# Appendix F: Design Documentation for multisensory therapy system

This appendix contains in details all the system design. It summarizes at the structure design, electrical design, and software design.

## F.1 System Structure

The structure design was designed to be separated in two pieces to make it lightweight and portable, hence it consists of three bases and three towers. This design allows to position the towers at place according to the patient anthropometric measurements.

### F1.1 Towers

The chosen material to build the towers was PVC panels since it is lightweight, resistant, and cheap for build the first prototype. The central tower is the most important since it contains the system power source, the Raspberry Pi that serves as wireless access point, the Arduino Mega which is the microcontroller used to control the routines of the light module, tree light modules, the sound amplifier, the odor module, all electrical cables that distribute power and data signals, status LEDs and the power switch. The main tower also contains output ports to connect and power up the other two towers.

The left and right tower contains the same component: three light modules, a speaker and electrical power and data connection. They receive power and data through a DB-15 ports. The signals that goes through this connector are the VCC, GND and the four signals coming from the Arduino Mega. The DB-15 input port is connected to another DB-15 port at the main tower through 9 feet 15 pin cable. The speakers are connected through two RCA cables. More details about electrical connection will follow in Appendix F.

The towers design was reinforced with wooden frames to make them more rigid, since the thickness of the PVC board used is ¼ inch and tends to be fragile. These were placed at the top, center and bottom of each tower.

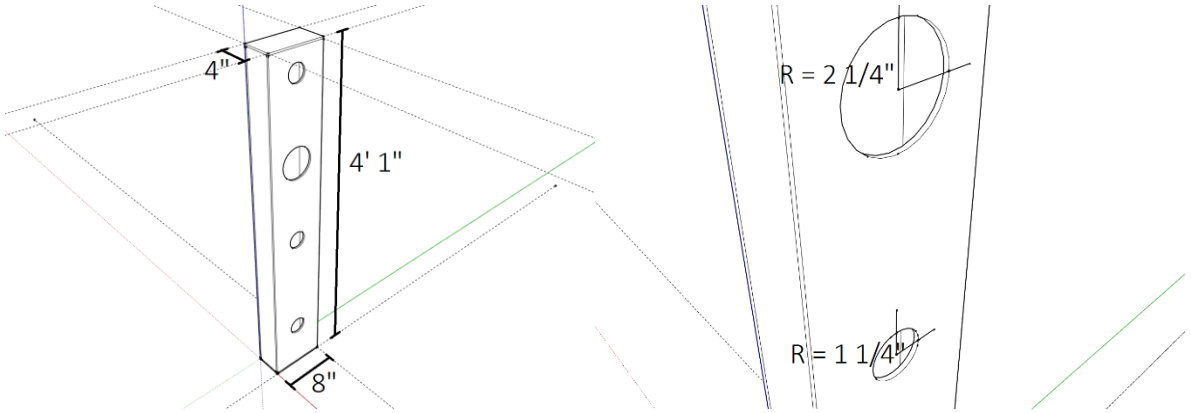



Figure F.1 Main Tower design

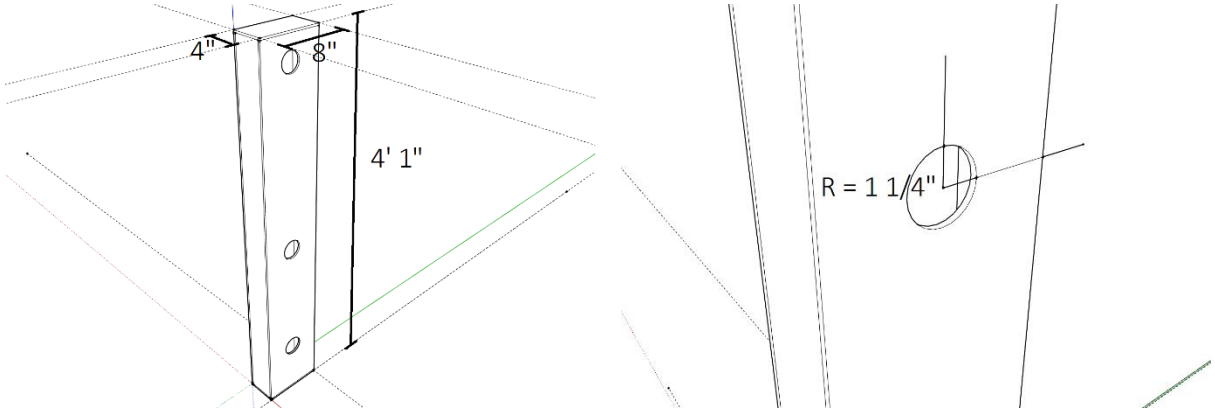


Figure F.2 Lateral Towers design

## F1.2 Bases

The bases serve as a stand and provide support to the towers. They are made of wood and are covered with PVC panels with volume of 10.5' x 7.75' x 14.5. At the top of each base, there is a slot of 4 inches' depth to put the towers and keep them in place and is covered with a piece of foam to let the towers enter smoothly.

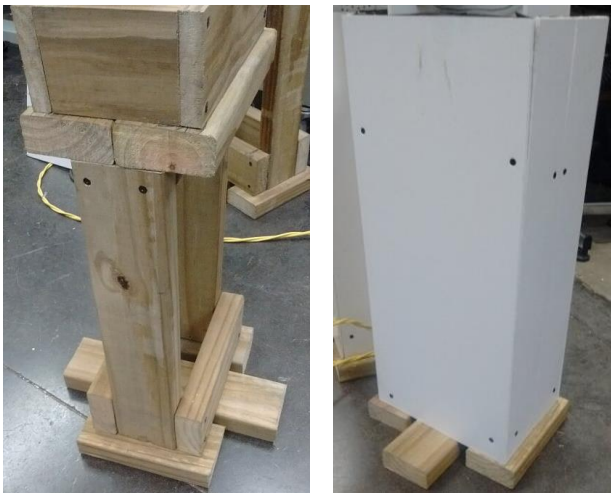


Image F.1 Bases

## F1.3 3D Printing Light Module Design

A custom 3D printed piece was designed using SketchUp Pro 2017 and build on a 3D printer. This module provides support to the NeoPixel, the ultrasonic sensor and to the PCB that contains the light module circuit. The module keep the all electrical components fixed to the machine structure in a compact space. The main advantage of this module is that it can be easily replace if it is damaged.

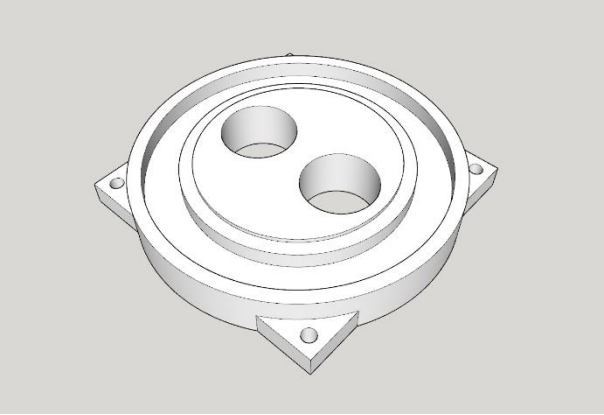


Image F.1.3-1 Top View

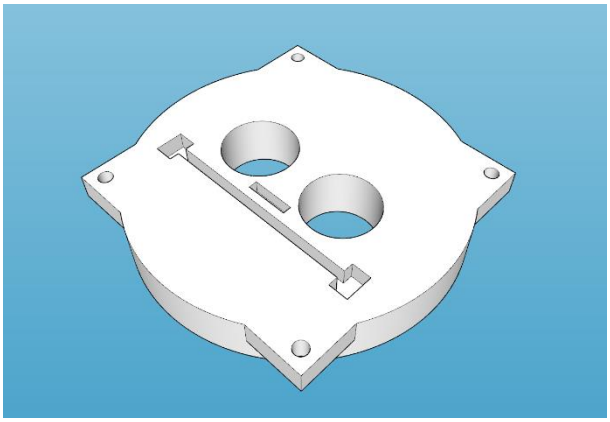


Image F.1.3-2Back View

A piece to bring support the PCB on the back of the module and a clear ring was also designed to protect the NeoPixel and reduce the LED brightness.

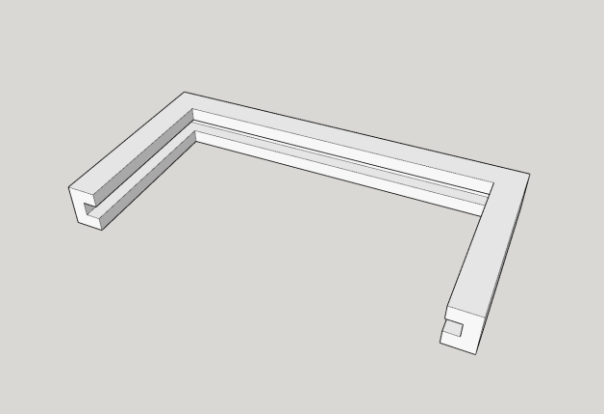


Image F.1.3-3 PCB Supporter

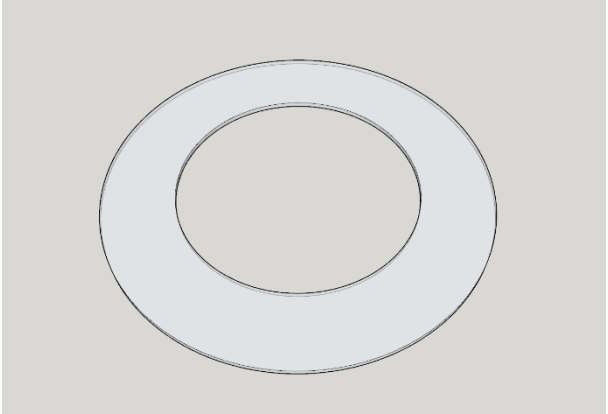


Image F.1.3-4 Clear Ring

Both the circular piece and the PCB supporter were printed using a 1.75 mm black PLA 3D printer filament. For the ring, a 1.75 mm clear PLA 3D Printer Filament was used.

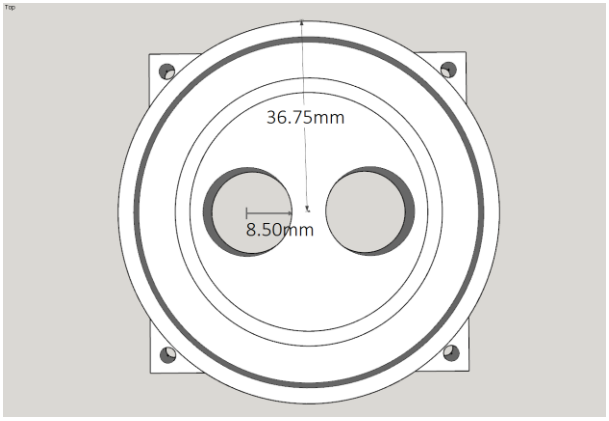



Image F.1.3-5 Top View

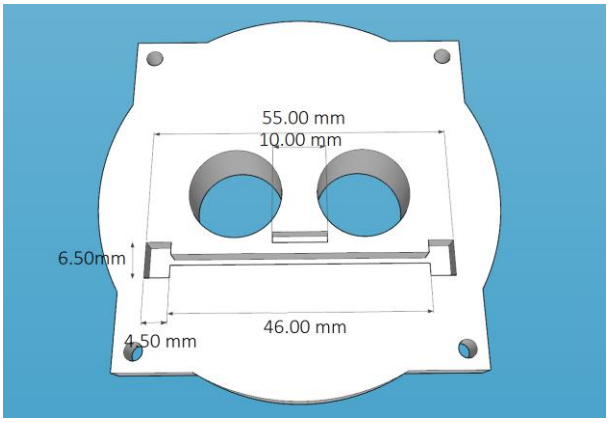



Image F.1.3-6 Back View

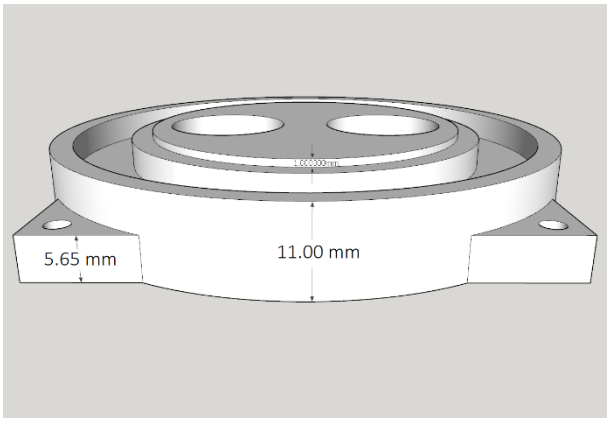



Image F.1.3-7 Front View

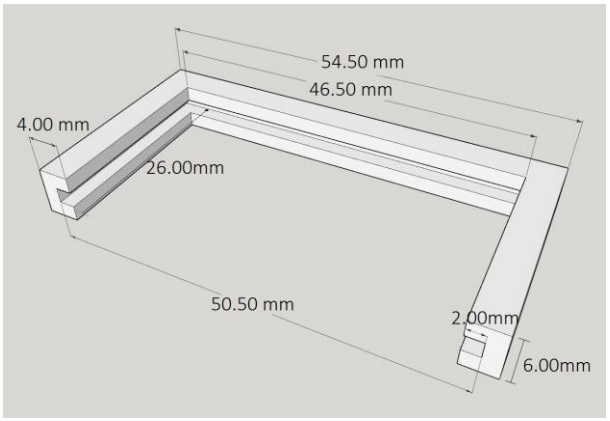



Image F.1.3-8 PCB supporter

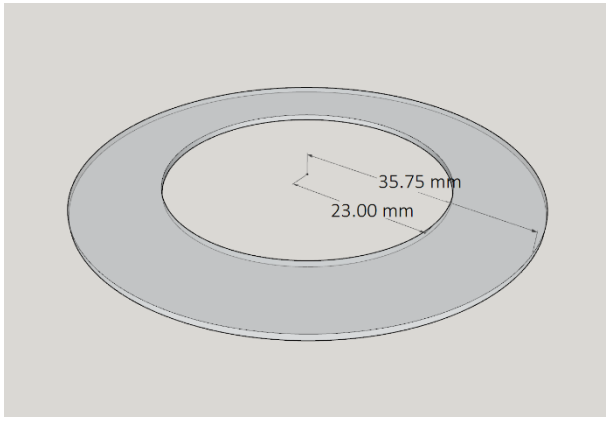



Image F.1.3-9 Clear Ring

## F1.4 3D Printing Tablet Design

For the therapist tablet and the patient tablet, a 3D design to fix the touchscreen, the Raspberry Pi and in the case of the therapist tablet, the Li-Ion rechargeable battery and the power boost. Although several 3D designs exist on the were, none of them satisfied the requirements, for example, be compact and bring access to the Raspberry Pi ports and provide a way to attach the tablet at the central tower, therefore, a custom design was made. The tablet dimensions are 196 mm x 114 x 35.4 mm. The only difference between the therapist tablet and the patient tablet is that the therapist is powered up through a power boost that charges a battery so the Micro USB of the Raspberry Pi is covered and has a hole at the top side of the tablet for the Micro USB of the power boost. That avoid confusions about where to connect the power cable. The patient tablet receives power directly from the Raspberry Pi, therefore the Micro USB port is not covered on the side. Also, the patient tablet has two holes to fix it with to screws to the central tower. The 3D design is shown in the next images. More information about the tablets electrical design are in the next section of this appendix.

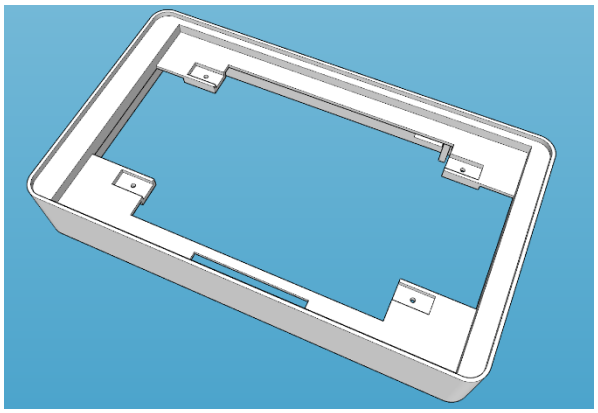


Image F.1.4-1 Top View

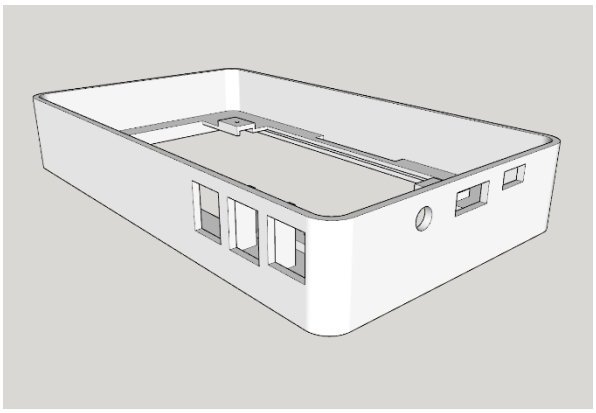


Image F.1.4-2 Side View

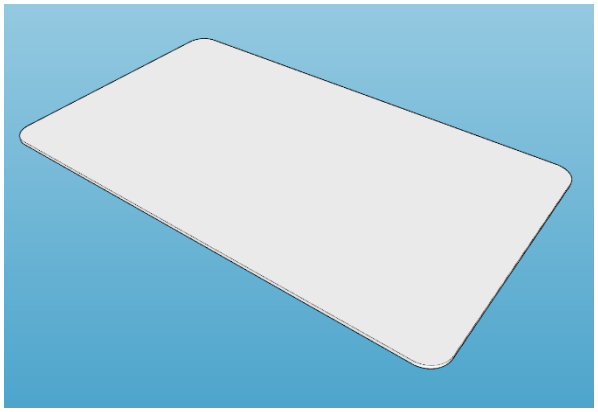


Image F.1.4-3 Back lid Top View

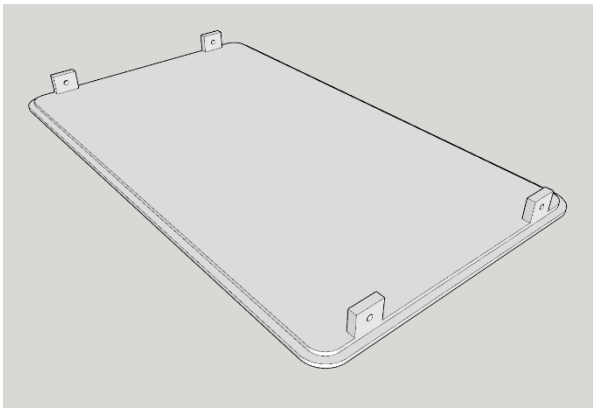


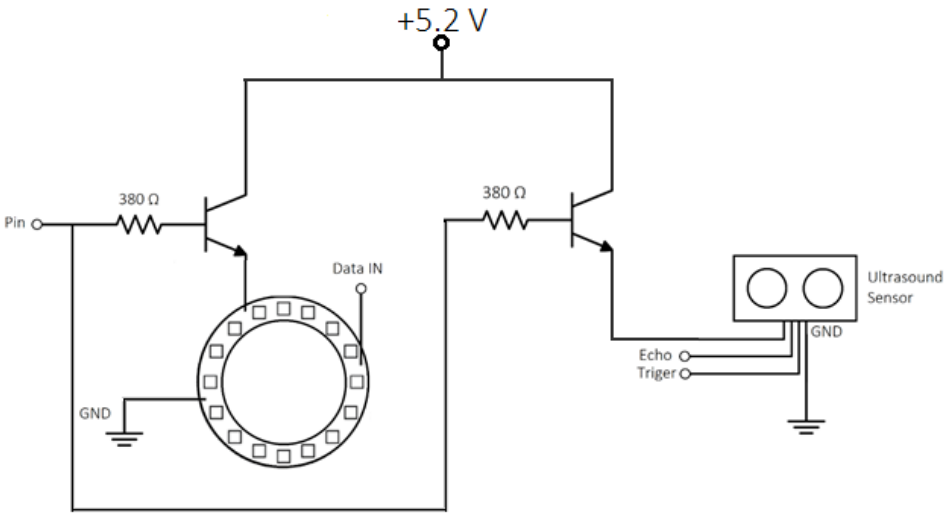
Image F.1.4-3 Back lid Side View

## F.2 Electrical Design

In this section, all the electrical design of each module and the entire system is explained. The system is composed of a light module that have several data connections, two tablets, an odor module and the principal power distribution circuit which distribute power to the entire system.

### F.2.1 Light Module Electrical Design

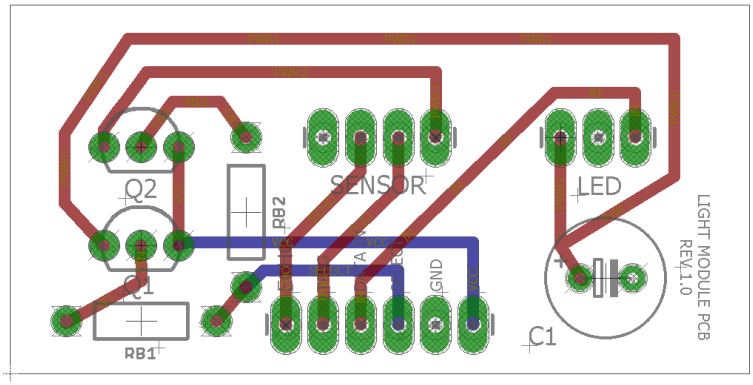
A circuit was designed for the light module, which is composed of a NeoPixel and an ultrasonic sensor. Since the NeoPixel can draw 60 mA per LED and each NeoPixel is composed of 24 LEDs that means that it can draw up to 1.44 A when it operates with a white color at maximum brightness. This current is too high for an Arduino pin because a single pin can only supply 40 mA so it might cause damage to the microcontroller although at normal operation, a NeoPixel can draw 20 mA per LED. This designed circuit is composed of a transistor that works as switch. The design was made keeping in mind the highest current mode operation, therefore, a BJT model S8050 was selected since it can operate with a maximum collector current Ic = 1.50 A. As an additional safety measure, a 380 Ω resistance was added between the pin and the transistor base to limit the current drawn from the microcontroller. To protect the NeoPixel from a sudden voltage peak when it turns on, a 1000 μF was added to the circuit. Also, the same configuration was used for the ultrasonic sensor. The circuit schematic is shown in figure F2.1.1




Schematic 2.1.1 Circuit of a single light module

Each light module requires six signals to function: VCC, GND, select, data, trigger, and echo. The module operates with 5.2V from VCC to GND provided by the power source and select, data, trigger and echo signals that comes directly from the Arduino Mega. The select signal activates the base of the transistors and is used to choose what module will be active. The data signal sends through the PWM ports a string of 24 bits to each NeoPixel at a frequency of 800 kHz. The ultrasonic sensor uses trigger to send a pulse and an echo signals to measure how much time the same pulse takes to return. This is how the distance of the object is measured. The following table shows the pin mapping of the Arduino Mega.

A double layer PCB for the light module was designed using the program Eagle 7.7.0. The recommended parameters for the design used were: width of the lines: 30 mils, drill size: 20 mils and the clearance: 10 mils. The PCB dimensions are 25 mm x 50 mm. This PCB keep all the electrical components well positioned. The PCB design is shown next:




PCB Design using Eagle

## F2.2 Olfactory Module Design

The olfactory module was implemented in the system using a DC motor fan to spread the scent that is placed on the central tower. Attached to the fan, there is a plastic duct that extends to the outer back side of the central tower. Through this tube, the therapist will be able to insert a scented oil that will reach the patient within seconds.

### F2.2.1 Olfactory Module Electrical Design

The DC fan operates with 12 V, for this a relay was used as a switch to turn it on with an Arduino output pin that use 5 V connected to a NPN transistor that powers the relay coil. This feature of the system can be activated through the therapist user interface.

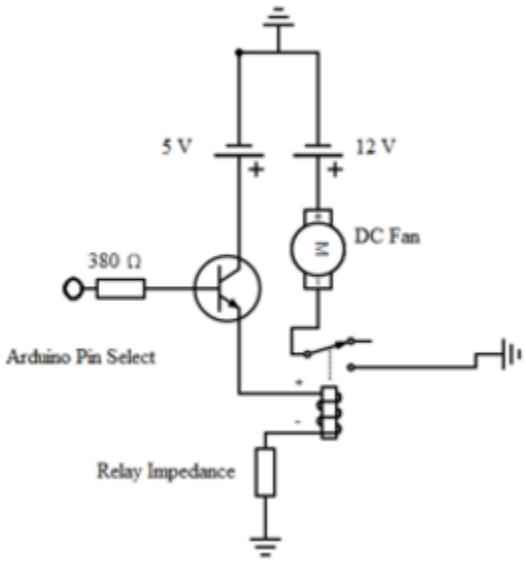



Figure 2.2.1 DC fan circuit diagram

### F.2.3 Electrical Design for Data Transmission

All electrical connections with the Arduino Mega and each light module are presented in the following table.

Table 3.3.1 Pin used on the Arduino Mega

| Pin | Signal |
|---|---|
| **2 (PWM)** | Data 1 |
| **3 (PWM)** | Data 2 |
| **4 (PWM)** | Data 3 |
| **5 (PWM)** | Data 4 |
| **6 (PWM)** | Data 5 |
| **7 (PWM)** | Data 6 |
| **8 (PWM)** | Data 7 |
| **9 (PWM)** | Data 8 |
| **10 (PWM)** | Data 9 |
| **22** | Trigger 1 |
| **23** | Echo 1 |
| **24** | Trigger 2 |
| **25** | Echo 2 |
| **26** | Trigger 3 |
| **27** | Echo 3 |
| **28** | Trigger 7 |
| **29** | Echo 7 |
| **30** | Trigger 8 |
| **31** | Echo 8 |
| **32** | Trigger 9 |
| **33** | Echo 9 |
| **34** | Select 1 |
| **35** | Select 2 |

| | |
|---|---|
| **36** | Select 3 |
| **37** | Select 7 |
| **38** | Select 8 |
| **39** | Select 9 |
| **40** | Trigger 4 |
| **41** | Echo 4 |
| **42** | Trigger 5 |
| **43** | Echo 5 |
| **44** | Trigger 6 |
| **45** | Echo 6 |
| **46** | Select 4 |
| **47** | Select 5 |
| **48** | Select 6 |
| **49*** | Motor |

*Pin 49 is used for the odor motor activation.

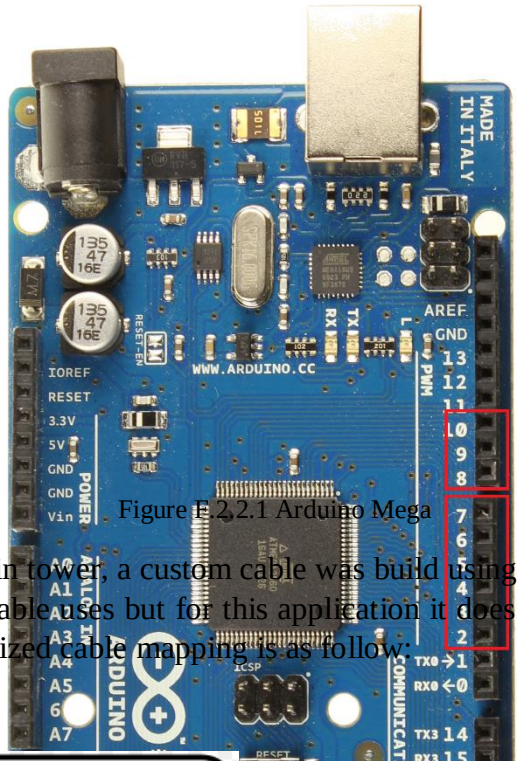



Figure F.2.2.1 Arduino Mega

To interconnect the left and right towers with the main tower, a custom cable was build using a DB-15 port. This port is the same one that the VGA cable uses but for this application it does not follows the same VGA standard. Instead, this customized cable mapping is as follow:

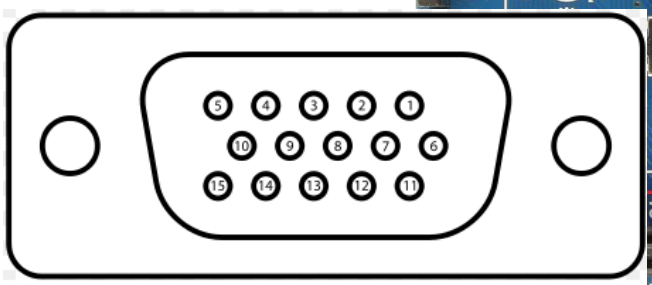



Figure F2.2.2 DB-15 Port

Table 1: Pin Mapping for DB-15 on left tower

| Pin | Signal |
|---|---|
| 1 | VCC |
| 2 | Data 1 |

| | |
|---|---|
| *3* | *Not Used* |
| 4 | Select 3 |
| 5 | Echo 2 |
| 6 | Select 1 |
| 7 | Trigger 1 |
| 8 | Echo 3 |
| 9 | Echo 1 |
| 10 | Select 2 |
| 11 | Data 2 |
| 12 | Trigger 2 |
| 13 | Data 3 |
| 14 | Trigger 3 |
| 15 | GND |
| 16 | *Not Used* |

| | |
|---|---|
| 12 | Trigger 8 |
| 13 | Data 9 |
| 14 | Trigger 9 |
| 15 | GND |
| 16 | *Not Used* |

Table 2: Pin Mapping for DB-15 on right tower

| Pin | Signal |
|---|---|
| 1 | VCC |
| 2 | Data 7 |
| 3 | *Not Used* |
| 4 | Select 9 |
| 5 | Echo 8 |
| 6 | Select 7 |
| 7 | Trigger 7 |
| 8 | Echo 9 |
| 9 | Echo 7 |
| 10 | Select 8 |
| 11 | Data 8 |

## F2.3 Tablets Electrical Design

Both the therapist and the patient tablets share the same electrical connections but since the therapist tablet is autonomous, it contains additional connections for the battery and the power boost. The battery used provide only 2500 mAh. The power boost is used to rise the battery voltage from 3.7 V to 5 V.

Figure F.2.3.1 Patient Tablet internal components

Figure F.2.3.2 Therapist Tablet internal components

Figure F.2.3.1 Tablets

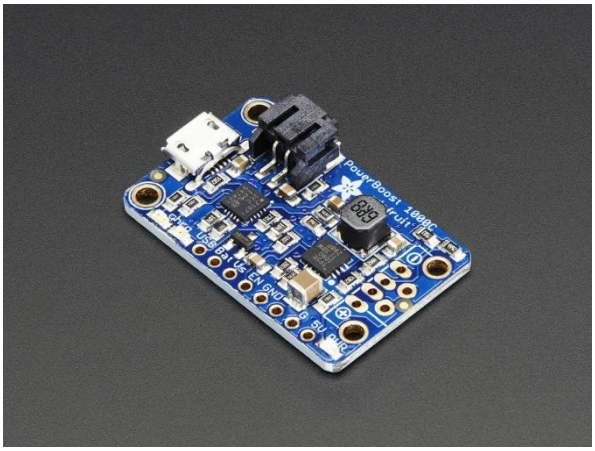
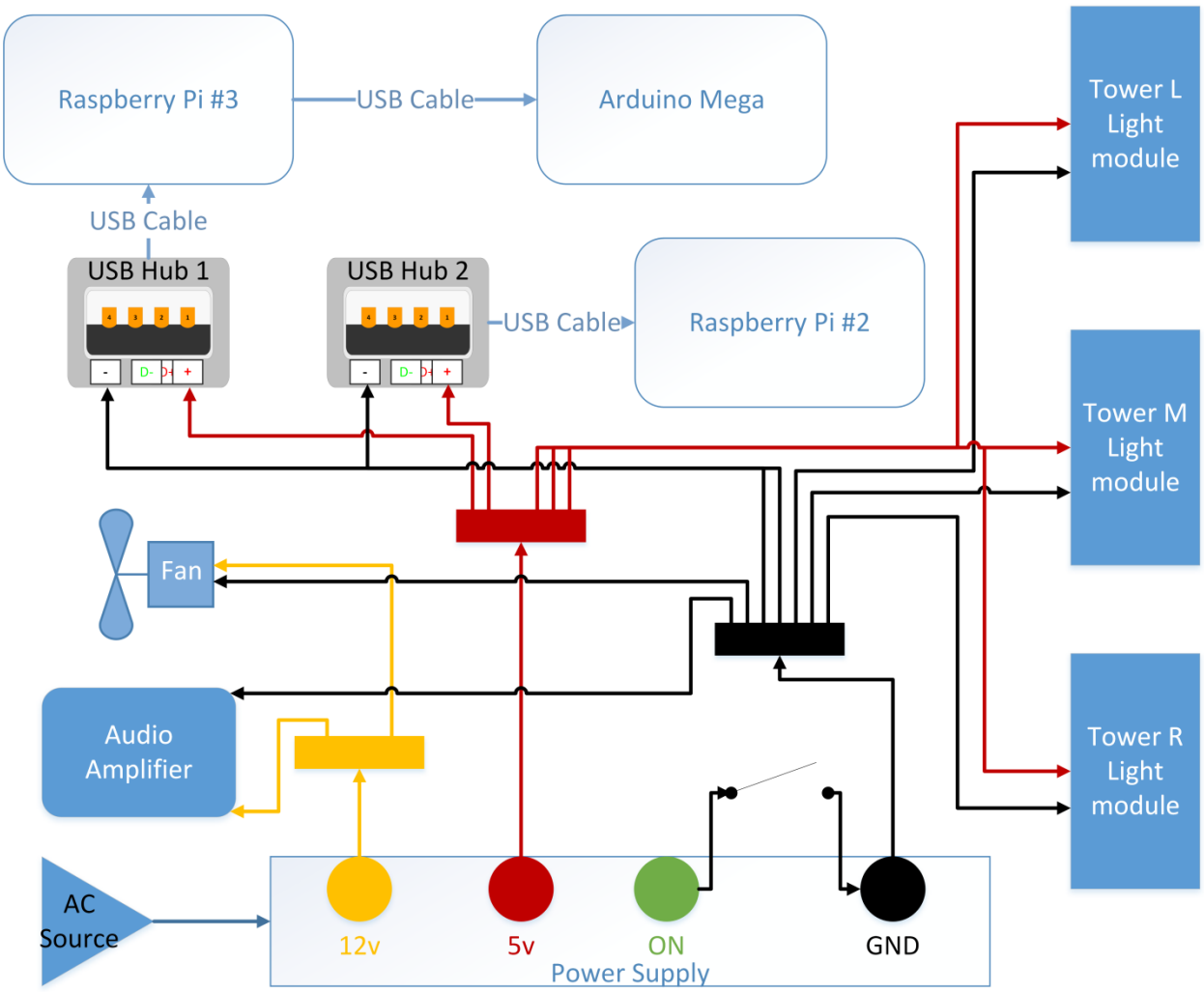


Figure F.2.3.4 Power Boost [8]

## F2.4 Electrical Power Distribution Design

The light modules and the microcontrollers all use 5 V while the odor module motor and the sound amplifier use 12 V. The power supply provides both voltages. The following diagram describes the electrical connections to the source.



**F2.4.1** Power Distribution Board PCB

A power distribution board was designed using Eagle. This PCB receives the power coming from the power supply and distribute it through the main electrical component: The Raspberry Pi, the Arduino Mega and the sound amplifier. It has two ports for the USB outputs which supplies 5 V, three 5V outputs and two 12 V outputs. It also provides a ground connection for the microcontrollers. Finally, it has a port to connect the switch of the power supply.

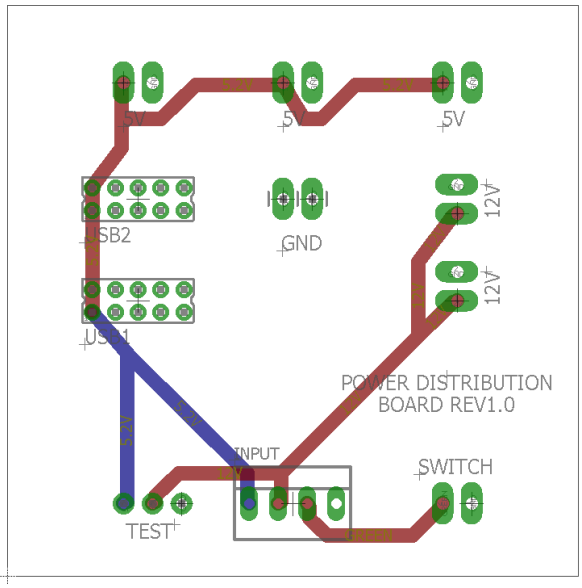



Figure X.X+2 Board

An additional power distribution board were used to power up the three light modules of the central tower. On this one, only de three 5V ports were used.