Smart Ladder

Design Review

TA: Luke Wendt

Bradden Pesce : bpesce2
Lingying Cai : lcai12

October 04, 2016
Table of Contents:

1. Introduction....................................................................................................................4
   1.1. Statement of Purpose..............................................................4
   1.2. Objectives.................................................................................4
      1.2.1. Goals and Benefits...............................................................4
      1.2.2. Functions and Features.........................................................4

2. Design...........................................................................................................................5
   2.1. Block Diagram and Descriptions.......................................................5
      2.1.1. Block Diagram........................................................................5
   2.2. Block Descriptions.................................................................................5
      2.2.1. Microcontroller.....................................................................5
      2.2.2. Power Source.........................................................................6
      2.2.3. Load Sensors.........................................................................6
      2.2.4. Digital Display........................................................................7
      2.2.5. LEDs........................................................................................7
      2.2.6. Speaker...................................................................................7
      2.2.7. Accelerometer.......................................................................8
      2.2.8. Switches...............................................................................8
      2.2.9. Amplifier..............................................................................8
   2.3. Circuit Schematics.............................................................................9

3. Tolerance Analysis and Calculations.........................................................10
   3.1. Power Consumption Calculations..................................................10
   3.2. Noise and Tolerance of Accelerometer...........................................10
   3.3. Tolerance of Load Cells................................................................12
   3.4. Ladder Safety Calculations.............................................................13
      3.4.1. Scenario 1........................................................................13
1. Introduction:
   1.1 Statement of Purpose
   Improper use of ladders often causes them to fall and this is a safety hazard in both the workplace and around the home. Falls are one of the leading causes of injury mortality, and according to the CDC 43% of all fatal falls involve a ladder; there are around 30,000 injuries per year from falling ladders based on numbers from previous years. Our ladder solves this problem by analyzing all the forces applied on the ladder and then displaying how close the ladder is to slide or rotate by using digital display. The user would also be warned if certain conditions for using the ladder are not ideal such as weight surpassing the ladder rating and improper usage. Currently there is no way for someone to know how stable the ladder they are using is or if they are pushing the ladder too far.

1.2. Objectives

   1.2.1. Goals and Benefits
   1. Prevent ladder related injuries due to falls from improper use
   2. Increased work efficiency from stability assurances
   3. Prevent users from using the ladder if the conditions are unsafe before use
   4. A user would be able to safely use the ladder if placed on two legs

   1.2.2. Functions and Features
   1. Determine center of gravity relative to the base stability of the ladder
   2. Calculate and display a percent margin of stability
   3. Audibly warn the user if the margin of stability is below 50%
   4. Sound override button to disable the warning
   5. Detect the user’s weight and active a LED if too much weight is being applied
   6. If the user climbs too high a switch will trigger to warn them not to continue
   7. Power management system
   8. The ladder will be 6 ft tall on two legs.
   9. If the angle between the ladder and the surface it is leaning against is greater than 75.5° then the ladder is unsafe based on OSHA regulations and the warning will activate.
2. Design

2.1. Block Diagram and Block Descriptions:

2.1.1. Block diagram

![Block Diagram of design](image)

2.2. Description of Blocks

2.2.1. Microcontroller

**Inputs:** Regulated 8VDC +/-10% from power source, 3-axis acceleration data, switch data, analog data from load cells.

**Outputs:** Sends information to the LED, Digital Display, and Speaker.

The microcontroller is responsible for collecting data from the sensors and controlling all the feedback devices in the system. The accelerometer and load sensors will be connected to microcontroller; then it will analyze the data, determining whether the ladder is safe or not, and send a signal to LED, Digital Display and speaker. This part is important because it will analyse the data collected by all of the sensors and determine the degree of safety of the ladder.
The data will be analyzed and the information will be used in computing the center of gravity of the ladder relative to the base stability by comparing all the forces acting on the base of the ladder; the safety margin of the ladder is computed based on how close the ladder is to slipping by first finding the forced applied from the user on the ladder and comparing that value to the friction force the ladder makes with the ground. If the force applied is greater than friction then it is not safe. If the user reaches out in any direction, the amount of force this creates will be compared to the forces acting on the ladder to determine if the ladder will fall to the right or left as well. This module analyzes the accelerometer and switch data in order to know the user’s position and the angle that the ladder is set at. It must also reduce the safety margin by 8% to account for the tolerance error of the load sensors. i.e. The ladder will never read 100% safe; 92% would be the maximum value displayed.

2.2.2. Power Source

**Inputs:** None  
**Outputs:** 12VDC, to microcontroller, to load cells, to accelerometer, to switches, to LED, to digital display, to speaker

We will use resistors to regulate the voltage going to different components. The power source will have a switch which will be controlled by a signal sent by microcontroller. If the switch is on, the LED, digital display and speaker will show their behaviors respectively. For example, the red LED will be turned on if there is too much weight on the ladder, the digital display will show the safety and the speaker will be activated if the condition is considered as unsafe.

2.2.3. Load Sensors

**Inputs:** Regulated 8VDC +/-10% from power source, Force applied to sensor from the user  
**Outputs:** Analog change in resistance corresponding to forces sent to voltage amplifier

We will place load sensors at the base of the ladder in order to detect the directions of all the forces being applied, including gravity. This information will be used to detect the center of gravity of the ladder relative to the
base of stability and will be sent to the microcontroller. The load sensors will also determine if the ladder can handle the weight of the person and whatever they might be carrying. These sensors are connected to the voltage amplifier.

2.2.4. Digital Display

**Inputs:** Regulated 5VDC +/- 10% from power source, data to display from microcontroller  
**Outputs:** Visual % of how close the ladder is to falling

This module will receive a signal from the microcontroller to display to the user how safe and stable the ladder currently is. If the center of mass of the ladder is completely stable, a 92% reading would be displayed; if the ladder is falling 0% to 8% would be displayed. Since the tolerance and noise of the load cells and accelerometer will affect the accuracy of the safety margin, a percentage of 8% is being reduced and added to the total above. This is shown in the tolerance and noise calculations. One 330Ω resistor must be placed in series with each segment (seven total) to control the current.

2.2.5. LED

**Inputs:** Regulated 3.3VDC +/- 10% from power source, signal from microcontroller  
**Outputs:** Lights up for user

There will be one LEDs and it would only be on if there is too much weight being applied on the ladder's first step than it would theoretically be able to handle. The LED receives its signal from the microcontroller.

2.2.6. Speaker

**Inputs:** Regulated 3.3VDC +/- 10% from power source, signal from microcontroller  
**Outputs:** Audio warning to the user

This module will receive a signal from the microcontroller if the ladder is reaching a point of about 50% its safety margins where it would be close to falling. It will then play a warning to the user to caution them that the ladder will fall if they continue.
2.2.7. Accelerometer

**Inputs:** Regulated 3.3VDC +/- 10% from power source, physical orientation of ladder  
**Outputs:** Output voltage data to microcontroller

This module is used to determine the gravity vector of the ladder. It is also used to determine if the angle the ladder makes with the wall is within OSHA regulations of 75.5° by measuring the static acceleration due to gravity. The accelerometer measures the acceleration that is being experienced by the chip on the x, y, and z axes in space. The natural acceleration of gravity allows this sensor to give a measurement of the ladder’s orientation with respect to the ground.

2.2.8. Switches

**Inputs:** 12VDC +/- 10% from power source, input from user  
**Outputs:** Signal to microcontroller to note position

This module determines which rung of the ladder the user is currently on in order to determine the height of the center of gravity and then sends this information to the microcontroller. There will be a switch on each rung, and a signal will be sent when the switch is triggered.

2.2.9. Amplifier

**Inputs:** 5VDC +/- 10% from power source, analog data from the load cells.  
**Outputs:** Signal sent to microcontroller

This module amplifies the data received from the load cells in order for the microcontroller to read the data more clearly.
2.3. Circuit Schematic

Figure 0: Circuit diagram
3. Tolerance Analysis and Calculations

3.1. Power Consumption Calculations

<table>
<thead>
<tr>
<th>Devices</th>
<th>Worst power consumption(unit: mWatts)</th>
<th>Average power consumption(unit: mWatts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load sensors</td>
<td>711</td>
<td>316</td>
</tr>
<tr>
<td>Speaker</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>LED</td>
<td>297</td>
<td>82.5</td>
</tr>
<tr>
<td>Microcontroller</td>
<td>360</td>
<td>360</td>
</tr>
<tr>
<td>Accelerometer</td>
<td>4.95</td>
<td>3.96</td>
</tr>
<tr>
<td>Switches</td>
<td>3600</td>
<td>3600</td>
</tr>
<tr>
<td>Digital Display</td>
<td>530.3</td>
<td>530.3</td>
</tr>
<tr>
<td>Amplifier</td>
<td>2.3</td>
<td>2.63</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>5705.55</strong></td>
<td><strong>5095.39</strong></td>
</tr>
</tbody>
</table>

The capacity rating of the battery is 5Ah and the consumption is from \( \frac{5.70555W}{12V} = 0.4755 \text{ A} \), which would give \( \frac{5}{0.4755} = 10.5 \) hours of use.

3.2 Noise and Tolerance of Accelerometer

The tilt angle that the ladder makes with the ground can be found from the equation below. The values of 1650mV and 800mV/g are found on the MMA6260Q datasheet. The tolerance on the datasheet is +/- 5% in regards to the output voltage, and the typical noise is 1.8mV.
\[ \theta = \arcsin\left(\frac{V_{\text{OUT}} - V_{\text{OFFSET}}}{\frac{\Delta V}{\Delta g}}\right) \]

If \( V_{\text{OUT}} \) is 2V, then

\[ \theta = \arcsin\left(\frac{2000\text{mV} + 1.8\text{mV} - (2000\text{mV} \times 1\%) - 1650\text{mV}}{800\text{mV} / g}\right) \theta = 27.69^\circ \]

\[ \theta = \arcsin\left(\frac{2000\text{mV} + 1.8\text{mV} + (2000\text{mV} \times 1\%) - 1650\text{mV}}{800\text{mV} / g}\right) \theta = 24.5^\circ \]

\[ \theta = \arcsin\left(\frac{2000\text{mV} - 1650\text{mV}}{800\text{mV} / g}\right) \theta = 25.94^\circ \]

Therefore, the margin of error is \((27.69^\circ - 25.94^\circ)/25.94^\circ \times 100 = +6.75\%\) and \((24.5^\circ - 25.94^\circ)/25.94^\circ \times 100 = -5.55\%\). The angle measurement must take into account a +7\% maximum error and a -6\% minimum error.

The angle the ladder makes with the wall is \((90^\circ - \text{tilt angle})\), which is the angle used in the formula (1.1) calculation. For the sake of determining the tolerance effect, \( M1 = 70 \text{ kg} \), \( \theta = 14.5^\circ \) (based on the angle with the base being 75.5\(^\circ\), which is the maximum angle allowed for safety), \( a = 0.73 \) (based on the maximum height the person of this weight can theoretically climb before the ladder will slip and fall based on the total force acting on the base which would be around \( 162.68 \text{ N} \) if the friction coefficient is 0.2: \( Ffr = (g(M1+M2) \times \mu) \). Using formula 1.1, The total \( F = 145.98 \text{ N} \). The percent safety margin for this specific scenario would be \( 10.27\% \) safe with no tolerance. Since the accelerometer we are using has an angular error of +7\% and -6\%, the angle that the ladder makes with the wall would be either \( 15.52^\circ \) or \( 13.63^\circ \). Plugging in 15.52\(^\circ\) instead of 14.5\(^\circ\) in the equations with all other parameters the same yields \( F = 156.76 \text{ N} \); the safety margin would now read 3.64\% safe. The difference between the two
safety margin values is about 6.63%. Plugging in 13.63° instead of 14.5° in the equations with all other parameters the same yields \( F = 136.875 \text{ N} \); the safety margin would now read 15.86% safe. The difference between the two safety margin values is about 5.60%, and therefore our tolerance for the accelerometer would be \(+/- 7\%\) from using the worst case angle above.

3.3 Tolerance of Load Cells

The force of the ladder against the wall must be greater than the force of the ladder against the base or the ladder will slip and fall. We would use load cells at the base of the ladder to determine the total force acting on the base. This value is then compared with formula 1.1 below; \( M \) is the mass of the user which is determined by a load cell placed on the first rung of the ladder; \( 'a' \) is the fraction of the ladder height the user is currently located which is determined by switches placed on each rung of the ladder (if the user is on two rungs at one an average is taken); \( \theta \) is the angle the top of the ladder shares with the wall; \( m \) is the mass of the ladder which is equal to 10 kg for the ladder we plan on using and 3 kg more for all the sensors and components added on; \( g \) is gravity and equal to 9.8 m/sec^2.

For the sake of determining the tolerance effect, \( M = 70 \text{ kg} \), \( \theta = 14.5^\circ \) (based on the angle with the base being 75.5^\circ, which is the maximum angle allowed for safety), \( a = 0.73 \) (based on the maximum height the person of this weight can theoretically climb before the ladder will slip and fall based on the total force acting on the base which would be around \( 162.68 \text{ N} \) if the friction coefficient is 0.2; \( F_{fr} = g(M1+M2) \times \mu \)). The total \( F = 145.98 \text{ N} \). The percent safety margin for this specific scenario would be 10.266% safe with no tolerance. Since the load cells we are using have a maximum error of 0.05%, the mass of the person would be detected as 70 kg \(+/- 0.035 \text{ kg} \). Plugging in 70.035 kg instead of 70 kg in the above equations with all other parameters the same yields \( F = 146.05 \text{ N} \) and \( F_{fr} = 162.75 \text{ N} \); the safety margin would now read 10.261% safe. The difference between the two safety margin values is about 0.005%, and therefore our tolerance would be \(+/- 0.005\%\); This value is extrapolated to a tolerance of \(+/- 1\%\) which will cover all possible unaccounted for sources of error, especially the low noise.
The total tolerance would be from the angular component and the load cell component, therefore $1\% + 7\% = \ldots$ and $-1\% + -7\% = \pm 8\%$ is our total safety margin tolerance.

3.4. Ladder safety calculation

3.4.1. Scenario 1:

Figure 1.1: slipping analysis of the ladder
\[ \sum \tau = 0 = \sum r \times \bar{F} = M \cdot g \cdot d_1 + m \cdot g \cdot d_2 - F_w \cdot d_3 - f_2 \cdot d_4 \]

Therefore,

\[ F_w = \frac{M \cdot g \cdot d_1 + m \cdot g \cdot d_2 - f_2 \cdot d_4}{d_3} \]

\[ = \frac{M \cdot g + a \cdot L \cdot \sin(\theta) + m \cdot g + \frac{L}{2} \cdot \sin(\theta) - (M \cdot g + m \cdot g - N) \cdot L \cdot \sin(\theta)}{L \cdot \cos(\theta)} \]

\[ = \frac{M \cdot g + a \cdot \sin(\theta) + m \cdot g + \frac{1}{2} \cdot \sin(\theta) + N \cdot \sin(\theta) - M \cdot g \cdot \sin(\theta) - m \cdot g \cdot \sin(\theta)}{\cos(\theta)} \]

\[ = (M \cdot g \cdot (a - 1) + 0.5 \cdot m \cdot g \cdot N) \cdot \tan(\theta) \]

(1.1)

If \( F_w \leq F_{\text{friction, max}} \), the ladder is considered safe, otherwise, not safe.

The smaller \( F_w \) is, the safer the ladder is.

**Safety Analysis:**

![Figure 1.2: Setup for safety margin plot](image)
Figure 1.3: 3D plot of safety margin

\[
safe = -\frac{1}{F_{\text{friction, max}}} * F_w + 1
\]

\[
safe(a, \theta) = -\frac{1}{F_{\text{friction, max}}} * (M \cdot g \cdot (a - 1) + 0.5 \cdot m \cdot g + N) \cdot \tan(\theta) + 1 \tag{1.2}
\]

suppose M = 60kg, m = 10kg, g=9.8m/s², \(F_{\text{friction, max}}\) is constant
3.4.2. Scenario 2:

Figure 2.1: rotation analysis of the ladder

Figure 2.2: plot for x
x is the distance between the position of user and the center of the ladder
treat N1 - N2 as a variable

\[ x = 0, \ N1 = N2 = 0.5(Mg + m^*g), \quad N2-N1=0 \]
\[ x = 0.5w, \quad N1=0, \ N2=Mg + m^*g, \quad N2-N1=Mg + m^*g \]

\[ \Sigma \tau = 0 = \sum r \times \vec{F} = \begin{align*}
&= -M \cdot g \cdot (0.5 \cdot w - x) \cdot \sin(\theta) - m \cdot g \cdot (0.5 \cdot w) \cdot \sin(\theta) - f_{11} \cdot w \cdot \cos(\theta) + F_{w1} \cdot w \cdot \cos(\theta) + N1 \cdot w \cdot \sin(\theta) + F_p \cdot (0.5 \cdot w - x) \\
&= \begin{array}{c}
- M \cdot g \cdot (0.5 \cdot w - x) \cdot \sin(\theta) - m \cdot g \cdot (0.5 \cdot w) \cdot \sin(\theta) - f_{11} \cdot w \cdot \cos(\theta) + F_{w1} \cdot w \cdot \cos(\theta) + N1 \cdot w \cdot \sin(\theta) \\
0.5 \cdot w - x
\end{array}
\end{align*} \tag{2.1} \]

If \( F_p \leq f_{11,max} + f_{12,max} - F_{w1} - F_{w2} \), the ladder is consider safe, otherwise, not safe.
The smaller \( F_p \) is, the safer the ladder is.

\textbf{Safety Analysis:}

\[ \text{safe} = \frac{1}{f_{11,max} + f_{12,max} - F_{w1} - F_{w2}} \cdot F_p + 1 \]

\[ \text{safe(a, } \theta) = \frac{1}{f_{11,max} + f_{12,max} - F_{w1} - F_{w2}} \cdot \left( -M \cdot g \cdot (0.5 \cdot w - x) \cdot \sin(\theta) - m \cdot g \cdot (0.5 \cdot w) \cdot \sin(\theta) - f_{11} \cdot w \cdot \cos(\theta) + F_{w1} \cdot w \cdot \cos(\theta) + N1 \cdot w \cdot \sin(\theta) \right) + 1 \tag{2.2} \]
3.4.3. Scenario 3:

\[ \sum \tau = 0 = \sum \tau \times \vec{F} = -M \times g \times a \times L \times \sin(\theta) - m \times g \times (0.5 \times L) \times \sin(\theta) + (F_{w1} + F_{w2}) \times L \times \cos(\theta) + F_p \times a \times L \times \sin(\theta) \]

\[ F_p = \frac{M \times g \times a \times L \times \sin(\theta) + m \times g \times (0.5 \times L) \times \sin(\theta) - (F_{w1} + F_{w2}) \times L \times \cos(\theta)}{a \times L \times \sin(\theta)} \]  

(3.1)

If \( F_p \leq f_{11,\text{max}} + f_{12,\text{max}} \), the ladder is consider safe, otherwise, not safe. The smaller \( F_p \) is, the safer the ladder is.
Safety Analysis:

\[
\text{safe} = \frac{1}{f_{11,\text{max}} + f_{12,\text{max}}} \cdot F_p + 1
\]

\[
\text{safe}(a, \theta) = \frac{1}{f_{11,\text{max}} + f_{12,\text{max}}} \cdot \\
\frac{M \cdot g \cdot a \cdot L \cdot \sin(\theta) + m \cdot g \cdot (0.5 \cdot L) \cdot \sin(\theta) - (F_{w1} + F_{w2}) \cdot L \cdot \cos(\theta)}{a \cdot L \cdot \sin(\theta)} + 1
\] (3.2)

Program size and software speed: Our program will use the data measured by sensors as input and output the safety percentage that will be displayed on digital display. The time complex is linear and space complex is constant.

3.5. Flowchart:

Figure 4: Flowchart for calculating safety percentage
3.6. Pseudocode:

\[ F_{w1} \leftarrow \text{value from load sensor1} \]
\[ F_{w2} \leftarrow \text{value from load sensor2} \]
\[ N1 \leftarrow \text{value from load sensor3} \]
\[ N2 \leftarrow \text{value from load sensor4} \]
\[ \theta \leftarrow \text{value from accelerometer} \]
\[ a \leftarrow \text{value based on which switch is pushed} \]
\[ m \leftarrow \text{weight of the ladder} \]
\[ M \leftarrow \text{weight of user} \]
\[ L \leftarrow \text{length of the ladder} \]
\[ N \leftarrow N1 + N2 \]
\[ f \leftarrow \mu_1 \times N \]
\[ f_{11,\text{max}} \leftarrow \mu_1 \times N1 \]
\[ f_{12,\text{max}} \leftarrow \mu_1 \times N2 \]

safe_scenario1 \leftarrow \text{formula(1.2)}
\]
safe_scenario1 \leftarrow \text{formula(2.2)}
\]
safe_scenario1 \leftarrow \text{formula(3.2)}
\]
total_safety \leftarrow \frac{\text{safe_scenario1} + \text{safe_scenario2} + \text{safe_scenario3}}{3}
4. Requirements and Verifications:

### 4.1. Requirements and Verifications Table

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Verification</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Load Sensors:</strong></td>
<td><strong>Load Sensors:</strong></td>
<td><strong>10</strong></td>
</tr>
<tr>
<td>a. Must be able to determine the value and direction of the perpendicular forces acting on the base of the ladder from a range of 1kg to 200kg. The tolerance is within 1kg +/- 0.0005 kg.</td>
<td>a. Use a force gauge to determine an applied force and compare it to the value measured from the load sensor by measuring the current change due to added resistance by using a ammeter.</td>
<td></td>
</tr>
<tr>
<td>b. Supply voltage must be between 5VDC and 12VDC</td>
<td>b. Attach the sensor input to a DC power supply, and sweep the voltages from 4.0 VDC to 13.0 VDC. Check that the device is active within the specified range.</td>
<td></td>
</tr>
<tr>
<td>c. The output voltage signal must be amplified before being processed by the microcontroller.</td>
<td>c. Make sure the voltage increased by a gain of 4 from the amplifier by using a multimeter across the output of the amplifier.</td>
<td></td>
</tr>
<tr>
<td><strong>4. Data analyzer:</strong> Must analyze the data collected from microcontroller, calculate how close the</td>
<td><strong>Data analyzer:</strong> Theoretically work out the safety margin percentage based on the current stability of the ladder and insure the value that the</td>
<td><strong>30</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ladder is to falling with the center of gravity relative to the base of stability, and then provide an appropriate percentage within +/- 1% to send back to microcontroller. It also must reduce the safety margin by 8% to account for the tolerance error of the load sensors. i.e. The ladder will never read 100% safe; 92% would be the maximum value displayed.

data analyzer calculates is within the required tolerance. The center of gravity would be calculated theoretically as well by finding the balance point of the ladder and we would insure that the center of gravity we measure is within a reasonable distance from the theoretical value.

<table>
<thead>
<tr>
<th>5. Microcontroller: must send appropriate threshold voltages to activate the loads such as LEDs, digital displays and speakers. Power to the circuit board elements is controlled through transistor gates.</th>
<th>Program the microcontroller to send a HIGH to turn on LEDs, digital displays and the speaker.</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. Power Source:</td>
<td>Power Source:</td>
<td>30</td>
</tr>
<tr>
<td>a. Must be able to provide a 12VDC +/- 1.2VDC output</td>
<td>a. Measure the voltage across the battery using a multimeter and verify that it is within the correct tolerance.</td>
<td></td>
</tr>
<tr>
<td>b. Voltage regulated to 3.3VDC +/- 0.3VDC output for the LED, accelerometer, and speaker</td>
<td>b. Connect voltage regulator input voltage to power supply and sweep the input voltage from 5 VDC to 10 VDC. Use a multimeter to</td>
<td></td>
</tr>
</tbody>
</table>
c. Voltage regulated to 8VDC +/- 0.8 VDC output for the load cells and microcontroller.

d. Voltage regulated to 5VDC +/- 0.5 VDC output for the digital display.

e. Must be able to last an 8 hour workday before needing to be recharged.

<table>
<thead>
<tr>
<th>8. Accelerometer:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a. The accelerometer must sense an acceleration of 1g +/- 1% on a single axis when completely flat.</td>
<td>a. Connect the output of the accelerometer to the microcontroller. Observe the sensor output values. When the sensor is flat, the microcontroller should indicate high values on one side (+1g +/- 1%) and values close to zero for the other sides (1g +/- 0.01g).</td>
</tr>
</tbody>
</table>

| | verify that the voltage stays within 3.3VDC +/- 10% |
| | c. Connect voltage regulator input voltage to power supply and sweep the input voltage from 6 VDC to 12 VDC. Use a multimeter to verify that the voltage stays within 8VDC +/- 10% |

| | d. Connect voltage regulator input voltage to DC power supply and sweep the input voltage from 6 VDC to 10 VDC. Use a multimeter to verify that the voltage stays within 5VDC +/- 10% |

<p>| | e. Power Source: Turn on all the devices at once and insure that the battery last over 8 hours. |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>b.</strong> Supply Voltage is between 2.0 V and 3.6 V.</td>
<td>As the sensor is rotated about a single axis, the values of one axis should increase and another axis should decrease.</td>
</tr>
<tr>
<td><strong>c.</strong> Must be able to determine tilt angle with horizontal within +7% and -6% error.</td>
<td>b. Attach the accelerometer input supply to a DC power supply and sweep the voltages from 1.0 V to 4.0 V. Check that the device is active within the specified range.</td>
</tr>
<tr>
<td><strong>c.</strong></td>
<td>c. Measure the output voltage and insure that the angle measured is within the bounds of the theoretical value from the tilt angle calculation.</td>
</tr>
<tr>
<td><strong>9. Speaker, Digital Display and LED:</strong> Must all turn on at the appropriate time. i.e at 50% safety, if too much weight is applied on the ladder (200 to 375 pounds depending on ladder rating), or show the percentage of safety.</td>
<td><strong>Speaker and LEDs:</strong> Measure the theoretical values and compare to the value displayed and see if the signal should or should not be sent.</td>
</tr>
<tr>
<td>0</td>
<td><strong>10. Switches on Rungs:</strong> Must be able to determine if the user is currently on which rung of the ladder.</td>
</tr>
</tbody>
</table>
5. Cost and Schedule

5.1. Cost Analysis

5.1.1 Labor Costs

<table>
<thead>
<tr>
<th>Name</th>
<th>Hourly Rate</th>
<th>Total Hours Invested</th>
<th>Total Labor Costs (Hourly Rate * 2.5 * Total Hours Invested)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brad</td>
<td>30.00 $/hour</td>
<td>225</td>
<td>$16,875.00</td>
</tr>
<tr>
<td>Lingying</td>
<td>30.00 $/hour</td>
<td>225</td>
<td>$16,875.00</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>450</td>
<td>$33,750.00</td>
</tr>
</tbody>
</table>

5.1.2 Parts

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>665-AS05008PR2R Speaker</td>
<td>1</td>
<td>$3.69</td>
</tr>
<tr>
<td>Adafruit 878 LED 7-Segment Digital Display</td>
<td>1</td>
<td>$9.95</td>
</tr>
<tr>
<td>1PCX 200 kg Load Cell</td>
<td>2</td>
<td>$29.74</td>
</tr>
<tr>
<td>HLMP1340 Red LED</td>
<td>1</td>
<td>$0.12</td>
</tr>
<tr>
<td>INA-125 Amplifier</td>
<td>1</td>
<td>$6.12</td>
</tr>
<tr>
<td>1528-1021-ND Microcontroller</td>
<td>1</td>
<td>$9.95</td>
</tr>
<tr>
<td>MMA6260Q Accelerometer</td>
<td>1</td>
<td>$8.42</td>
</tr>
<tr>
<td>CoCOM-08720 ROHS Switches</td>
<td>6</td>
<td>$18.00</td>
</tr>
<tr>
<td>PS-1250 12V 5AH Battery</td>
<td>1</td>
<td>$11.99</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>$97.98</td>
</tr>
</tbody>
</table>
5.1.3. Grand Total

<table>
<thead>
<tr>
<th>Section</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>$33,750.00</td>
</tr>
<tr>
<td>Parts</td>
<td>$97.98</td>
</tr>
<tr>
<td>Grand Total</td>
<td>$33,847.98</td>
</tr>
</tbody>
</table>

6. Weekly Schedule

<table>
<thead>
<tr>
<th>Week</th>
<th>Task</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sep 12</td>
<td>Finish Project Proposal</td>
<td>Brad</td>
</tr>
<tr>
<td></td>
<td>Finish Project Proposal</td>
<td>Lingying</td>
</tr>
<tr>
<td>Sep 19</td>
<td>Order sensors, devices, and ladder</td>
<td>Brad</td>
</tr>
<tr>
<td></td>
<td>analyze the data(figure out formula)</td>
<td>Lingying</td>
</tr>
<tr>
<td>Sep 26</td>
<td>Run tests on sensors</td>
<td>Brad</td>
</tr>
<tr>
<td></td>
<td>Begin microcontroller</td>
<td>Lingying</td>
</tr>
<tr>
<td>Oct 3</td>
<td>Implement and test power source</td>
<td>Brad</td>
</tr>
<tr>
<td></td>
<td>Design the data analyzer (program part)</td>
<td>Lingying</td>
</tr>
<tr>
<td>Oct 10</td>
<td>Finish microcontroller</td>
<td>Brad</td>
</tr>
<tr>
<td></td>
<td>Test external devices</td>
<td>Lingying</td>
</tr>
<tr>
<td></td>
<td>(speaker, display, LEDs)</td>
<td></td>
</tr>
<tr>
<td>Oct 17</td>
<td>Assemble prototype circuitry</td>
<td>Brad</td>
</tr>
<tr>
<td></td>
<td>Test prototype circuitry</td>
<td>Lingying</td>
</tr>
<tr>
<td>Date</td>
<td>Task Description</td>
<td>Responsible Party</td>
</tr>
<tr>
<td>----------</td>
<td>-------------------------------------------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>Oct 24</td>
<td>Write the individual progress and R&amp;V table</td>
<td>Brad</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lingying</td>
</tr>
<tr>
<td>Oct 31</td>
<td>Solder modules together</td>
<td>Brad</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lingying</td>
</tr>
<tr>
<td>Nov 7</td>
<td>Prepare for/finalize mock demo and R&amp;V table</td>
<td>Brad</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lingying</td>
</tr>
<tr>
<td>Nov 14</td>
<td>Run tests on final project</td>
<td>Brad</td>
</tr>
<tr>
<td></td>
<td>Finalize software changes</td>
<td>Lingying</td>
</tr>
<tr>
<td>Nov 21</td>
<td>Solve Final Issues</td>
<td>Brad</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lingying</td>
</tr>
<tr>
<td>Nov 28</td>
<td>Final Demos and Presentation</td>
<td>Brad</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lingying</td>
</tr>
<tr>
<td>Dec 5</td>
<td>Final report</td>
<td>Brad</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lingying</td>
</tr>
</tbody>
</table>
7. Discussion of Ethics and Safety:

7.1. IEEE Code of Ethics

Here are some specific IEEE codes of Ethics that must be considered:

1. to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;

This point is important because of the safety issues that come with using a ladder. It is crucial that we thoroughly instruct the users on how to properly operate the ladder in order to avoid injury. Improper use of the device from poor documentation will likely lead to injuries.

3. to be honest and realistic in stating claims or estimates based on available data;

If we make false claims on how well the ladder can evaluate a user’s safety on the ladder, it could lead to improper usage and incorrect feedback to the user. It is our responsibility to thoroughly test our ladder and insure that our safety claims are backed by data.

7.2. Safety

There are many ways to improperly use a ladder that our ladder would not be able to detect and may tell the user that they are safe when in reality they are not; We would place a sticker showing the correct way to use the ladder for the safety readings to be accurate, and it would also warn the user that they might not be safe if the ladder isn’t properly set up. According to OSHA regulations, ladders must be placed at an angle of from the vertical wall; we would make this clear on the sticker as well and the angle will be taken into account in the calculations for safety.
8. Citations:

Datasheets for accelerometer:

Datasheet for digital display:

Datasheet information for load cells:

Datasheet for microcontroller:

Datasheet for battery:
http://www.batteryclerk.com/assets/documents/BatteryClerk-AJC-Battery-D5S.pdf

Datasheet for amplifier:

Datasheet for switches:

Datasheet for speaker: