CapSafe Necklace

Design Review

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### Table of Contents

1. Introduction .................................................. 2
   1.1 Purpose ............................................. 2
   1.2 Functionality ..................................... 2
   1.3 Unique Features ................................. 2

2. Block Diagram and Block Descriptions ......................... 3
   2.1 Power Module ...................................... 3
      2.1.1 Battery .................................... 3
      2.1.2 Linear Regulators ......................... 3
      2.1.3 Low-Power Protection ....................... 4
   2.2 Activation Module .................................. 5
      2.2.1 Force-Sensing Circuit ....................... 5
      2.2.2 Filter .................................... 5
   2.3 Capture Module ..................................... 6
      2.3.1 Camera .................................... 6
      2.3.2 Memory ................................... 7
   2.4 Control Module ..................................... 7
   2.5 Wireless Connectivity Module ..................... 8
   2.6 Software Interface Module ....................... 9

3. Requirements and Verification .............................. 12

4. Tolerance Analysis .......................................... 15
   4.1 Activation ........................................ 15
   4.2 Overall PCB Power Dissipation ................... 16

5. Cost Analysis ................................................. 17
   5.1 Labor ............................................. 17
   5.2 Parts ............................................. 17
   5.3 Total Cost ....................................... 18

6. Safety and Ethics Considerations ............................ 18
   6.1 Safety ........................................... 18
   6.2 Ethics ........................................... 18

7. Schedule ..................................................... 19

8. References .................................................. 20
1. Introduction

1.1. Purpose

The issue of sexual assault is an all-too-prevalent one, especially on college campuses. There’s plenty of literature on how to avoid becoming an assault victim and what to do after one becomes a victim, but there aren’t many products on the market that enable a victim to take action in the midst of an assault, and none of them give the victim any better chance at legal closure if assistance arrives too late. The CapSafe necklace will allow victims to call for help even if they have no direct access to their phone (as is common with sexual assault) while also discreetly taking pictures of the attacker to ensure that, if worse comes to worst, the victim can be assured of successful legal action.

1.2. Functionality

This project’s technical functions include the following: Bluetooth connectivity; functioning camera and memory; an analog-filtered voltage-dividing circuit as an activation system; and low-battery detection and protections. All of this is embedded in a necklace for discreet usage, to be partnered with an app for ease of use.

1.3. Unique Features

Other personal-safety wearable products alert predetermined contacts, but not 911. These products also use no capture technology whatsoever. The biggest problem with similar products, though, is that if the user is already being assaulted, they are either not discreet or not likely to be close at hand. CapSafe will message predetermined contacts in addition to 911, use a camera to take photos of the attacker, and always be at hand and ready for discreet usage.
2. Block Diagram and Block Descriptions

![Figure 2.1: Block Diagram of CapSafe Necklace](image)

2.1 Power Module

2.1.1 Battery

**Input:** N/A

**Output:** Linear Regulators, Comparators, Microcontroller

The power source of this project is a rechargeable 9V battery. It should power the system in standby/sleep mode for twelve hours, or 30 minutes in activation mode.

2.1.2 Linear Regulators

**Input:** Battery, Low-Power Protection

**Output:** Bluetooth breakout, camera module, and SD breakout

Our circuit implements one 5V and two 3.3V linear regulators. The linear regulators provide power to every other module except the microcontroller. They provide stable voltage to every other component and accept 9V input from the battery.
Total Power = ( (9-3.3)V + (9-3.3)V + (9-5)V ) * 300mA = 4.62W

2.1.3 Low-Power Protection

**Input:** Battery  
**Output:** Linear Regulators

The low-power detection subcircuit uses a pair of fixed resistors as a stable voltage divider, the output of which is tied to a comparator that, when the battery voltage falls below 7.5V, an LED turns on. Another voltage divider circuit is tied to another comparator which will flip off the MOSFET switch when the battery voltage falls below 7V. This switch is connected to the rest of the circuit, thus powering off the circuit when the battery voltage goes too low.

![Circuit Diagram](image)

**Figure 2.2: Battery Protection**
2.2 Activation Module

2.2.1 Force-Sensing Circuit

**Input:** Linear regulator, force-sensitive resistor  
**Output:** Filter  

The force-sensing circuit takes input directly from the user. The user applies a firm force of 4N on a force-sensitive resistor (FSR) to have the comparator output a high voltage of 3.3V. The resulting change in the voltage across the FSR is then routed to the microcontroller. A filter is used to remove noise from the input to the FSR comparator.

\[
\text{Power}_{\text{FSR}} = I^2 R = \left( \frac{5V}{7.5k\Omega} \right)^2 \times 2.5k\Omega = 1.2\text{mW}
\]

2.2.2 Filter

**Input:** Force-Sensing Circuit  
**Output:** FSR Comparator  

The activation module uses a 2nd-order low-pass Tschebyscheff filter to remove extraneous noise from the input of the FSR comparator. We implemented a cutoff frequency of 1.05kHz using appropriate resistor and capacitor values. The filter has 3dB passband ripple and unity gain, so it does not alter the appropriate value for the comparator. Figure 2.3 is a simulation of the frequency response of the filter using the value found in Figure 2.7.

\[
\text{Power} = 2 \times (P_{\text{Comparator}})  
\]

\[
P_{\text{Comparator}} = (T_{J_{\text{Max}}} - T_A)/J_A = (150-25)/(186) = 0.67\text{mW}
\]

Power = 1.34mW
2.3 Capture Module

2.3.1 Camera

**Input:** Microcontroller, linear regulator  
**Output:** Memory

The camera, an LS-Y201-Infrared serial port camera module, takes VGA 160*120 resolution photos on command from the microcontroller. The data from the photo is sent to the microcontroller, which then stores the file info into the SD card memory.

\[
\text{Power(camera)} = (3.3V+10\%) \times 100 \text{ mA} = 363 \text{ mW}
\]
2.3.2 Memory  
**Input:** Camera, Linear Regulator, Microcontroller  
**Output:** N/A  
The memory module is a MicroSD card breakout board. The card in the slot will hold all of the pictures taken while the system is in active mode. The photo data will be sent from the camera to the microcontroller and to the memory.

Power = 9V * 100mA = 0.9W

2.4 Control Module  
**Input:** FSR Comparator  
**Output:** Bluetooth Chip, SD Breakout Board, Camera Module  
Arduino Mini Pro wraps in the microcontroller ATmega328. It operates on 5V. This module is responsible for activating and sending data packets to the camera and Bluetooth modules. It comes with analog inputs which is usable by the force-sensing circuit in this project. The microcontroller reads the analog voltage signal and determines whether the voltage is at the expected 3.3V to trigger circuit activation. Upon receiving this signal, it sends data packets consisting of HEX capture command to the camera module and activates camera capturing. Then it sends a STOP command to the camera module. Consecutively, it also sends a data packet telling Bluetooth to change its mode to CONNECTED. After Bluetooth is in connected mode, the BLE module will send an interrupt to the microcontroller indicating it is ready to receive the commands. The microcontroller then sends data to the module which is then sent to the software.
application. Our Program code should be no more than 300 lines; less than 20Kb. Arduino mini provides an onboard flash memory of 32Kb that is more than sufficient for our code. It is also small enough to meet our requirements quite nicely.

\[ \text{Power} = 3.3V \times 100mA = 0.33W \]

**Pseudo code for force detection**

```pseudocode
while time<5secs
    sensor_val=read(pin)
    If sensor_val <sensor_min
        sensor_min=sensor_val
    End if
End while

Function loop
    Read the value at pin
    If sensor value above threshold
        Write to camera and bluetooth output pin
    Else
        Do nothing
    End if
End if
```

### 2.5 Wireless Connectivity Module

**Input:** Microcontroller  
**Output:** Microcontroller

This chip operates on 5V. The Bluetooth LE module establishes a link between the Arduino microcontroller and the android (4.3+) device. This module functions by sending ASCII data back and forth between the devices. Microcontroller will send a signal on MOSI pin of BLE after reading an interrupt signal from RDY pin on BLE. The ACTIVE pin lets the microcontroller and software interface know that the BLE is busy. If the microcontroller sends a high signal then the bluetooth starts sending valid ASCII data to the software interface. This activates the software module. Baud rate: 19200

\[ \text{Power} = 5V \times 30mA = 0.15W \]

Slave latency is set to <10 in connected mode and >100 in standby mode
Pseudo Code for Activating software application

Function BLE (Bluetooth State)
    If State == ACTIVATED
        if BLE_data.available()
            char=Read from port
            If char == ‘A’
                Activate software commands
            End if
        End if
    End if

2.6 Software Interface

Input: Bluetooth signal
Output:

The software interface here refers to a cellphone application. The function of this application is to send the current location of the user to the emergency contacts and call 911. Both these actions are executed after waiting for an interval of 10-15 seconds. This is to avoid any false positives from getting through. Note that 10-15 seconds is sufficient for a user to deactivate these actions by tapping the deactivate button provided on the app. The app also allows the user to modify its emergency contacts list and can add up to 10 contacts. The app also detects if the GPS is disabled while the system is active and indicates the user to switch on the location services. Refer to Figure 2.2.
Figure 2.6: Software Flow Chart
Figure 2.7: Full Circuit Schematic Diagram
### 3. Requirements and Verification

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Testing &amp; Verification</th>
<th>Points</th>
</tr>
</thead>
</table>
| **Battery**  | **Checking battery life for activated circuit**  
1. Fully charge battery  
2. Connect battery to complete circuit  
3. Activate circuit by pressing FSR for 3+ seconds.  
4. Probe battery and ensure battery doesn’t cutoff for 30 minutes  
**Checking battery life for standby circuit**  
1. Fully charge battery  
2. Connect battery to complete circuit  
3. Do not activate circuit, probe battery, and ensure battery doesn’t cutoff for 12 hours.  
**Checking cutoff circuit**  
1. Place battery with charge > 7.2V in circuit  
2. Probe battery voltage and ensure circuit cuts off when battery between 6.8-7.2V.  
**Checking low battery indicator**  
1. Place battery with charge > 7.7V in circuit.  
2. Probe battery voltage and ensure LED turns on when battery between 7.3-7.7V. | 5 |
|              | **Resistance test**  
1. Probe comparator output  
2. Place 4N force on FSR  
3. Verify comparator output = 3.3V  
**Resistance test #2**  
1. Probe comparator output  
2. Place 1N force on FSR  
3. Verify comparator output = 0V | 10 |
| **Force-Sensitive Resistor**  
- Comparator connected to FSR voltage divider must output positive input when ≥ 4N is pressed.  
- Comparator must output negative input when ≤ 1N is pressed. | **Operation Voltage Test**  
1. Connect microcontroller to adjustable power supply  
2. Sweep voltage supply 7-10V  
3. Probe VCC and verify 5V  
Ensure microcontroller has required number of pins | 30 |
| **Microcontroller**  
- Operates under 7-10V  
- >1 Analog input  
- >13 digital pins |
<table>
<thead>
<tr>
<th>Bluetooth Module</th>
<th>Ensuring operation works under supply</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Operates under 5V supply</td>
<td>1. Attach 5V power supply to module</td>
<td></td>
</tr>
<tr>
<td>• Maximum current draw is 30mA</td>
<td>2. Ensure module powers</td>
<td></td>
</tr>
<tr>
<td>• Minimum wireless range required &lt; 2 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Must have a min latency of 0.2s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Must have a baud rate &gt;32</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Verifying current consumption</strong></td>
<td>1. Power on module</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. Probe VIN with oscilloscope</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Ensure current draw is less than or equal to 30mA</td>
<td></td>
</tr>
<tr>
<td><strong>Wireless Range Test</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Upload test code to microcontroller to send one signal to phone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Place phone 2m away from Bluetooth module</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Use app and verify connection is made.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Minimum latency test</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Configure the Bluetooth Module to send at it's default baud rate which is 9600</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Set the Slave latency to 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Set the connection interval to 100ms. Thus Effective Connection Interval =500ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Therefore, we can transmit the data within this interval by running a while loop in the code and check if anything is received on the software side within this interval and print it on the interface</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>5V Linear Regulator</strong></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>• Input voltage range &gt;10V</td>
<td><strong>Input Voltage Range Test</strong></td>
<td></td>
</tr>
<tr>
<td>• Output Voltage = 5±0.3V</td>
<td>1. Connect regulator to 10V supply</td>
<td></td>
</tr>
<tr>
<td>• Current range &gt;300mA</td>
<td>2. Probe output and verify 5±0.3V</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Output Voltage Test</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1. Connect regulator to variable power supply</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. Sweep voltage 7-10V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Probe output and verify 5±0.3V</td>
<td></td>
</tr>
<tr>
<td><strong>Current Range Test</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Connect regulator to variable power supply</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Attach 30 ohm power resistor in series to ground</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Probe output of regulator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Sweep power supply 7-9V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Ensure regulator output remains 5±0.3V</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3.3V Linear Regulators</strong></td>
<td><strong>Input Voltage Range Test</strong></td>
<td>3</td>
</tr>
<tr>
<td>• Input voltage range &gt;10V</td>
<td>1. Connect regulator to 10V supply</td>
<td></td>
</tr>
<tr>
<td>• Output Voltage = 3.3±0.3V</td>
<td>2. Probe output and verify 3±0.3V</td>
<td></td>
</tr>
<tr>
<td>• Current range &gt;300mA</td>
<td><strong>Output Voltage Test</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1. Connect regulator to variable power supply</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. Sweep voltage 7-10V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Probe output and verify 3±0.3V</td>
<td></td>
</tr>
<tr>
<td><strong>Current Range Test</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Connect regulator to variable power supply</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Attach 30-ohm power resistor in series to ground</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Ground | 3. Probe output of regulator  
| 4. Sweep power supply 7-9V  
| 5. Ensure regulator output remains 5±0.3V |
|---|---|
| Memory Card SD & SD Breakout | Voltage Operation Test |
| - Operates under 5±0.3V  
| - Current draw <100mA  
| - Writes data correctly | 1. Connect module to variable power supply  
| 2. Probe 3Vo pin on Bluetooth Module  
| 3. Sweep voltage from 4.7-5.3V.  
| 4. Ensure output of 3Vo = 3.3V throughout |
| Current Draw Test | 1. Power on module  
| 2. Probe VIN with oscilloscope  
| 3. Ensure current draw is less than or equal to 100mA |
| Data Write Test | 1. Initialize the SD card using Adafruit customer fat16lib  
| 2. Open a sample text file  
| 3. Write anything to it  
| 4. If the text file contains the text written, the SD card is good to go |
| Software Interface | Verification: Without Bluetooth module |
| - 1. Must be an android or IOS application  
| - 2. Must be compatible with the Bluetooth module  
| - 3. Must be able to call 911, send location to emergency contacts  
| - 4. Should use Maps API | 1. Make the application  
| 2. Make buttons on the application such that each button executes one function.  
| 3. Tap every button to check if the calls are generated or location data is sent to the contacts specified |
| With Bluetooth module | 1. Poll the Bluetooth RX port till it is has data packets available  
| 2. If a valid data packet (ASCII data) is detected, print it on the screen.  
| 3. Later activate an in-built java timer of 15 seconds upon valid character detection  
| 4. If Deactivate button is pressed before the completion of 15 seconds, the app does not do anything.  
| 5. If >15 seconds the app calls 911 and sends location to contacts |
4. Tolerance Analysis

4.1 Activation

FSRs are very sensitive to touch. Emergency situations are identified by the user applying pressure above a particular threshold. Therefore, it is critical that the force sensitive resistor does not activate under a false positive. For this, we have to ensure that we choose an FSR that changes resistance in a manner that allow us to easily distinguish between a press and no press. We measured a firm finger press with a scale to be approximately 4N of force. Thus, we want the FSR resistance to drop under 4N of force such that the voltage swing is discernible.

Because the output voltage actually comes from a voltage divider subcircuit, we can select the resistance of the fixed resistor based on the particular FSR’s force-response, around 4.7 kΩ, resulting in a voltage swing of about 2V.

\[
\frac{4N}{9.8m/s^2} \times \frac{1000g}{1kg} \approx 408.2g
\]

Thus, the FSR’s resistance under 4N of force will be approximately 2.5 kΩ.

We also need to verify that the FSR will not show a false positive. Originally we tried to implement a voltage divider such that a firm press would output a logic high and a minute press would output a logic low, but this proved to be impossible to achieve such a large voltage swing from such a small change in resistance. We then came up with the idea to use a comparator.
The comparator will output logic high to the microcontroller when 4N or more is pressed. We used a voltage divider with R2=4.7kohm fed to the positive terminal and 3.3V fed to the negative terminal to implement this. This way, until 4N or more is pressed, the output will be 0V, and once 4+N is achieved, it will output 3.3V to the microcontroller.

Another factor to consider is temperature conditions. We want to make sure the FSR will change resistance at a similar rate under different temperature conditions. The FSR resistance must be within 10% of the room temperature resistances at a range of 0°F to 100°F.

4.2 Overall PCB Power Dissipation

Calculating overall power dissipation by PCB is necessary as it is crucial for the safety of the person wearing the technology. We have used the components that generate less heat loss and therefore the power dissipation is minimal. Calculating the heat generate by Traces is shown as

Min Trace Width = 10 mils

Assuming PCB area to be 41cm²

Power Loss by External + Internal Layers (For 5 deg temp rise) = 0.00847 + 0.00326 = 0.01173W

Power loss by all components = 6.364 Watts

Total Power = 6.48217 Watts

Total Heat = Power * time = 6.5W * 28800 secs (8 hrs) = 186 KJ in 8 hrs

Heat dissipated per sec = 6.5 Joules

The specific heat of copper, Cu, is c = 0.386 J/g°C.

Using the given formula:

Q = mcΔT

ΔT = 0.084 deg Celsius

As the temperature generated is close to 0.084 deg, our PCB should not put the wearer at risk.
5. Cost Analysis

5.1 Labor Costs

<table>
<thead>
<tr>
<th>Name</th>
<th>Hours Invested</th>
<th>Hourly Rate</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joshua Graham</td>
<td>150</td>
<td>$35</td>
<td>$5250</td>
</tr>
<tr>
<td>Kevin Horton</td>
<td>150</td>
<td>$35</td>
<td>$5250</td>
</tr>
<tr>
<td>Richa Meherwal</td>
<td>150</td>
<td>$35</td>
<td>$5250</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>450</strong></td>
<td><strong>$105</strong></td>
<td>15,750 x 2.5 = $39,375</td>
</tr>
</tbody>
</table>

Table 5.1 - The projected labor costs associated with this project

5.2 Component Costs

<table>
<thead>
<tr>
<th>Part and Quantity</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round Force Sensitive Resistor-Intelink 402</td>
<td>$7</td>
</tr>
<tr>
<td>9V Battery</td>
<td>$10</td>
</tr>
<tr>
<td>LS-Y201 Camera</td>
<td>$45</td>
</tr>
<tr>
<td>Arduino Pro Mini 348</td>
<td>$25</td>
</tr>
<tr>
<td>nRF8001 Bluetooth chip</td>
<td>$20</td>
</tr>
<tr>
<td>SD Breakout</td>
<td>$10</td>
</tr>
<tr>
<td>SD Card</td>
<td>$5</td>
</tr>
<tr>
<td>Misc. wires, resistors, capacitors, etc</td>
<td>$2.50</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$124.50</strong></td>
</tr>
</tbody>
</table>

Table 5.2 - The projected cost of parts associated with this project
5.3. Total Costs

<table>
<thead>
<tr>
<th>Sector</th>
<th>Total Fees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>$39,375</td>
</tr>
<tr>
<td>Parts</td>
<td>$124.50</td>
</tr>
<tr>
<td>Total</td>
<td>$39499.50</td>
</tr>
</tbody>
</table>

Table 5.3 - The total projected costs associated with this project

6. Safety and Ethics Considerations

6.1 Safety

For safety of our customer we will apply a conformal coating to our PCB to prevent it from being damaged by moisture and any corrosion. To protect the user from any the heat generate by PCB, we wrap it with insulation on the backside of the necklace. All exposed wires or any circuitry will be thoroughly insulated. We will also follow the ethics code of safety, such as not touching any electrical component with wet hands. No partially damaged device will be used, even for verification purposes. Heated components will be well spaced on PCB such that no component is close enough to damage the other component with the heat dissipated from it.

6.2 Ethics

It does bear noting that there are legal considerations with this project. First, photography is invariably legal in public places. Secondly, in the case of sexual assault, the victim is under some degree of duress and, therefore, cannot be held as an intruder as defined in the American Law Institute’s Restatement of the Law, Second, Torts, §652. Thirdly, in locations where photography is barred, a person’s well-being (or ability to pursue legal action, where said person’s well-being has already been compromised) should supersede such limitations, though that is a matter yet to be discussed with a legal professional. Ethically, this product does not introduce any previously-unknown risk of non-consensual photography, as spy camera necklaces already exist and are marketed as such, and any photographs taken will be taken exclusively in conjunction with a 911 phone call—misuse of which is well known to be a misdemeanor.

Applying IEEE code of ethics

1. “to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations”

All of our group members have undergone the required lab and electrical training for this lab.
2. “to treat fairly all persons and to not engage in acts of discrimination based on race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression.”

We intend to distribute all the works and findings fairly among our group members and aim to promote better cooperation among us.

7. Schedule

<table>
<thead>
<tr>
<th>Date</th>
<th>Task</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-Oct</td>
<td>Finalised Schematic Ordering Parts</td>
<td>All Josh</td>
</tr>
<tr>
<td>12-Oct</td>
<td>Testing and Debugging Hardware Module</td>
<td>Josh Richa</td>
</tr>
<tr>
<td></td>
<td>Testing and Debugging Bluetooth Module/App</td>
<td>Kevin</td>
</tr>
<tr>
<td></td>
<td>Integrating all tested modules on a breadboard and testing its overall functionality</td>
<td></td>
</tr>
<tr>
<td>19-Oct</td>
<td>Finalize Circuit Design (Recheck with TA)</td>
<td>Josh Kevin</td>
</tr>
<tr>
<td></td>
<td>Eagle CAD Design</td>
<td>Richa</td>
</tr>
<tr>
<td></td>
<td>Order PCB</td>
<td></td>
</tr>
<tr>
<td>26-Oct</td>
<td>Finalize hardware testing with supplementary debugging process</td>
<td>Josh</td>
</tr>
<tr>
<td></td>
<td>Finalize software testing with supplementary debugging process</td>
<td>Richa</td>
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<td>Final PCB test</td>
<td>Kevin</td>
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<td>2-Nov</td>
<td>Begin Final Report</td>
<td>Kevin &amp; Richa</td>
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<td>Obtain feedbacks from the customers for development of the product.</td>
<td>Josh Richa</td>
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<td>9-Nov</td>
<td>Mock final presentation</td>
<td>Josh Kevin</td>
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<td>Compile first draft of final paper</td>
<td>Richa</td>
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<td>28-Nov</td>
<td>Final Presentation</td>
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<tr>
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8. References:


