerate, which can be used to control the quality of the stream to account for various network speeds. The camera we have chosen is able to be connected as a USB webcam which will allow us to use this software.

*Desktop Application*
When discussing the desktop application, we realized that there could be two ways to solve this problem. The first would be to build a normal application that would be run in a way similar to Skype, and the second would be to access a website hosted by the Beaglebone through a web browser.

The second approach has its merits. It would reduce the amount of software that has to be written; we would have to add additional functionality to the web site on the Beaglebone, but overall there would be less code to be written. However, due to the necessity of controlling the desktop's camera and microphone, it soon become apparent that this approach would not be suitable. Additionally, the digital zoom functionality would be difficult and potentially cumbersome to implement in client-side Javascript, which would be the only way to do this. Also, the single-threaded execution model of a browser could result in an unresponsive feeling interface.

So, we decided to take the first path, writing a full program. There are several choices to develop in: C, C++, Java, Python, and C#. The first two choices would be good choices for extremely performant software, but this is not a critical issue at the present time. Java and Python allow for cross-platform programs by their nature; however, Python does not have suitable libraries for graphical interfaces. The choice between Java and C# was solved by the excellent graphical interface and system libraries provided with C# through the .NET Framework. Though this does limit the software to the Windows operating system, we considered this an acceptable tradeoff.

The software will take user input in the form of a key press, mouse click, or controller input and send a GET request to the Beaglebone. This request will then be processed by the website built in the Flask framework. The streaming video and audio from the Beaglebone will be handled by using the VLC ActiveX plugin, which allows us to embed a VLC instance in the program and has support for handling multimedia streams.
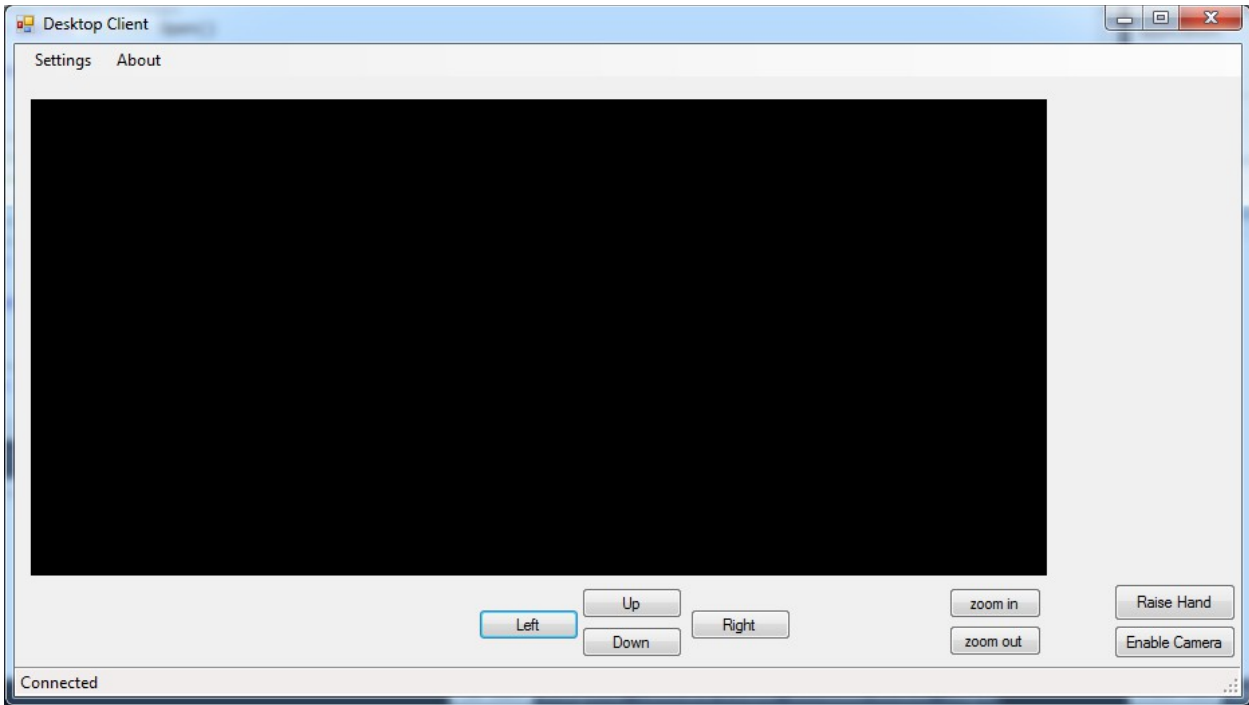
*Figure 2: An early version of the client interface.*
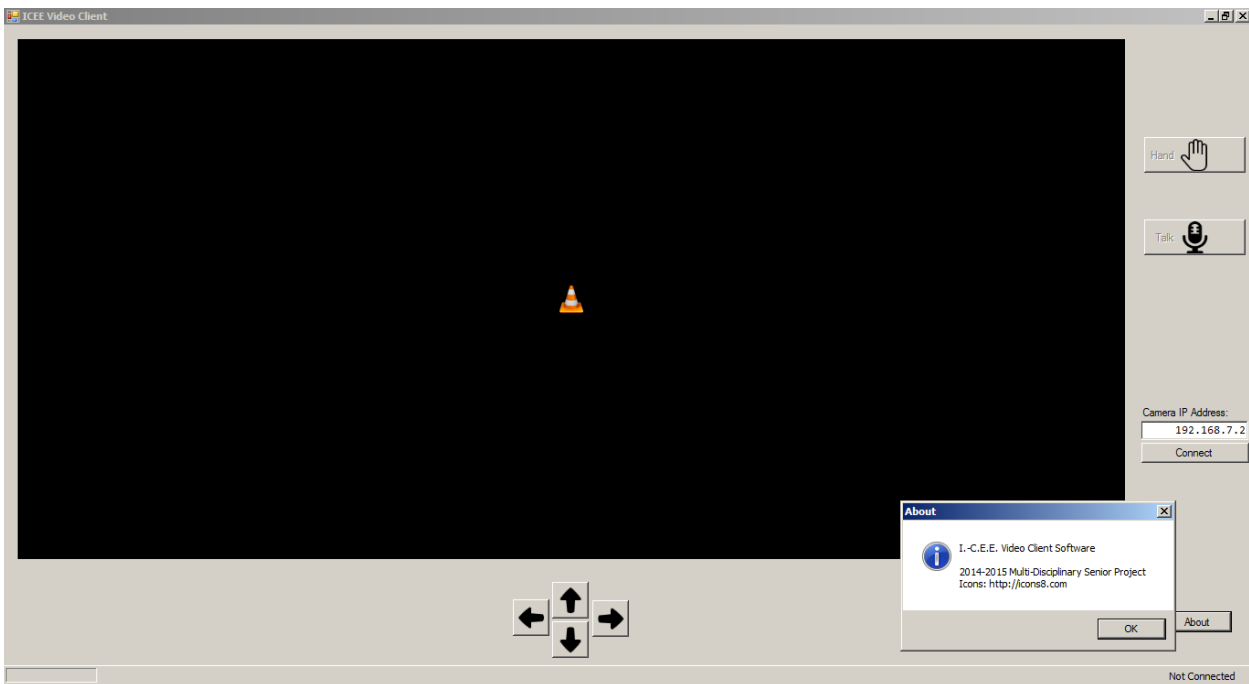


*Figure 3: The most recent version of the client interface.*

# Chapter 4: Description of the Final Design

## Requirements Table

The final design was influenced heavily by the design requirements table, shown below in table 1. These requirements were determined to be the most important specifications that Nathan needs in order to fully enjoy the product. The parameters were later verified through testing and research.

| Spec. # | Parameter | Requirement | Tolerance | Verification |
|---------|-----------|-------------|-----------|--------------|
| 1 | Camera panning | x: -90 to 90 y: -90 to 90 | Max | Servos can move +/- 90 degrees |
| 2 | Audio Quality | 75dB | +/- 5dB | Sensitivity: -28 dB ±3 dB at 1 kHz (0 dB=1 V/Pa) $R_L$=3.9 kΩ $V_{CC}$=5 V<br><br>Impedance: 2.4 kΩ ±30 % at 1 kHz ($R_L$=3.9 kΩ)<br><br>Signal/Noise Ratio: 80 dB Typ. at 1 kHz ( 1 Pa, A weighted network )<br><br>Max Input Sound Level: 122 dB S.P.L. Typ. |
| 3 | Video Quality | 2 MegaPixels | Min. | Camera has multiple video recording modes, 1080P/30fps wide, 1080P/30fps narrow, 720P/60 fps standard & 720P/30fps standard. |
| 4 | Zoom Capability | 10 Meters | Min | Camera can stream up to 720P, a digital zoom will have a clear enough image |
| 5 | Weight | 20lbs | Max | Will verify with testing |
| 6 | Battery Capacity | 6 hours | Min | Currently not applicable to our current design |
| 7 | Filtering | 0.3~3.4KHz | +/- 100Hz | 3Dio has a frequency response of 100-10,000 Hz |
| 8 | Size | 18 inches per side | Max | Refer to Ch. 4 Under Mechanical Design |

Table 1: Requirements Table

## Electrical Hardware Block Diagrams

The following functional flow block diagram illustrates the component connectivity of the telepresence module. The arrows, with the exception of the cooling fans, show connections between modules. The outputs of the BeagleBone are GPIO pins or USB input/outputs in the case of the USB hub.
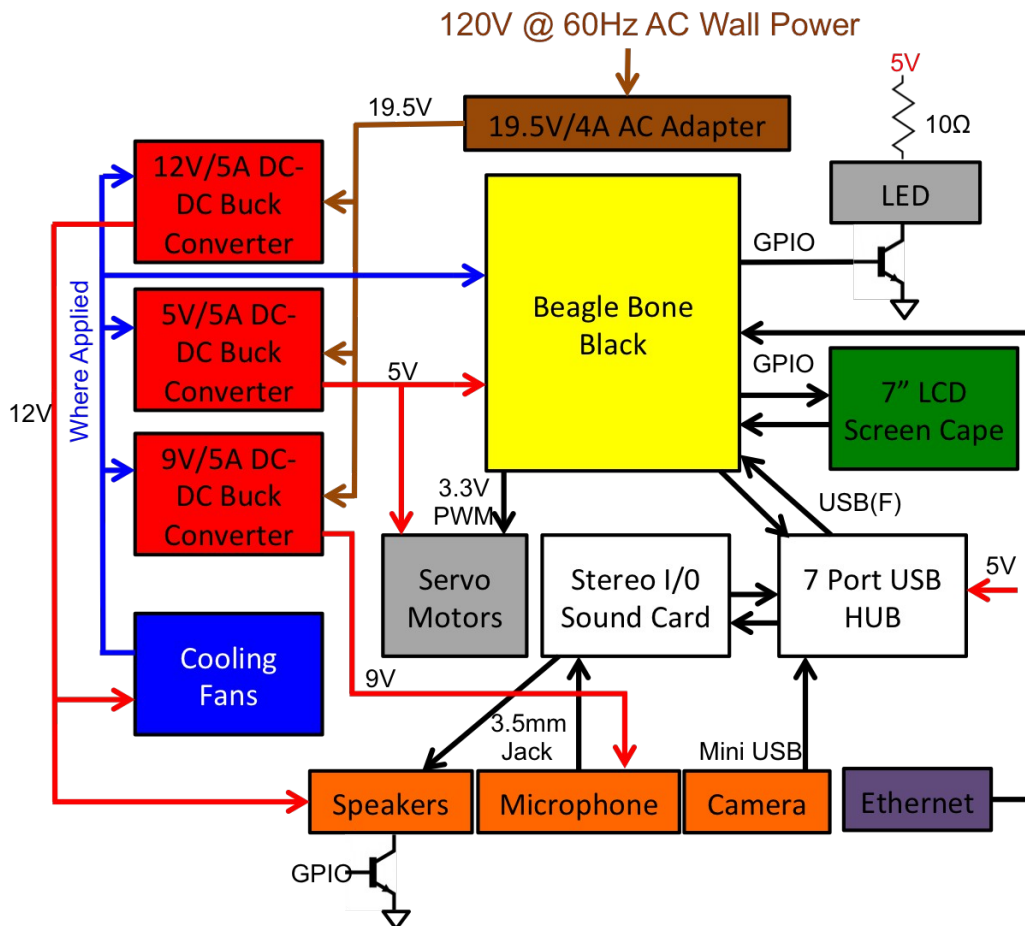


*Figure 4: The third-level hardware black-box diagram of the system, detailing connections to different components.*

## Hardware

*BeagleBone Black*

The BeagleBone Black will be responsible for regulating most of the power connections and logic for external components. A USB hub with a separate DC power connection will be used to avoid overloading the BeagleBone. The BeagleBone will take power from the wall and have a series of power converters to step down the voltage and current to usable levels.

*USB Hub*

The USB hub will be a 7-port hub. The hub will be powered by a 5V rail. The hub will source enough power to run our components without overloading the BeagleBone USB port. This USB hub will help to drive the sound card, the camera, and other peripherals that may be needed like a keyboard.

*Other Hardware considerations*

Cooling fans have been added to the black box design. This addition was made in order to attempt to mitigate or prevent system overheating, and will serve to improve both system functionality and student safety. These cooling fans will be powered from a 12V DC input, which would be stepped down from 19.5V DC.

## Software Block Diagrams

The following block diagrams illustrate the components comprising both the Beaglebone Black and the desktop application. The arrows connecting the components show which components are interconnected, that is which ones communicate with each other. The outputs of the Beaglebone Black are the GPIOs pins.

I.    Beaglebone Black
    A.  Level 0
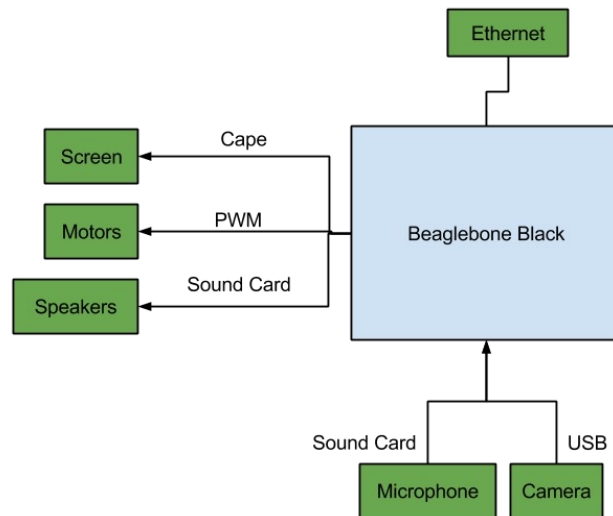


*Figure 5: Level 0 software black box diagram.*

The Beaglebone is the controller for the attached peripherals. The BeagleBone communicates over the Ethernet connection, and then manipulates the state of the motors, speakers, microphone, and camera.

B. Level 1
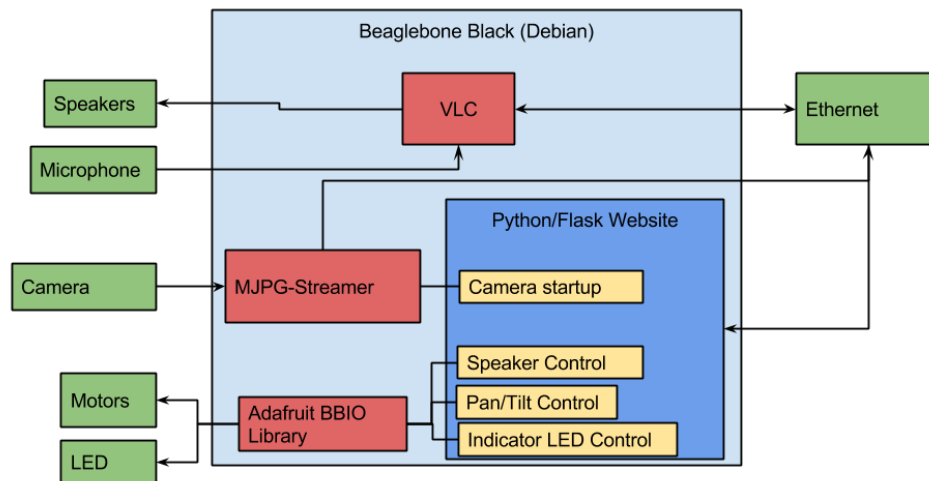


*Figure 6: Level 2 software black box diagram.*

The Beaglebone runs a Python web server which receives commands from the Ethernet connection, and modify the GPIO and PWM pins on the board. VLC receives and transmits the audio stream to and from the Ethernet. The camera video is streamed by MJPG-Streamer.

II.    Desktop Application
       A. Level 0
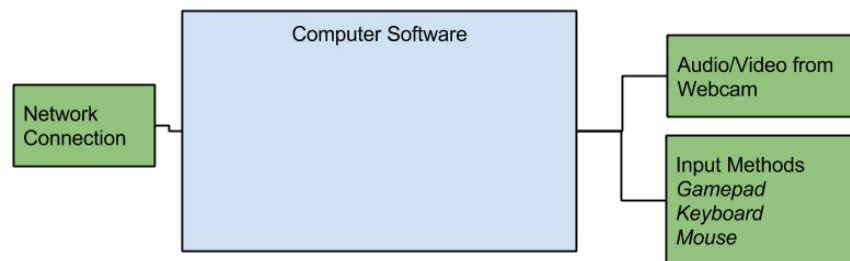


*Figure 7: Level 0 desktop application black box diagram.*

The computer (desktop client) is responsible for receiving input and audio from the user and sending those to Beaglebone across the local area connection. The software also receives the audio and video stream from the Beaglebone and displays it to the user.

B.  Level 1
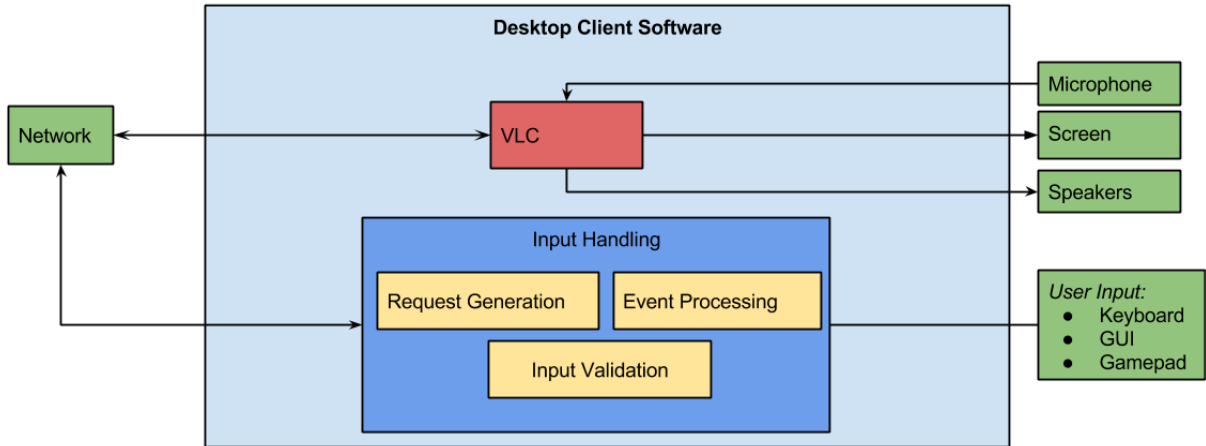


*Figure 8: Level 2 desktop application black box diagram.*

> The software can take input from several different input methods (keyboard, mouse, or
> game controller). The software then takes those inputs and creates the appropriate request
> to send the Beaglebone

For more details regarding the design decisions, see the **Conceptual Design: Software** section.

## Software

*Beaglebone Black*
The Beaglebone Black will be running the Debian operating system.. On top of that, we will be running
the web site which was built using the Flask web framework. The Flask site will receive HTTP GET
requests that are sent by the desktop application. Based on the URL is requested, the Flask site will
respond differently. The GET request will be constructed with parameters as opposed to the URL scheme
previously discussed.

An example of the URL structure:
```
  i.    /camera?move=<action>&direction=<direction>
          i.    action: pan
                  i.  direction: left, right
        ii.    action: tilt
                  i.  direction: up, down
ii.    /led?action=<power>
          i.    action: on, off
```

An example URL sent by the desktop application could be:
**<BeagleBone IP>:5000/camera?move=pan&direction=left**, which would pan the camera left by a
small amount.

To stream the video, we initially elected to use VLC, which runs a web server that is capable of streaming audio and video. However, during testing we realized the CPU was entirely utilized by the VLC process, because of the need to transcode video and combine together both the audio and video, preventing other needed processes from running. We switched to using MJPG-Streamer, which is able to stream raw video without any need for conversion. Audio is streamed separately using VLC, however, when streaming audio this process does not take over the CPU. These streams will be able to received by any video player which supports playing a network stream.

*Desktop Application*
The desktop application will be written in C# and utilize the .NET Framework.

The desktop application will support the following input methods:
- mouse (clicking on-screen buttons)
- keyboard (using arrow keys to pan camera, etc.)
- controller (using thumbstick to pan/tilt camera)

## Software Flowcharts

The following flowcharts illustrate the important processes in the software part of this project.

I. **Beaglebone Black**
    A. Server Handling Connection Attempt from User
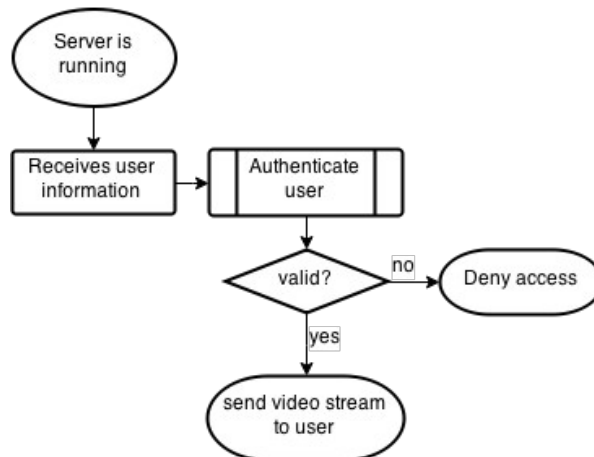


*Figure 9: Connection to the BeagleBone as seen by the server.*

## II.    Desktop Application
### A.   Program Startup and Connecting to Beaglebone Black
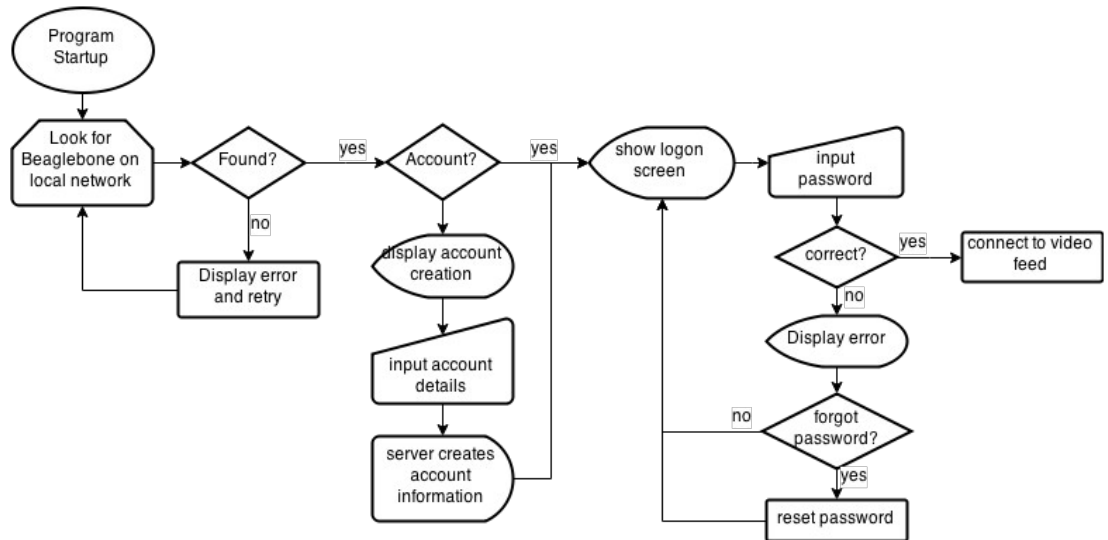


*Figure 10: Start-up process flowchart.*

### B.   Issuing a Command to the Beaglebone
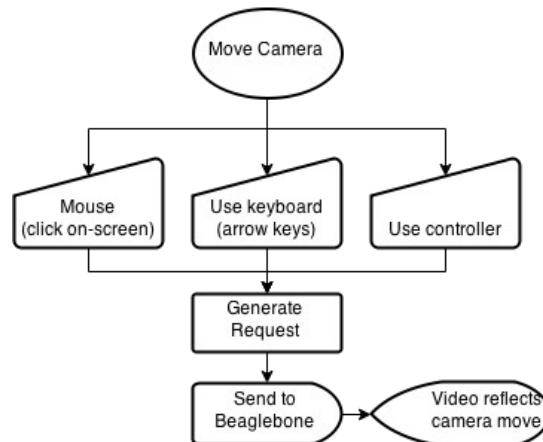


*Figure 11: Flowchart Detailing BeagleBone Command Handling*

## Mechanical Design

The mechanical design of this telepresence device relies heavily on the specifications that are driven by the electrical components and their connectivity. The bulk of our efforts thus far have been put towards choosing the components that have the necessary electronic specifications rather than the physical appearance. Once the choice of components started taking shape, we were able to move forward with figuring out how they would mechanically come together.

The important mechanical design criteria were taken from conversation with the client as well as online media and communities that have provided feedback on the chosen components. They are as follows (in decreasing order of importance): longevity, usability, aesthetic, and weight. These criteria were taken into account in all aspects of the design, including mechanical.

### I.    The Chassis
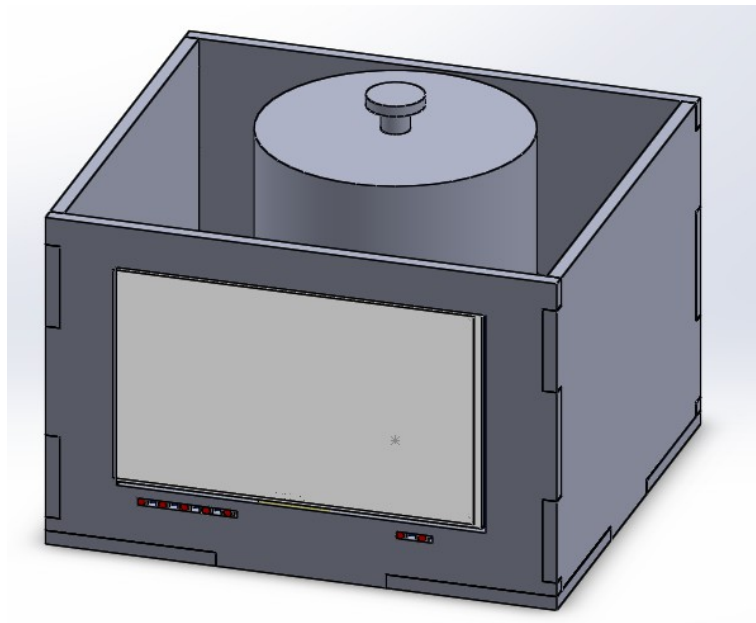


*Figure 12: 3D Conceptual Scale Model of Chassis.*

The goal of the overall appearance is to be compact and not distracting while still giving Nathan the feeling that he is more connected to his classmates. The original idea was to place the LCD screen in front of the microphone, which would make the device resemble a face. However, after receiving the microphone and the LCD screen it became obvious that they would not be so easily mounted in this configuration. Figure 12 shows a new conceptual model with the LCD mounted on the base of the chassis in a non-moving location. This model provides less moving wires, a shorter overall design, and a lower center of gravity.

It is likely that the speakers will be mounted on the lateral sides of the chassis, but before that decision is made there will need to be testing to ensure that the speakers do not create a feedback loop with the microphone.

Additionally, the design in figure 12 does not have any weight on the lid of the chassis (not shown). This will allow the lid to be easily removable for troubleshooting, which was originally not possible. The lid design can be as simple as two halves of plexiglass that slide in on a track. This way all of the LEDs will be visible and the components will be able to be accessed without having to remove any screws.

## II.     Wire Connectivity

One main concern with connecting such a multitude of components is the wires. If the wires are too visible then the device will appear messy. If the wires that move above the neck during the panning motion are constricted, then there could be broken connections or unnecessary stress on the motors. For this reason, the wires will be fed through holes at the top of the panning servo housing and through holes in the lid. With an appropriate amount of slack, keeping the wires close to the axis of rotation will reduce their overall motion without creating points where they can snag.

## III.     Base Assembly
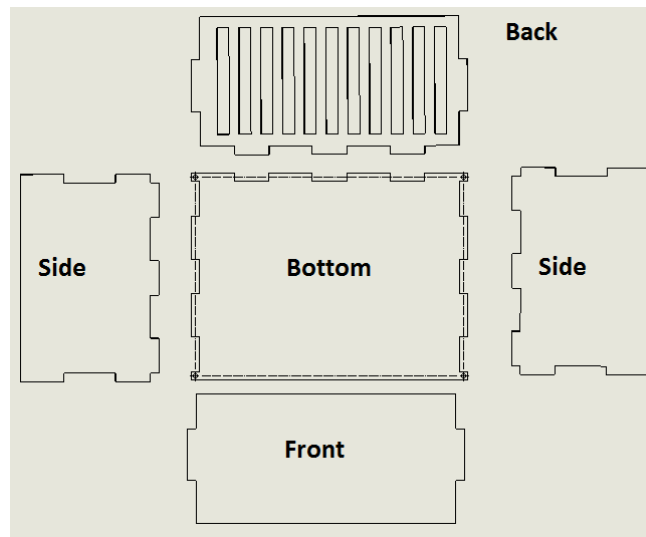


*Figure 13: Drawing of Base Assembly Concept. The four pieces assemble to form a 8" x 6" x 4" box when pieced together (dimensions not visible in diagram).*

The base of the chassis will also be the storage for all other components, such as the USB hub, the sound card, the power transformers, the A/D converter, and the motor controller. Figure 13 is a model of the

chassis design prior to the relocation of the LCD screen. The new design will have a cutout in the front for the mounting of the LCD screen as seen in figure 12.

The new base unit will be 8" x 9" x 6", which will provide more than enough space for the listed components. Those dimensions are selected based on the LCD screen length and height and the panning servo housing. Further iterations need to be done once the wiring for the power system is designed in order to optimise space. If more space is needed the dimensions can be adjusted easily.

The four pieces of the base unit are designed to fit together snugly and then be fastened together at the edges with small screws. The pieces will be cut out of a 1/4" thick sheet of ABS plastic. Sheet metal was considered as a possible material, but it was decided against because of its potential for having sharp edges and for deformation.

## IV.    Other Mechanical Design Considerations

The remaining considerations for the mechanical design concern transportation. With the current chassis design, there are no convenient locations to hold the device while transporting it. It is necessary to implement a carrying method, either through additional handles on the device or a separate carrying bag or box. This solution could be as simple as using a milk crate to hold the device for transportations. However, more concept development with the client is necessary before any conclusions are made.

The power cable that attaches to the wall outlet will be very short. This way there can be an extension cord that can be left in the classroom, which will save the teacher/assistant the hassle of moving any obstacles that may be in the way of the outlet (i.e. shelves, other plugs, desks).

The addition of four support legs beneath the base unit were considered as a method of placing this device on an uneven surface. After considering classroom conditions, it is likely that the teacher/assistant will designate a location for the device to sit that has a flat surface and will continue to leave that space open specifically for the device.

Finally, the choice of 1/4" thickness ABS plastic as the desired material for chassis manufacturing removes the option of using the casing as a heat sink for the transformers and other heat generating components. This issue can be negated by adding a heat sink wherever necessary since the base unit has ample room for additional components.

**Update 1:** Integration on speakers
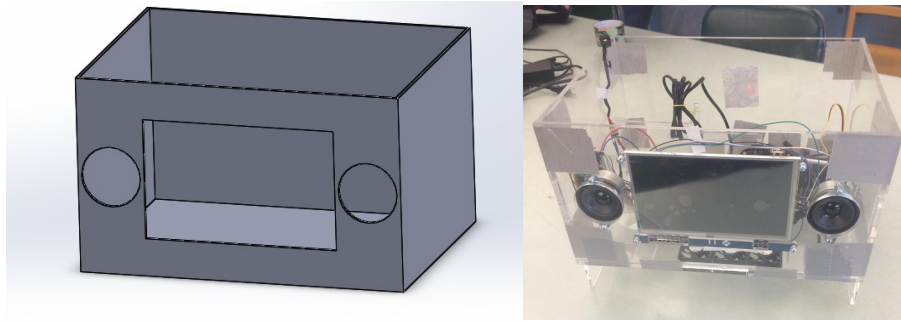


*Figure 14: CAD image of Update 1 next to an image of the first iteration of the chassis*

As an improvement to the previous design, it was decided to integrate the speakers into the chassis. This would reduce the bulkiness of the chassis and allow for the wiring of the speakers to be internal rather than passed through the walls of the chassis. Figure 14 shows a CAD rendition of this change next to the first iteration of the chassis. The speakers were separated from their original housing and then mounted on the chassis. In addition to the two speakers was a circuit board that had some kind of amplifying and filtering effect.

**Update 2: Transition to sheet aluminum instead of acrylic**
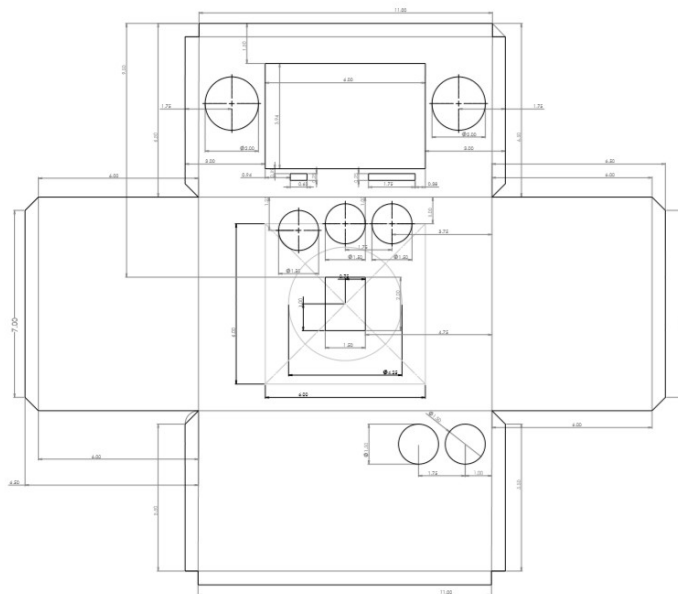


*Figure 15: Schematic of the shape to be cut into the sheet metal.*

Do to the brittle nature of acrylic we needed to switch to a material that was more machinable. Sheet aluminum was the next best option because of its strength and malleability. Using sheet metal means that

laser cutting was no longer an option, however, by cutting out the correct template, a box could easily be made using equipment that can be accessed in Cal Poly's machine shops. A rendition of the template is seen in figure 15. The dimensions and lines of the schematic were transferred by hand to the metal sheet prior to cutting.

**Update 3: Application of a lazy Suzan hardware**



*Figure 16: Final design of the chassis with all of its elements.*

Figure 16 displays the final chassis design. The wood platform that is at the base of the device is connected to the panning servo through the bottom of the chassis. The specs of the servo and the pan base support were sufficient to withstand this added load. This option allows us to meet our original goal of allowing the entire device to pan rather than just the microphone and camera. Adding this to the design creates a few more difficulties for manufacturing which will be talked about later in chapter 7.

*Safety Considerations*
Special Safety considerations include manufacturing the chassis to disclude any sharp or pointed edges. The electrical portion of the project was carefully thought about when choosing power adapters and components. The Beaglebone and USB hub collectively draw the largest current from the system, which is rated at 6 Amps. A 120V wall power adapter was chosen at 19.5 Volts/4 Amps to supply power to the telepresence device. It is not expected, and very unlikely, that the system will draw the rated 6 Amps at any time during normal operation so a 4 Amp power adapter will be fine to power the design.
The DC-DC power convertors were also chosen to have a output current much higher than the actual current that will be drawn from them. The rated output current value of the DC-DC power converters is 5 Amps. One of the converters is powering the USB hub, which again is rated at 4 Amps and under the rated output current of 5 Amps that the converter can produce. The power converters and Beaglebone will also be cooled with fans to regulate overheating during long hours of operation.
Fuses will also be installed after the power adapter and every DC-DC convertor to protect the currents from short circuit damage.

The system will need to be maintained at least once a month by cleaning off any dirt or dust that collects on the system to maintain its lifespan.  The camera and microphone will need to have special attention on their upkeep because they are the most important modules in the design.

Possible repair consideration may include non operational cooling fans or motors.  The cooling fans/motors are the only moving components in our design that move and may stop working after continuous use due to fatigue.  These should first be tested by making sure they still move under a no-load condition, and will respond to an electrical input signal.  If neither of the motors move/respond, they will have to be replaced.

# Chapter 5: Manufacturing and Design Verification Plan (Testing)

The custom chassis will be made on campus in the digital fabrication lab using a laser cutter. The components will be placed in a way that will allow the smallest, but most effective size as well as optimal operation. Careful measurements and schematics will be drawn to reduce errors when manufacturing the chassis.

Each electrical component will be tested for correct operation, continuity, power consumption, and heat dissipation. The necessary equipment will be a DC power supply, a multimeter, a signal(function) generator, an oscilloscope, and a thermocouple. The DC power supply will supply power to the unit under test (uut) and will also supply the input for the DC-DC power convertors/other digital systems.  For the servo motors, the signal (function) generator will serve as the input. The multimeter and oscilloscope will measure the output and verify it is correct to the theoretical output.  A thermocouple will also be used to measure the heat being dissipated.  If too much heat is being dissipated, a cooling method will have to be implemented. Currently, it is speculated that only fans will be needed for the Beaglebone and power converters.

The location of the speakers in relation to the microphone is another point that needs to be tested. It is possible that the speakers in proximity to the microphone could cause interference or feedback loops. To test for this, the two speakers will be placed at locations and tested at different volumes and sensitivities.

The chassis will be stress tested with certain weights to verify its mechanical stability and toughness. Strain gauges could be used to measure the stresses on the chassis, but verification through inspection will be acceptable because the telepresence device is not expected to be normally used under high mechanical stress.

**Update 2: Transition to sheet aluminum instead of acrylic**

This update changes the methods for manufacturing drastically. Laser cutting is no longer an option for sheet aluminum. Instead, the aluminum will be cut using a shear, a hole punch, and sheet metal shears to meet the specifications of the template in image ??. Once cut, the sheet will be folded into a box using a finger break. Rough edges will be removed using a deburrer and a file will be used to straighten out any bad cuts. Once folded, the edges will be either welded or fastened with rivets. Testing this new chassis will be done the same way as previously mentioned.

**Update 3: Application of a lazy Suzan hardware**

The portion of the chassis that interacts with the lazy Suzan needs to be precisely manufactured so that the axis of the servo lines up directly with the axis of the lazy Suzan. If they do not line up perfectly then there could be added stress to the servo that could inhibit the panning motion. This means that transferring the schematic onto the metal sheet needs to be done with precision.

*Design Verification Plan Table*

**ENGR459-461 DESIGN VERIFICATION PLAN AND REPORT**

| Report Date | 5/27/15 | Sponsor: Kevin Taylor | Component/Assembly: Telepresence Device | | | REPORTING ENGINEER: Team I-CEE | |
|---|---|---|---|---|---|---|---|

**TEST PLAN**

| Item No | Specification | Test Description | Acceptance Criteria | Test Responsibility | Test Stage | SAMPLES TESTED Quantity |
|---|---|---|---|---|---|---|
| 1 | Range of Vision (Horizontal) | Measure the range of device Panning | Panning Servo turns 0 to 180 (degrees) | Andrew | ✔ | 1 |
| 2 | Range of Vision (Vertical) | Measure the range of camera Tilt | Tilting servo turns -60 to 60 (degrees) | Nick | ✔ | 1 |
| 3 | Range of Zoom | Observe an adequate zoom ratio | 6" image on board 40 feet away is readable on screen | Daniel | | 1 |
| 4 | Clarity of sound | Distinguish between noise from children and information from teacher | In a clasroom with typical chatter, device should be able to clearly pick-up and transmit sound that is relevant | Andrew and Nick | ✔ | 1 |
| 5 | Life of Servo | Servos under load must function continuously without damage or noticable wear | 5 sessions of 8 hour continuous movement of moderate speed without observable damage | Luke | | 1 |
| 6 | Chassis Durability | Chassis will be subject to relatively high heat | Chassis shows no visible sign of warping, cracking, or melting and does not have any significant structural weakness (ie breaks when bent in hands, etc) | Nick | | 1 |
| 7 | Sound sensitivity | Microphone will be subject to audio testing in the Anechoic Chamber | Microphone detects desired sound with clarity from about 25 feet away from source. | Andrew and Nick | ✔ | 1 |
| 8 | Status Indicators | Testing LED arrays to ensure the status indicators will light up in the event of component failure | LEDs will be lit up using the appropriate voltage levels | Daniel | | 1 |
| 9 | Power Regulation | Test current draw, input/output voltages, and component heating | Required voltages of 5V, 6V, 9V (+/- 0.2V) with an allowable output amp draw of 5A MAX | Nick | ✔ | 1 |
| 10 | Wifi/Ethernet Connectivity | Show that an internet connection can be established and maintained from the BeagleBone. | The internet connection is sturdy and provides a stable connection for a period of at least 30 minutes at a time. | Luke and Daniel | ✔ | 1 |
| 11 | System Weight | Measure overall system weight with a scale | The overall system weighs about 10 pounds at most. | Luke | ✔ | 1 |
| 12 | System Dimensions | System fits to required specification | The system will fit onto an area equal to or less than 12"x12" | Luke | ✔ | 1 |

*Table 2: Design Verification Plan and Report*

## Design Verification Plan Tests

**Specification:** Life of Servo
**Item No:** 1
**Determine:** Whether servos can operate under load continuously without damage or noticeable performance degradation.
**Preconditions:** Beaglebone control signal voltage = 3.3V square wave, servo rail voltage= 6VDC,

**Procedure:**
1. Create a simulated load approximately 1.5x heavier than the expected weight of the overall system (10 lbs).
2. Connect 1 servo motor to Beaglebone Black PWM pins and power supply rails.
3. With a micro-USB to USB cable, connect the Beaglebone Black to a computer. The Beaglebone Black will power on when it is connected.
4. Connect to the Beaglebone Black using a serial terminal (eg. PuTTY or RealTerm for Windows, ssh for *nix and Macintosh computers), by connecting to IP address **192.168.7.2** and port **22**.
5. Login with username **debian** and password **temppwd**.
6. The program that will run the test script is located in the home directory and is called `test_servo_life.py`. A `ls` command will confirm that the file is present.
7. After verifying the connections, run the script command with `python test_servo_life.py`. The servo script should put the servo through a full 180 degree range of motion quickly and continuously for 10000 iterations.
8. Place the servo on a flat surface at room temperature while the servo runs through the test iterations.
9. Wait until the test is finished. Immediately after the testing is complete, check the servo chassis for excessive heating, wear on the servo shaft, and wire damage. If there is excessive wire damage or excessive wear on the servo shaft, the servo may not be ideal for the purpose of this project.
10. Wait for 1 hour to allow the servo time to rest.
11. Run the sample code that will make the servo sweep once from 0 to 180 degrees (+/- 5% error) and back. This is to ensure that the servo still has the correct functionality and reasonable precision.
12. The servo is determined to have good lifetime performance (5 years)  if the servo can complete all these tasks and still maintain its precision and function.

**Specification:** Beaglebone Network Connectivity
**Item No:** 2
**Determine:** That the Beaglebone device is able to connect to the local network when connected using an Ethernet cable, and that the laptop can communicate with the Beaglebone.
**Preconditions:** The screen cape shall be attached to the Beaglebone for visual verification, the laptop and Beaglebone shall be connected to the same local area network, and the desktop client shall be installed on the laptop.

**Procedure:**
1. Attach the screen cape to the Beaglebone by following the correct orientation diagram that is outlined on the cape.
2. Connect the USB hub to the Beaglebone and plug in a keyboard and mouse (or use the touchscreen).
3. Plug in an Ethernet cable to the Ethernet port on the Beaglebone.
4. Apply power to the Beaglebone using the barrel jack connector and the 5 V DC adapter.

5. The screen will turn on and the system will boot to the desktop.
6. Open a terminal window on the device and enter the following command to retrieve the IP address: `ifconfig eth0`.
7. Write down the 4 numbers that comprise the IP address and start up the ICEE Video Client and enter the IP address. The last good IP address will be saved for subsequent sessions.
8. Once this is complete, the desktop software should connect to the server.

**Specification:** Beaglebone Server Responds to Hardware Commands from Desktop Application
**Item No:** 3
**Determine:** The Beaglebone responds to the software and performs the requested action.
**Preconditions:** The system should be fully assembled and in its final configuration, and the desktop client should be installed on the laptop.

**Procedure:**
1. The Beaglebone system should be fully assembled and connected to a network using the Ethernet port and powered on.
2. Open the desktop client and connect to the desktop server. Enter the IP address of the Beaglebone server if needed, see Test 2 for details. If a connection has already been successful, the IP address will be saved.
3. Press the on-screen left arrow button, or the left keyboard arrow. Verify that the camera has panned to the left.
4. Press the on-screen right arrow button, or the right keyboard arrow. Verify that the camera has panned to the right.
5. Press the on-screen up arrow button, or the up keyboard arrow. Verify that the camera has tilted up.
6. Press the on-screen down arrow button, or the down keyboard arrow. Verify that the camera has tilted down.
7. Press the LED enable on-screen button. Verify that the notification LED has turned on.
8. Press the LED enable on-screen button again. Verify that the notification LED has turned off.

**Specification:** Speakers do not interfere with the microphone
**Item No.:** 4
**Determine:** Where the speakers can be placed without creating feedback
**Preconditions:** The microphone must be working the same way that it will in the final product (i.e. same power, software, soundcard)

**Procedure:**
1. The microphone will be connected to the BBB through the sound card and USB hub.
2. The audio portion of the telecommunication software will be running on a computer with a built-in microphone in a different room.
3. The speakers will be oriented in multiple positions that are feasible for mounting (i.e. not in the way of the moving parts)
4. At each position a team member will attempt to talk through the device at different volumes and then will record notes on the quality/clarity of the sound.

**Specification:** Wire security and integrity
**Item No.:** 5
**Determine:** All wires are arranged such that there is a minimum chance of the wires snagging on, or being otherwise damaged from, the moving components of the device.
**Preconditions:** The device is fully assembled, with the internals clearly visible to observe any potential snagging.

**Procedure:**

1. Independently pan and tilt the two servos slowly between the two extreme positions. It is highly encouraged to pan and tilt between all possible configurations of the device.
2. Observe for potential stresses, including friction between wires and moving parts, snagging on the servo shaft or any of the moving parts connected to the servo, and unwiring caused by the servo or associated moving parts. The wiring position is considered good if no wires are in the way of the servo or associated moving parts.
3. If any sign of potential damage is seen in the process of the test, stop the test immediately and secure the loose wire in such a way that it does not snag against any moving parts. Once this has been done, resume the test from the beginning to ensure that the newly secured wire will not snag against a different part.

**Specification:** Power Regulation
**Item No:** 6
**Determine:** All power regulators are operational, providing the correct output voltage and current within 10% error.
**Preconditions:** No preconditions

**Procedure:**
1. Acquire a DC power supply, multimeter, and high power variable resistive load (>=27 Watts).
2. Hook up the DC-DC buck converter input with the DC power supply and configure the voltage and current into: 19V/3A.
3. Hook up the resistive load to the output ensuring that the product of (voltage * current) will not burn out the load.
4. Turn the knob on the adjustable DC-DC buck converter so the output is 9V, 6V, and 5V.
5. Measure the voltage and current from the output of the buck converter and show that it does not exhibit an error of more than +/- 10%.
6. Leave the buck converter on for at least 2 hours (if possible) to measure the heat dissipation from the component.
7. If the on-chip heat regulation is insufficient, cooling fans will need to be added.
8. If the error is more than +/- 10%, or it is not regulating/powering on more testing will need to be done to determine if it is an operator error or if the component is broken.
9. If the buck converters operate within specification, no new changes will need to be made.

**Specification:** Sound Sensitivity
**Item No:** 7
**Determine:** The sensitivity of the microphone to various noise inputs in a controlled environment.
**Preconditions:** Microphone connected to sound card, microphone input from battery is 9V, Test done in anechoic chamber

Procedure:

1. While in the Anechoic chamber, play music at 100% max volume from a computer 25 feet away from the microphone. Record for 30 seconds. This recording will be the maximum volume baseline.
2. Without moving the noise source, lower the music to 90% max volume and repeat step 1, preferably with the same music sample.
3. Repeat step two, decreasing the volume by 10% of the max volume every iteration. The microphone will be considered very sensitive if it can pick up the sound at 30% max volume or less, and reasonably sensitive if it can pick up the sound at between 40-50% max volume.

**Specification:** Chassis Durability
**Item No:** 8
**Determine:** The strength and durability of the chassis under stress up to ten times the expected load weight and under impact up to twice the expected drop height.
**Preconditions:** Chassis must be completed and assembled, chassis is devoid of any hardware or other valuable components.

**Procedure:**

1. Obtain weights of various sizes ranging from 5 lbs to 200 lbs.
2. Place weights on top of the chassis, incrementing the weight each time. This will simulate static stresses that the chassis may experience. Be sure to include the nominal weights of the components that will be installed and place weight on the chassis.
3. Rotate the chassis on each side to ensure that each side can withstand the same stresses.
4. Simulate the chassis falling off of a high shelf or altitude by loading the inside of the chassis with the nominal weight of the components it will house and drop it off of heights of 1 to 15 feet.
5. If the chassis breaks or is damaged so it can no longer support the installed hardware, a new chassis will have to be designed to withstand the tests. A new chassis will also have to be built if any of the tests scratch or dent the chassis in a way that makes the appearance unfavorable.
6. If the chassis sufficiently passes all test cases, no further changes will need to be made.

**Specification:** Sound Clarity
**Item No:** 9
**Determine:** Whether the 3Dio microphone can effectively pick up the desired sound of a teacher's voice in a noisy room from a distance of at least 25 feet away.
**Preconditions:** Microphone input voltage from DC-DC converter is 9V, room has sufficient ambient noise to interfere with clear audio reception, microphone is connected to sound card.

**Procedure:**
1. Record in a noisy room, and focus in on audio from a particular source about 25 feet away. A good area would be in an open lab room where free discussion is allowed.
2. Record for about 15 minutes and check the audio quality. The microphone is considered to have good audio quality if it can pick up the desired sound source with reasonable fidelity and clarity while not amplifying the ambient noise.

**Specification:** Quality of Zoom
**Item No:** 10
**Determine:** Whether the zoom functionality implemented in the Mobius Dash Camera will generate a legible image from a source about 25 feet away.

**Preconditions:** Dash camera has digital zoom capabilities added in, dash camera powered with a USB-mini-USB cord and is connected to Beaglebone or computer, image with approximately 48-pt. font words at 25 feet from camera.

**Procedure:**
1. Position the camera so that the image is within the camera's center of view.
2. Zoom in on the image until the image takes up the entire screen. The Zoom quality is considered exceptional if the image is clearly legible with no blur, and is considered good if the image is clearly legible with slight blur.

**Specification:** Range of Vision (Horizontal)
**Item No:** 11
**Determine:** Whether the HS-7954SH panning servo can comfortably move from 0-180 degrees under no-load conditions.
**Preconditions:** Control signal voltage = 3.3V square wave, servo rail voltage= 6VDC, no load on servo arm, servo arm has been calibrated to correct angles, initial servo arm position at 90 degrees

Procedure:
1. Input a square wave pulse to move the servo arm to 0 degrees. Hold for two minutes.
2. Input a square wave pulse to move the servo arm to 180 degrees. Hold for two minutes.
3. Input a square wave pulse to return the servo arm to 90 degrees. The servo is determined to have good performance if the servo arm can maintain the extreme positions without shaking.

**Specification:** Range of Vision (Vertical)
**Item No:** 12
**Determine:** Whether the HS-485HB tilt servo can comfortably move from -60-60 degrees in the vertical direction under no load conditions.
**Preconditions:** Control signal voltage = 3.3V square wave, servo rail voltage= 6VDC, no load on servo arm, servo arm has been calibrated to correct angles, initial servo arm position at 0 degrees from vertical (60 degrees in normal configuration)

Procedure:
1. Input a square wave pulse to move the servo arm to -60 degrees from vertical (0 degrees in normal configuration). Hold for two minutes.
2. Input a square wave pulse to move the servo arm to 60 degrees from vertical (120 degrees in normal configuration). Hold for two minutes.
3. Input a square wave pulse to return the servo arm to 0 degrees from vertical. The servo is determined to have good performance if the servo arm can maintain the extreme positions without shaking.

**Specification:** Status Indicators
**Item No:** 13
**Determine:** The status indicators operate nominally with appropriate stimuli
**Preconditions:** Electrical power system will need to be established, connected, and completed.

**Procedure:**
1. Turn on the power to the telepresence system.

2. Verify that all the LEDs are off indicating that all systems are being supplied power when the main power is on.
3. Verify the correct voltage and current are being supplied to the LEDs to ensure the right amount of power is being delivered to the LEDs, and no excess power is being used with a multimeter.
4. Simulate failure by either turning off or disconnecting the individual component (if applicable) to turn the LEDs on.
5. If the indicators are burning out, drawing too much power, or not turning on, troubleshoot to make sure the LED is being provided the right about of power or change the design to bias the LEDs at the correct current.
6. If all nominal functionality is operating correctly, no further changes are needed.

# Failure Mode and Effects Analysis

**FAILURE MODE AND EFFECTS ANALYSIS**

| Item: | Telepresence Module | Responsibility: | I-CEE | FMEA number: | |
|---|---|---|---|---|---|
| Model: | Current | Prepared by: | I-CEE | Page : | 1 of 1 |
| Core Team: | Luke Cole, Andrew Ma, Nick Ross, Daniel Williams | | | FMEA Date (Orig): | 2/24/2015    Rev:   1 |

| Process Function | Potential Failure Mode | Potential Effect(s) of Failure | Sev | Class | Potential Cause(s)/ Mechanism(s) of Failure | Occur | Current Process Controls | Detec | RPN | Recommended Action(s) | Responsibility and Target Completion Date | Action Results | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Actions Taken | Sev | Occ | Det | RPN |
| Power Conversion | DC-DC converter malfunction (Open Circuit) | Camera, sound card, and wifi turn off (no visual, audio, or network connection) | 7 | | Open circuit at broken 6v/5A converter shuts off power to USB hub | 3 | lack of feedback on user's computer | 7 | 147 | Insert LED indicator lights on all post-converter power connections | | | 7 | 3 | 3 | 63 |
| | | BBB and servo motors turn off | 8 | | Open circuit at broken 5V/5A converter shuts off power to BBB and servos | 3 | lack of feedback on user's computer | 7 | 168 | Insert LED indicator lights on all post-converter power connections | | | 8 | 3 | 3 | 72 |
| | | microphone turn off (lack of audio) | 4 | | Open circuit at broken 9V/5A converter shuts off power to microphone | 3 | lack of feedback on user's computer | 7 | 84 | Insert LED indicator lights on all post-converter power connections | | | 4 | 3 | 3 | 36 |
| | DC-DC converter malfunction (short circuit) | damage to component(s) associated with drawing too much current | 9 | | Short circuit at ANY of the converters | 3 | loss of connection to the device. Potentially a gradual loss in signal as the devices are overheating | 8 | 216 | Insert fuse box on all post-converter power connections | | | 4 | 3 | 3 | 36 |
| Chassis/support | wire snagging | loss of communication with moving parts (mic, camera, tilting servo, LCD screen, BBB) | 7 | | wires get physically tangled and pull loose from their connection ports during panning or tilting motion. | 4 | lack of feedback on user's computer | 7 | 196 | Test under typical operating conditions and observe for potential locations of wire snagging | | | 7 | 1 | 7 | 49 |
| Camera | Camera not streaming | No video | 4 | | Camera not turned on | 2 | lack of feedback on user's computer | 7 | 56 | Create LED notification when camera is off | | | 4 | 2 | 3 | 24 |
| | | | | | Camera broken | 1 | lack of feedback on user's computer; camera does not activate | 8 | 32 | Attempt to turn on camera; if camera does not respond, buy new camera | | | 4 | 2 | 1 | 8 |
| Microphone | No sound on user's side | No audio | 4 | | Microphone not connected | 2 | lack of feedback on user's computer | 7 | 56 | Create LED notification when camera is off | | | 4 | 2 | 3 | 24 |
| | | | | | Microphone broken | 1 | lack of feedback on user's computer; microphone does not activate | 8 | 32 | Unplug/plug in microphone; if microphone does not respond, troubleshoot inside further or purchase new microphone | | | 4 | 2 | 1 | 8 |
| Servo Motor | Motor operation malfunction | Motor Stalls | 5 | | Too much load for servo | 4 | Module will not pan/tilt | 2 | 40 | Lighten load on servo by removing weight from construction and have detection mechanism with LED indicating stalling | | | 1 | 2 | 2 | 4 |
| | | | | | Servo overturns (turns past 180 degrees) | 5 | Module will not pan/tilt | 2 | 50 | Correct for servo position so that servo will not overturn | | | 2 | 2 | 2 | 8 |
| | | Motor Overheats | 7 | | Motor remains stalled for too long | 4 | Module will not pan/tilt | 3 | 84 | Have LED sensor check for stalling (see solution for stalling above) | | | 4 | 2 | 2 | 16 |
| Software | Unable to connect to Beaglebone | Unable to use system | 7 | | Beaglebone not connected to network | 2 | None | 2 | 28 | Guidelines on how to troubleshoot network connection | | | 3 | 1 | 1 | 3 |
| | Camera not streaming | No video or audio to be seen | 7 | | Beaglebone not connected to network or Misconfigured software | 3 | None | 3 | 63 | Configure streaming software to run when the Beaglebone is powered on | | | 2 | 1 | 2 | 4 |
| | Beaglebone not responding to pan/tilt controls | Camera won't be able to pan | 6 | | Wires connecting motors to Beaglebone have become detached | 3 | | 5 | 90 | Send a user message indicating that connections are missing | | | 3 | 2 | 2 | 12 |

*Table 3: Failure Mode and Effects Analysis*

# Chapter 6: Project Management Plan

**Roles and Responsibilities**

Each member of I.-C.E.E. will be expected to attend and participate in all group meetings. In the event that a member is unable to attend a meeting, it is the responsibility of the other members to inform that member of the meeting details, clearly communicating with them what was accomplished in the meeting and what the new deliverables are. When any member commits to a task, it is expected that they accomplish it in a timely manner. All difficulties and challenges with said task will be communicated with the remaining members of the team to ensure an effective and efficient solution. In general, there is an expectation of professional and frequent communication between all members of the team.

**Communication Plan**

Our primary venue of communication to the client and sponsor will be with a kinesiology student, Margot Allen.  Margot will supervise  and update us on any requirement changes or additions from the sponsor or the client.

**Separation of Tasks**

Nicholas Ross and Andrew Ma will be responsible for the electrical engineering aspects such as component selection, power supply, and connectivity. Daniel Williams will be responsible for the software development. Luke Cole will be responsible for the mechanical design and manufacturing of machined components.

**Software Development Plan**

The software development process can mostly be done independently of the Beaglebone Black. By utilizing a guest virtual machine running a Linux operating system, it is possible to install the software that will be required on the Beaglebone Black and interact with the host operating system (Windows). The host operating system will be able to send requests to the virtual machine and replicate much of the interaction between the two. Streaming video clips from the virtual machine can emulate the actual streaming of the camera in the final product. Obviously, once the core functionality has been implemented, integrating with the Beaglebone and its hardware components will begin.

The source code will stored on a private Bitbucket Git repository, which will provide version control. This is vital for an involved software project like this to avoid unfortunate accidents like hard drive failures or worse.

# Chapter 7: Realization of the Project

## Manufacturing the Chassis

**Chassis iteration #1**:
The first iteration of the chassis was using the 1/4" thick acrylic sheets. With the CAD designs made for each piece, all that had to be done was convert the file to RhinoCAM file. Since the CAD designs were made with Solidworks, Luke published the shapes to eDrawings and then opened the file in Rhinoceros. At the dFab lab at Cal Poly, the attendant assisted Luke in orienting the pieces on the cutting field. Since the 1/4" acrylic was thicker than what is normally cut, there were concerns about the kerf of the laser would be larger at the top of the piece than at the bottom due to longer burning time, which proved to become an issue when the pieces were picked up and put together. The extra kerf on the piece caused the constructed chassis to become lopsided. To mend this problem, silicon glue was used, which lasted about 3 days before the sides had to be duct taped together.

Other that the kerf problem, the laser cutting method created a clean surface for mounting the LCD screen and speakers. Drilling into the acrylic to make screw holes was not as difficult as expected; however, lining up the holes on the components with the holes in the acrylic was not as simple as expected. The components were placed over their respective holes and a pen was used to mark the screw hole locations. During assembly, the holes did not line up well.

**Chassis iteration #2,3,4**

For iterations 2, 3, and 4, the aluminum sheet replaced the acrylic sheet and manufacturing changed drastically. The holes for the fans were easily punched out with the school's 1.5" hole punch; however, the speakers needed to be 2" holes. To address this problem, the 1.5" punch was used for the speaker holes. Afterwards, a file and a deburrer were used to get the holes to the appropriate size. This process was difficult and yielded non-circular holes.

Cutting out the rectangular LCD screen hole on the front of the chassis was an entire struggle in itself. A lot of the material was removed by the hole punch, but hand shears needed to be used in order to get the corners and have clean edges. It was difficult to maneuver the shears into the right spot which led to some cuts that were not very straight. Since three of these aluminum chassis were created,each iteration proved better in quality than the last. However, by the last iteration, there were still obvious flaws in the appearance of the front of the chassis.

Bending the aluminum into a box was relatively simple. However, there were problems with the heights of the sides lining up. This was not much of a problem for this design, but it was more messy. The discrepancy in wall heights was due to the bending process and is hard to avoid. In an attempt to connect the edges of the box, the edges of the box were secured using a spot welding technique. However, aluminum transfers heat away from the spot weld too fast and prevented the bonds from properly forming. The next option was brazing, but due to a lack of time, this option could not be explored. The

final solution for this iteration was to simply add a nut and bolt to each of the four corners. The plan was to eventually add a rivet to those holes as a permanent solution.

For iterations 2 - 4, the lazy Suzan was added to the design. This meant that the pan servo housing was flipped upside down and joined it with a wood plate. As mentioned earlier, it was essential that the axis of the servo lined up perfectly with that of the lazy Suzan. By the final iteration, alignment was still a major issue, and the lazy Suzan had to be left unattached to the wood plate to facilitate chassis panning. The major indicator of a misaligned axis could be seen when turning the device on top of the lazy Suzan. During turning, the bottom of the Suzan shifted noticeably against the wood plate.

Although the addition of the lazy Suzan lessened the amount of moving wires, it created its own set of problems. It was important that the ethernet and power source adaptors did not move with the device. Therefore, they had to be fed down from the chassis along the servo axis and into a carved out slot on the wood plate. In assembling the components it turned out that the purchased ethernet adapter was too short and the port was too bulky to allow for a smooth panning motion. Coupled with the problem with the axis alignment issue, this stopped the device from having its desired 180 degree turning ability.

Finally, the lazy Suzan made the assembly of the device more complicated because everything had to be assembled in a particular order (see Disassembly Instructions)

## Design Changes

**Mechanical**

All design changes to the chassis are included as updates in chapter 4.

## Testing

The components of the device were tested modularly during multiple iterations. The hardware modules and subcomponents were thoroughly tested for quality and benchmark results before the components were compiled into the main module.

DC Power Converters:
The power converters were tested in order to ensure that they could handle the rated voltages and currents. To do this, the power converter was first connected directly to a 19.5V DC power supply. The power converter was then adjusted to ensure that it could reach the voltages that the subcomponents required. Next, the power converters were connected in series to a power resistor and connected to a high-current DC power supply set at 3A. The power converters were able to handle the specified voltages and currents without major fluctuations. During the 3A test, the power converter grew warmer over time, and the supply voltage dropped slowly over the course of 15 minutes. This was deemed acceptable, since the power converters should only have to handle high current (2A and above) in short surges, not over a long period of time.

Microphone:

The microphone were first tested by simply connecting the microphone to the sound card, and hooking the sound card up to a computer to perform recording. The resulting recording was very quiet, with the microphone peak to peak output at 0.5V. To solve this issue, a simple amplifier circuit was researched to increase the recording volume. The issue was solved when it was found that the BeagleBone had an internal automatic gain controlled (AGC) volume controller.

Amplification circuits:

Before the BeagleBone was shown to have an internal AGC volume control, several efforts were made to amplify the microphone sound. A simple LM386 audio amplification circuit, shown in figure 17, was the initial solution, but it was found that the amplification circuit clipped before a reasonable amplification (2x amplification) was achieved. An AGC breakout board was also considered and purchased, but the BeagleBone solution was found before this possibility was fully explored.
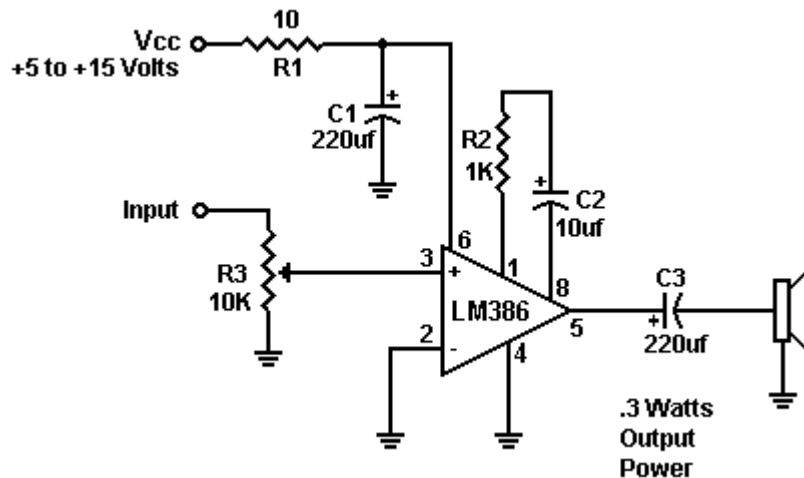


*Figure 17: Circuit diagram found online of amplification circuit.*
*Courtesy of rason.org.*

Speakers:

The speakers were originally housed in a Logitech plastic case. This case was discarded in favor of spacing. An internal transformer was found inside the casing, which was removed. The speakers were then tested by plugging in an audio source to the microphone jack. This was to make sure that the component would still work without the transformer. The speakers still functioned, indicating that the transformer was a step-down transformer to drop AC wall voltage down to manageable levels. One issue that was found in the speakers was a buzzing noise that occurred when the LCD screen was turned on. This buzzing was suspected to be ground loop noise, but the cause was not determined due to time constraints. While resoldering a ground wire helped lower the noise volume, the noise persisted. This was eventually circumvented with the addition of a "push to talk" feature. This feature toggled a transistor to turn the speakers on and off, and would be controlled on Nathan's side in the web server. This would only turn on the speakers when Nathan needed to talk, and would reduce the amount of time that the class would hear the buzzing.

Servos:

The servos were tested by introducing a pulse wave directly to the yellow wire of the servo while the servo was under no load. This pulse wave was given a width set between 1.1 and 1.9 ms. This swung the servo from between 0 to 180 degrees. The servo pulled about 0.4A during this operation. The servos were then moved between 0 and 180 degrees very quickly to simulate the maximum amount of torque that a servo would be subject to. Both servos were tested in this way.

Cooling Fans:

The cooling fans were tested by simply connecting voltage to the positive and negative terminals. The fans spun at full speed, despite the fact that the fans had a three-terminal input. It was later discovered that the third terminal, shown by the yellow wire in figure 18 below, was for speed measurement, and had no effect on the operation of the fan.



*Figure 18: Picture of the cooling fan.*

Chassis:

Testing of the final iteration of the chassis was not accomplished due to time constraints. The three metal chassis that were made were all able to support the components mounted on them without having to weld the edges or add bolts. This was because the flaps on the front and back walls were able to snuggly fit into the quarter inch fold along the top ridge. Because of this there was no concern with the chassis' ability to withstand stress. The panning set up (incl. lazy Suzan, servo, servo hub) was not tested under the necessary conditions, but there was a limitation to how far the device could pan in the final assembly. Reasons for this could be as follows: the bottom of the chassis interfered with the ethernet jack whenever it dislodged from the wood base, the ethernet adapter cable was not long enough to allow a full 180 degree rotation, or the power cable was catching on the internal edge of the chassis. Observing these problems were hard because, when the device was fully assembled, there was no way to see those wires.

Software:

The two software products were first tested independently and then in combination. The Beaglebone server software was tested first and is able to be tested manually using a web browser to access the appropriate urls. The connection established workflow was tested to ensure that the camera and audio streaming would start successfully and the PWM/GPIO pins would be ready to use. After this step, testing observed the commands to control both the servo motors and the LEDs worked successfully. The final independent test was done to ensure that all started programs would terminate successfully, since it is wasteful to have the system running even if it is not being used. This last test was completed successfully.

Independent testing was of the desktop software was accomplished by streaming a local video file until the software was stable enough to test with the Beaglebone. The two software products were then tested in combination by replicating the use case for a standard user. The software was able to startup and perform the connection process, and receive the video and audio streams from the Beaglebone when connected over the local network. Additionally, servo motors were verified to be performing correctly when move commands were issued from the client software.

Testing was not able to verify that microphone audio from the user was transmitted or received by the Beaglebone. We also did not perform a full system integration test with the assembled chassis where the operation and performance of the servos could be verified and adjusted.

## Future considerations

Due to time constraints, not all of the desired testing and functionality was enacted. Future recommendations would include adding digital zoom functionality and to find a solution to the ground loop buzzing found in the speakers when integrating the screen to the overall design. Authentication was not added to server software due to the focus on necessary functionality instead. However, it is recommended that some sort of user authentication is developed before deploying the device to a classroom. The chassis should also be stress-tested, and the internal pivot connecting the camera and chassis to the servo should be improved for better stability and a more flush fit. As an aesthetic and organisational task, the wires connecting to the buck converters should be organized in such a manner as

to be as organized and as unobtrusive as possible. This will make connections easier to make due to less confusion for wire placement.

A fuse or circuit breaker should also be added for the electrical safety of the device, as well as grounding the chassis (if it is still constructed from metal). The entirety of the chassis also needs to be powder coated and painted to have a Batman theme (requested by Nathan). Likewise, the user interface of the desktop software should be Batman theme.

**Chassis Design Recommendations**

There are many things that would have been done differently for both the design and realization of the chassis. The design of the chassis should have been complete prior to the beginning of manufacturing. A CAD model was made for each iteration; however, a lid was not included in the models. It was assumed that a lid would be relatively easy to come up with, but a lid design would have been more efficient to include in the model.

Also, it would have been better for the manufacturing of the metal chassis if the markings were transferred from the schematic to the metal sheet using a laser etching technique. During manufacturing, the drafting lines would commonly be misaligned or rubbed off. Manufacturing would be more precise if the metal sheet had machined lines on it.

It is important that the panning motion of the device is achieved in a way that will ensure longevity. Using the lazy Suzan is a practical solution for this, however, it did create a few more problems with moving wires getting caught on the hardware. The final, fully-assembled chassis was not able to be tested. Testing would show whether or not the lazy Suzan set up worked despite possible axis misalignment. In the future, it would be useful to find a way to assemble this part of the chassis with more precision. It may even be prefferable to eliminate the lazy Suzan from the design altogether. For this to work, the servo/servo hub combination would need to be strong enough to bear the weight of the moving chassis.

Finally, finding the most efficient component placement inside the chassis is very important. In the final realization, it was difficult to access some of the ports through the slew of wires. Improving on this aspect of the design could decrease the noise, overall weight, and overall size of the device.

**Disassembly Instructions:**

Taking apart the chassis as it currently is assembled needs to be done in a particular order.

1) Remove the 3Dio microphone (the ears).
2) Unscrew the 6 screws from the top of the pan base housing (the platform in the middle of the chassis.
3) Remove the LCD screen and the speakers from the chassis.
4) Remove the cylinder (Pull up on it and it should slide off the 6 screws that hold it in place).
5) Remove the servo screw from the hole in the bottom of the wood base.

a) A long star hex wrench that can fit into the hole on the bottom of the wood piece will be needed for this step. To find the size of the star hex, use the star hex screws included in the supplies since they are the same ones.

6) Pull the wood platform off the chassis, being careful not to damage the wires that are mounted on it.

7) Feed the wires up through the hole next to the servo.

8) Remove the servo and servo hub (with platform) by pulling it off the 6 screws.

## Chapter 8: Conclusions and Recommendations

All of our failures and successes in building this telepresence device have been documented in this report. We hope that it will be useful in the future when this project is done again.

This system is a one of a kind telepresence robot specifically designed for our client Nathan Stilts. This system will improve Nathan's ability to participate in the same education program as his peers. All of his requirements and needs will be met with the chosen components and design layout. Further recommendations include more time allocation set aside for component testing and software debugging and the utilization of a more streamlined work schedule through parallel component testing. The former is necessary as previous experiences in electrical and software work has proven that debugging is one of the most time-consuming processes in any project. The latter is recommended because of the relative independence of each component prior to final subsystem assembly. The independence of each component means that it would be advantageous to test different components individually to streamline the subsystem assemblies.

## Acknowledgments

# Appendices

## Appendix A: References

Double Robotics: http://www.doublerobotics.com/pricing.html
Rason.org: http://www.rason.org/Projects/icamps/icamps.htm

## Appendix B: QFD & Decision Matrices

**QFD**

Telepresence/Telerobotic Technology for Children with Disabilities — Nathan Stilts (Whats) / Customer Requirements (Step #2) / Engineering Requirements (HOWS) / Benchmarks

| Customer Requirements | Weighting (1 to 5) | < 20 lbs | <180 degree x-movement | <90 degree y-movement | ABS 3-D print casing | Microcontroller logic | HQ A/V system | Integrating Current Products | Motors | Standard Connectors | Wifi TX/RX | Battery | Other Electrical Power | Custom electrical/mechanical design/parts | User Interface | | | | | | Skype/Voodoo | General Telepresence Robots |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Neck-Like Movement | 5 | 6 | 9 | 9 | | 6 | | 3 | 9 | | | | | 6 | 3 | | | | | | | 6 |
| Portable | 1 | 9 | | | 3 | | | 3 | | 6 | 9 | 9 | | 9 | 3 | | | | | | 9 | 6 |
| Easy to Use | 3 | | | | | 9 | 9 | 6 | | 9 | | | | 6 | 9 | | | | | | 9 | 3 |
| Audio Quality | 5 | | | | | 9 | 9 | | | 6 | 3 | 3 | | 3 | | | | | | | 6 | 6 |
| Video Quality | 5 | | | | | 9 | 9 | | | 6 | 6 | 3 | | 3 | | | | | | | 6 | 6 |
| Nice looking | 2 | | | | 6 | | 3 | 3 | 3 | | | | | 9 | 9 | | | | | | 3 | 6 |
| Easy to clean | 4 | | | | 6 | | | | | | | | | 9 | | | | | | | | 6 |
| Lightweight | 3 | 9 | | | | 9 | | 6 | 6 | 6 | | | 6 | 9 | | | | | | | 9 | 9 |
| Interchangable Parts | 4 | 6 | 3 | 3 | 6 | 9 | 6 | 9 | 9 | 9 | 6 | 6 | 6 | 9 | 3 | | | | | | | 3 |
| Controller ergonomics | 5 | 9 | | | | 9 | | | | 3 | 3 | | | 6 | 9 | | | | | | 3 | 3 |
| Quiet/Non-intrusive | 3 | | | | | 3 | 9 | 3 | 9 | | | | 3 | 9 | | | | | | | | 6 |
| Camera Zoom | 5 | | | | | 9 | 9 | 6 | | | | | | 9 | 6 | | | | | | | 9 |
| Wifi Compatible | 4 | | | | | 9 | | 9 | | 9 | 9 | | | 9 | | | | | | | 9 | 9 |
| Raises Hand/Queue | 5 | 3 | | | 6 | 9 | | | 6 | | 3 | 3 | 3 | 9 | 3 | | | | | | | 3 |
| Cost Effective (future) | 2 | | | | 6 | 9 | 9 | 6 | 6 | 6 | | 3 | 3 | 9 | 3 | | | | | | 9 | 3 |
| Units | | | | | | | | | | | | | | | | | | | | | | |
| Targets | | | | | | | | | | | | | | | | | | | | | | |
| Benchmark #1 | | | | | | | | | | | | | | | | | | | | | | |
| Benchmark #2 | | | | | | | | | | | | | | | | | | | | | | |
| Importance Scoring | | 150 | 57 | 57 | 132 | 291 | 255 | 273 | 174 | 192 | 144 | 102 | 153 | 354 | 153 | 0 | 0 | 0 | 0 | 0 | | |
| Importance Rating (%) | | 42 | 16 | 16 | 37 | 82 | 72 | 77 | 49 | 54 | 41 | 29 | 43 | 100 | 43 | 0 | 0 | 0 | 0 | 0 | | |

| | |
|---|---|
| ● = 9 | Srong Correlation |
| ○ = 3 | Medium Correlation |
| Δ = 1 | Small Correlation |
| Blank | No Correlation |

Table 4: QFD Table

# Decision Matrix

## Engineering Requirements

| System Functions | Potential Solutions (From Convergent Thinking Exercise) | Double Robotics Telepresence Robot | <20lbs | <180 degree x-movement | <90 degree y-movement | ABS 3-D print casing | Microcontroller logic | HQ A/V system | Integrating Current Products | Motors | Standard Connectors | Wifi TX/RX | Battery | Other Electrical Power | Custom electrical/mechanical design/parts | User Interface | Weighted Sum + | Weighted Sum - | Weighted Sum S | Total Score | Specification Weighting Check |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Specification Weight** | | | 10 | 6 | 6 | 3 | 7 | 10 | 10 | 6 | 7 | 10 | 4 | 5 | 6 | 10 | | | | | 100 |
| Audio/Video | Wireless Video/Microphone | | | | | | S | + | S | | + | S | S | | S | S | 17 | 0 | 47 | 31 | |
| | Bluetooth | + | | | | | - | - | + | | | S | S | | S | - | 10 | 27 | 20 | -11 | |
| | Filtering | | | | | | + | + | + | | | | S | | + | + | 43 | 0 | 4 | 44 | |
| | Corded | | | | | | - | + | + | | + | + | + | | S | - | 41 | 17 | 6 | 26 | |
| Controller | Play Station Controller | | | | | | | | + | | - | + | - | | | + | 30 | 11 | 0 | 19 | |
| | Keyboard | + | | | | | | | + | | + | + | + | - | | - | 31 | 15 | 0 | 16 | |
| | Touchscreen | | | | | | | | S | | S | S | S | S | | S | 0 | 0 | 46 | 14 | |
| | Joystick | | | | | | | | + | | + | + | - | | | + | 37 | 4 | 0 | 33 | |
| Motion | "neck motion" | | + | - | S | + | S | | - | - | | | - | S | + | - | 19 | 36 | 18 | -12 | |
| | servo motor | + | + | + | - | + | - | S | + | + | | | | + | S | S | 36 | 9 | 18 | 32 | |
| | pivot motor | | + | - | + | - | S | | S | + | | | | - | S | S | 22 | 13 | 28 | 17 | |
| Interactivity | Handraising light | + | + | | | | + | | + | | | | | | + | + | 41 | 0 | 0 | 41 | |
| | Handraising mechanical arm | | + | | | + | - | | - | | | | | | + | | 19 | 21 | 0 | -2 | |
| Computer Interface | Terminal | - | | | | | | | | | | | | | - | - | 0 | 16 | 0 | -16 | |
| | GUI | | | | | | | | | | | | | | + | S | 6 | 0 | 10 | 9 | |

This cell should add to 100

*Table 5: Decision Matrix Table*

**Appendix C:  Final drawings (schematics, software diagrams, part drawings, bill of materials)**

| Item | Date | Purchased By | Quantity | Total Cost ($) |
|---|---|---|---|---|
| Beagle Bone Black Kit | initial | Lynne | 1 | |
| 7" LCD-TFT Cape Display for BB | initial | Lynne | 1 | |
| USB to 3.3V TTL Debug Cable | initial | Lynne | 1 | 233.79 |
| Cooling Fan(s) | initial | Lynne | 5 | |
| 3Dio Free Space Binaural Microphone | initial | Lynne | 1 | 513.25 |
| Black Box Mobius Pro Mini Action Camera | initial | Lynne | 1 | |
| S120 Speaker System | initial | Lynne | 1 | 128.98 |
| Stereo Audio USB External Sound Card with SPDIF & Built-in Microphone | initial | Lynne | 1 | |
| HS-485HB Servo | initial | Lynne | 1 | |
| HS-7954SH Servo | initial | Lynne | 1 | |
| DD155 Base Pan | initial | Lynne | 1 | 208.95 |
| DDT500 Direct Drive Tilt | initial | Lynne | 1 | |
| Belkin Hi-Speed USB 2.0 7-Port Hub Hub - 7 ports | initial | Lynne | 1 | 23.31 |
| 5A DC-DC Adjustable Step Down Module Power Supply Converter | initial | Lynne | 3 | 9.96 |
| 8 terminal strip | 4/25/2015 | Nick | 2 | 6.98 |
| 8-Pos bus strip | 4/25/2015 | Nick | 2 | 3.98 |

Bill of Materials(continued):

| | | | | |
|---|---|---|---|---|
| tax | 4/25/2015 | Nick | - | 0.88 |
| Stereo 2.8W Class D Audio Amp | 4/25/2015 | Nick | 1 | 9.95 |
| Shipping | 4/25/2015 | Nick | - | 4.07 |
| 5A DC-DC adjustable converters | 4/27/2015 | Nick | 3 | 12 |
| BeagleBone Black | 4/27/2015 | Nick | 1 | 52.93 |
| tax | 4/27/2015 | Nick | - | 4.76 |
| HS-485HB Servo (Replacement) | 4/16/2015 | Daniel | 1 | 16.98 |
| Tax | 4/16/2015 | Daniel | - | 1.27 |
| Machine Screw #6-32x3/4" | 4/23/2015 | Luke | 2 | 2.36 |
| Washer #6 | 4/23/2015 | Luke | 1 | 1.18 |
| Lock Washer #6 | 4/23/2015 | Luke | 1 | 1.18 |
| Tax | 4/23/2015 | Luke | - | 0.38 |
| DAP Silicone Glue | 4/16/2015 | Luke | 2 | 9.14 |

| | | | | |
|---|---|---|---|---|
| Tax | 4/16/2015 | Luke | - | 0.73 |
| Acrylic Sheet | 4/9/2015 | Luke | 3 | 43.68 |
| Shipping | 4/9/2015 | Luke | - | 12.72 |
| Tax | 4//9/2015 | Luke | - | 0 |
| Terminal Spade Connectors | 5/9/2015 | Nick | 1 | 11.99 |
| Bearing Lazy Susan | 5/9/2015 | Nick | 1 | 5.59 |
| Tax | 5/9/2015 | Nick | - | 1.41 |
| Aluminum Sheets | 5/14/2015 | Luke | 4 | 53.6 |

Bill of Materials(continued):

| | | | | |
|---|---|---|---|---|
| Beaglebone Black the 3rd | 5/16/2015 | Daniel | 1 | 53.39 |
| Beaglebone LCD Cape | 5/16/2015 | Daniel | 1 | 117.99 |
| Various Hardware -Home Depot | 5/21/2015 | Luke | - | 22.76 |
| Servocity - Shaft hub/hardware | 5/25/2015 | Luke | - | 36.79 |
| Shipping 2 day air | 5/25/2015 | Luke | - | 30.96 |
| Logitech controller | 5/25/2015 | Luke | 1 | 39.97 |
| Shipping and tax | 5/25/2015 | Luke | - | 7.51 |
| TOTAL | | | | 1606.93 |

*Table 6: Bill of Materials*

# Appendix D: List of vendors, contact information, and pricing

| Part Names | Website | Manufacturer | Distributor | Quantity | Unit Price ($) | Total Price ($) |
|---|---|---|---|---|---|---|
| Beagle Bone Black Kit | x | Texas Instruments | Logic Supply | 1 | 82.65 | 82.65 |
| 7" LCD-TFT Cape Display for BB | x | 4D | Logic Supply | 1 | 89.00 | 89.00 |
| 3Dio Free Space Binaural Microphone | x | 3Dio | 3Dio website | 1 | 499 | 499 |
| Black Box Mobius Pro Mini Action Camera | x | Mobius | Mobius website | 1 | 79.95 | 79.95 |
| S120 Speaker System | x | Logitech | B&H Photo | 1 | 9.95 | 9.95 |
| Stereo Audio USB External Sound Card with SPDIF & Built-in Microphone | x | StarTech | B&H Photo | 1 | 22.78 | 22.78 |
| HS-485HB Servo | x | Hitech | ServoCity | 1 | 17 | 17 |
| HS-7954SH Servo | x | Hitech | ServoCity | 1 | 100 | 100 |
| DD155 Base Pan | x | ServoCity | ServoCity | 1 | 40 | 40 |
| DDT500 Direct Drive Tilt | x | ServoCity | ServoCity | 1 | 25 | 25 |
| Toshiba Satellite Replacement Power Supply Cord 15V/8A | x | Toshiba | Laptopbatterylife | 1 | 27.25 | 27.25 |
| USB to 3.3V TTL Debug Cable | x | - | Logic Supply | 1 | 18 | 18 |
| Cooling Fans | x | - | Logic Supply | 2 | 5 | 10 |
| Belkin Hi-Speed USB 2.0 7-Port Hub Hub - 7 ports | x | Belkin | EIO | 1 | 31 | 31 |
| 5A DC-DC Adjustable Step Down Module Power Supply Converter | x | - | Banggood.com | 3 | 3.59 | 10.77 |

*Table 7: Vendor List*

# Appendix E: Vendor supplied component specifications and data sheets

**Beaglebone Black Feature Specifications**

| | | |
|---|---|---|
| **Onboard Flash** | 2GB, 8bit Embedded MMC | |
| **PMIC** | TPS65217C PMIC regulator and one additional LDO. | |
| **Debug Support** | Optional Onboard 20-pin CTI JTAG, Serial Header | |
| **Power Source** | miniUSB USB or DC Jack | 5VDC External Via Expansion Header |
| **PCB** | 3.4" x 2.1" | 6 layers |
| **Indicators** | 1-Power, 2-Ethernet, 4-User Controllable LEDs | |
| **HS USB 2.0 Client Port** | Access to USB0, Client mode via miniUSB | |
| **HS USB 2.0 Host Port** | Access to USB1, Type A Socket, 500mA LS/FS/HS | |
| **Serial Port** | UART0 access via 6 pin 3.3V TTL Header. Header is populated | |
| **Ethernet** | 10/100, RJ45 | |
| **SD/MMC Connector** | microSD , 3.3V | |
| **User Input** | Reset Button<br>Boot Button<br>Power Button | |
| **Video Out** | 16b HDMI, 1280x1024 (MAX)<br>1024x768,1280x720,1440x900<br>w/EDID Support | |
| **Audio** | Via HDMI Interface, Stereo | |
| **Expansion Connectors** | Power 5V, 3.3V , VDD_ADC(1.8V)<br>3.3V I/O on all signals<br>McASP0, SPI1, I2C, GPIO(65), LCD, GPMC, MMC1, MMC2, 7<br>AIN(1.8V MAX), 4 Timers, 3 Serial Ports, CAN0,<br>EHRPWM(0,2),XDMA Interrupt, Power button, Expansion Board ID<br>(Up to 4 can be stacked) | |
| **Weight** | 1.4 oz (39.68 grams) | |
| **Power** | Refer to Section 6.1.7 | |

*Table 8: BeagleBone Black Specifications*

**From:** http://www.adafruit.com/datasheets/BBB_SRM.pdf
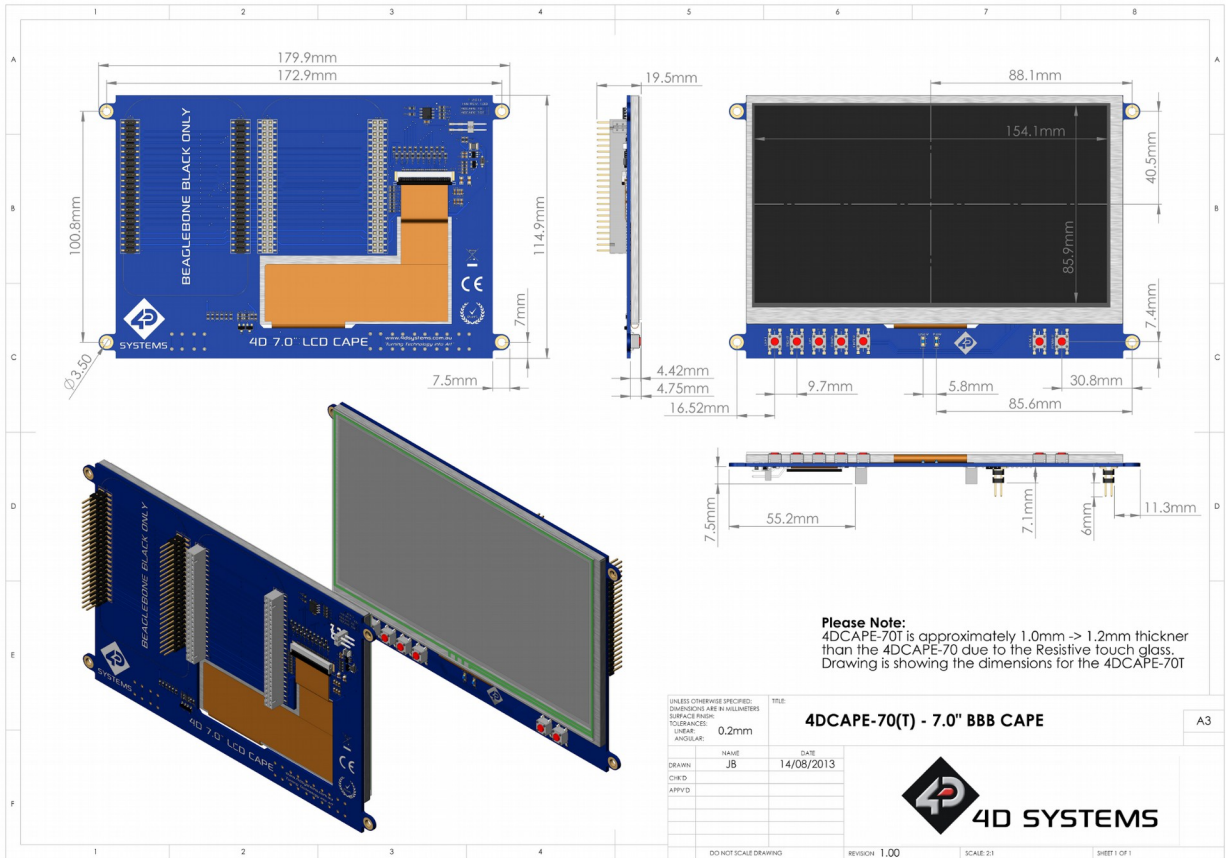
## LCD Cape Dimensional Drawing



*Figure 19: LCD Cape Drawing*

**Black Mobius Action Cam Dimensional Drawing**



*Figure 20: Mobius Action Camera*

**Appendix F: Detailed supporting analysis**

*Concerning the electrical power:*
After review the datasheets and measuring the current draw from the whole system , it was found that the entire system uses less than an amp to run during normal operation. The chosen power adapter for this project is rated at 19.5V/4A which can easily handle all of the power for the system. However, there is currently no fuse or circuit breaker in the design. To help better protect the electronics in the project, a fuse or circuit breaker should be added.
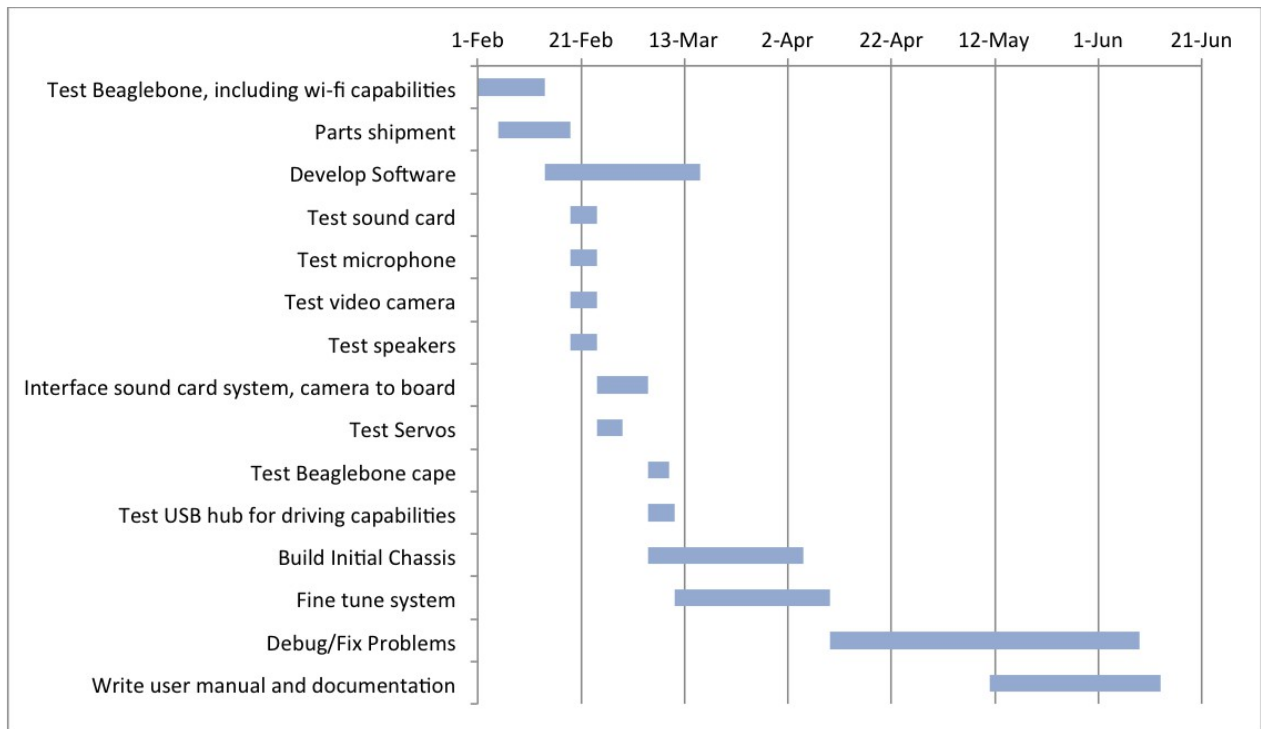
## Appendix G: Gantt chart



*Figure 21: Gantt Chart*