Accessible Wheelchair Scale

Design 1 - Miniature Load Cells

By

Eric Bernstein
Maria Elescano
Julie Rosario
Matt Veilleux

Contact:

Rehabilitation Engineering Research Center on Accessible Medical Instrumentation
National Student Design Competition
John Enderle
(860) 486 - 5521
Introduction

An accessible weight scale that can be used either at home by handicapped persons or at a health care facility would be of great use to many patients. The weight scale is accessible to patients who suffer from a variety of disabilities, such as patients with limited movement of the extremities, general frailty, paraplegics, wheelchair users, or those in need of a cane or a walker. Patients suffering from renal failure, heart failure, diabetes, multiple sclerosis, or others who need to monitor their weight regularly can also benefit from this device.

The weight scale will have a ramp to make it wheelchair accessible and will have removable side support bars for those patients in need of additional support to stand. In order to avoid rolling accidents, the weight scale will have stops maintaining the wheelchair and other walking instruments in place. To accommodate patients with poor eyesight the output will be easy to read, and available in several formats.

To calculate a person’s weight, the scale must have several critical components. First, a ramp allows for easy access to weighting platform for a wheelchair. Next, the platform rests on either one or several devices designed to convert mechanical force into an electrical signal, such as load cells. The electronic signal from the measuring device is then interpreted by a microcontroller along with decoding the desired user input from a keypad. Finally, the weight value is output to either a computer or an LCD for interpretation by the user.

This basic structure for a weight scale is used in the majority of the scales available on the market today. The following is an in depth design for a weight scale.
Objective

The scale design has several critical components. The device will have a platform resting on four load cells designed to convert the mechanical force into an electrical signal. The electronic signal, from the measuring device, is then interpreted by a microcontroller, which decodes the desired user input from a keypad. Finally, the weight value will be displayed to either a computer or an LCD for interpretation by the user.

The four load cells will be located between two aluminum alloy plates, at the corners of the platform. The ramp, also made out of aluminum alloy, has a small angle in order to facilitate access to the scale. The top of the upper platform plate, the bottom of the lower platform plate, and the top of the ramp, have a significant coat of rubber in order to provide friction. Stops, made out of aluminum alloy, and a side bar support, made out of steel, are designed for safety issues.

Mechanical Design

The weight scale will be designed to sustain a maximum weight of 500 lb; for the design we will be using a factor of safety of 1.2, which means that the maximum weight we will be using for the calculations is 600 lb. The scale platform will have dimensions large enough to accommodate a standard adult sized wheelchair (26in X 36in). The scale ramp will have a height to length ratio of 1:12, which is the standard relation for wheelchair ramps. The scale will have one side support bar that will be able to sustain the maximum weight applied to the platform. The LCD display will be paced on top of a rectangular beam, which will

1 http://www.usdoj.gov/crt/ada/descript/reg3a/figA3ds.htm
also be able to sustain the weight applied to the platform. The stops, to avoid rolling accidents, will be placed around the platform of the scale. The following is a side view of the weight scale.

Wheelchair Weight Scale

Note: Stops will be around the three sides of the platform but the side stops have been left out to show position of load cells.

**Mechanical Analysis**

**Platform Analysis:**

As mentioned before, the platform will have to sheets or plates, one on top of the four load cells and one below them; the plate below will be thinner to
minimize costs. The load cells will be placed one inch away from the edges of the plates.

Top & Bottom Platforms

Top Plate:
- $t_p = 0.19$ in
- $L_p = 36$ in
- $W_p = 36$ in

Bottom Plate:
- $t_p = 0.063$ in
- $L_p = 36$ in
- $W_p = 36$ in
For a plate or sheet the *flexural rigidity* is

\[ D = \frac{Et^3}{12(1-\nu^2)}, \]

where \( E \) is the modulus of elasticity and \( t \) is the thickness of the cross section.

The flexural rigidity for a narrow beam is equal to \( EI \), where \( I \) is the moment of inertia. For a rectangular cross section of one unit width this equation becomes \( Et^3/12 \). A plate therefore, manifests greater stiffness than a narrow beam by a factor of \( 1/(1-\nu^2) \) or about 10%.\(^2\) Therefore, for the scale platform, a narrow beam will be used as an approximation for the calculation of the bending stress, since the plate is stiffer than the beam.

\(^2\) Ugural and Fenster. *Advanced Strength and Applied Elasticity.*
Approximation with a beam:

\[ \sum F_y = P + W - R_1 - R_2 = 0 \quad \Rightarrow R_1 + R_2 = 630\text{lb} \]

\[ \sum M_1 = 630 \times 1.42 - R_2 \times 2.83 = 0 \quad \Rightarrow R_2 = 315\text{ lb} \quad \Rightarrow R_1 = 315\text{ lb} \]
**Calculation of Stress:**

To calculate the stress a small area of on unit width will be used.

\[
\sigma = \text{Bending Stress} \\
M = \text{Max Moment} = (\text{Load}/2) \times \text{Arm} \\
I = \text{Moment of Inertia} \\
c = \text{Largest Distance from Neutral Axis}
\]

\[
c = \frac{0.19}{2} = 0.095 \text{ in} \\
I = 1 \times \frac{0.19^3}{12} = 5.716 \times 10^{-4} \text{ in}^4 \\
M = (600 \text{ lb}/2) \times 18 \text{ in} = 5400 \text{ lb*in}
\]

\[
\sigma = \frac{Mc}{I} = \frac{5400 \times 0.095}{5.716 \times 10^{-4}} = 897,507 \text{ psi}
\]

**Load Cell Reactions:**

In order to choose the load cells for the scale, the maximum force that can be applied to each load cell must be calculated. The following are the free body diagram and the calculations for that situation.
**Summation of Forces and Moments:**

\[ +\downarrow \sum F_y = P + W - C_1 - C_2 = 0 \quad \Rightarrow \quad C_1 + C_2 = 630 \text{ lb} \]

\[ \sum M_1 = 30 * 1.42 + C_2 * 2.83 = 0 \quad \Rightarrow \quad C_2 = -15 \text{ lb} \quad \Rightarrow \quad C_1 = 645 \text{ lb} \]

Therefore the maximum load allowed for each load cell is 645 lb or 2870 N.

*Aluminum / Thermoplastic Composite Sheet with yield strength of 10 ksi and a maximum capacity load of 1850 lbs would be used for the Top Platform. Aluminum Alloy 6061 Sheet with yield strength of 140,000 psi, would be used for the Bottom Platform.*

**Ramp Analysis:**
To comply with the 1:12 ratio required for wheelchair ramps, the angle of the ramp will have the following value:

\[
h_r = 0.667 \text{ in} \\
L_r = 8 \text{ in}
\]

\[
\frac{h_r}{L_r} = \frac{1}{12} \Rightarrow \theta = \tan^{-1} \frac{1}{12} = 4.77^\circ
\]

This angle is small enough to prevent any wheelchair rollbacks.

To ensure a safe ramp, bending and frictional forces will be calculated using a worse case scenario. In this case let’s assume that the whole body weight (P) is located at the center of the ramp as indicated in the figure below.

\[
P_x = 600 \text{ lb} \\
P_y = 600 \sin \alpha = 598 \text{ lb} \\
P_x = 600 \cos \alpha = 49.8 \text{ lb}
\]

\[F_s = \text{Frictional Force}\]
**Summation of Forces and Moments:**

\[ \Sigma F_x = P_x - F_s = 0; \quad \Rightarrow \ F_s = P_x = 49.8 \text{ lb} \]

The frictional force is equal to the normal force times the coefficient of friction (\(\mu\)); therefore, we have that the required coefficient of friction for a static ramp is:

\[ \mu = \frac{F_s}{P_y} = \frac{49.8}{600} = 0.0825. \]

This coefficient of friction is smaller than that for rubber against ice (which is 0.15), which means that our scale will stay static almost anywhere it is placed. The bottom of the platform and the ramp will be coated with a rubber spray.

**Calculation of Stress:**

\[ c = \frac{0.25}{2} = 0.125 \text{ in} \]
\[ I = 1 \times 0.25^3 / 12 = 0.0013 \text{ in}^4 \]
\[ M = (698 \text{ lb}/2) \times 4.01\text{ in} = 2802 \text{ lb}\cdot\text{in} \]

\[ \sigma = \frac{Mc}{I} = \frac{2802 \times 0.125}{0.0013} = 268,961 \text{ psi} \]
Aluminum Alloy 6061 rectangular bar with a yield strength of 35,000 psi, will be used for the ramp.

**LCD Display Bar—Analysis:**

In order to analyze the LCD display bar we assume that the patient leans on the bar; the bar would be required to sustain a maximum load of 600 lbs. As such, the following calculations were done:
Aluminum Alloy 6063 with yield strength of 16,000 psi, would be used for the LCD Display Bar.

Side Bar Support Analysis:

\[ M = \frac{P \cdot h_d}{2} = \frac{600 \text{ lb} \cdot 50 \text{ in}}{2} = 15,000 \text{ lb} \cdot \text{in} \]
\[ c = 1.5 \text{ in} \]
\[ I = \frac{1}{12} \cdot (3^4 - 2.5^4) = 3.49 \text{ in}^4 \]
\[ \sigma = \frac{Mc}{I} = \frac{(15000 \text{ lb} \cdot \text{in}) \cdot (1.5 \text{ in})}{3.49 \text{ in}^4} = 6,447 \text{ psi} \]
In order to analyze for the worst case, all the of the Load (P) would be assumed to be located at the center of the bar as shown by the figure below.
Summation of Forces and Moments:

\[ P_y = W = 600 \text{ lb} \]

\[ P = \frac{W}{\cos 45^\circ} = \frac{600}{\cos 45^\circ} \equiv 850 \text{ lbs} \]

\[ + \sum F_y = 0 : 850 - R_A - R_B = 0 \]

25 in = 2.08 ft  
12.5 in = 1.04 ft

\[ \sum M_A = 0 : 850(1.04) - R_B(2.08) = 0 \]

\[ \Rightarrow R_A = R_B \equiv 425 \text{ lb} \]

Calculation of Stress:

\[ M = \frac{123 \times 850}{2} = 5525 \text{ lb } \text{ in} \quad c = 1.00 \text{ in} \]

\[ I = \frac{1}{4} \pi r^4 = (.25 \pi 1^4) - (.25 \pi .75^4) = .5369 \text{ in}^4 \]

\[ \sigma = \frac{Mc}{I} = \frac{5525 \times 1}{.5369} = 10,291 \text{ psi} \]

Steel Shim Bushing Stock Alloy 4130 with yield strength of 54,000 psi, would be used for the Side Bar Support. As shown the required strength is must less than the material's strength.
As mentioned before stops will be used to prevent rolling accidents. They will be soldered or welded around the platform. Aluminum Alloy 6061 Bar with yield strength of 35,000 psi, would be used for the Stops. The soldering material between metals and ceramics has a yield strength range of 44,000 to 116,000 psi, and an ultimate strength range of 51,000 to 150,000 psi. The welding product, Dura-FIX Rod, is made of a zinc base that welds metals, and it has a tensile strength of 47,000 psi, a compression strength of 75,000 psi, and a shear strength of 34,000 psi.

Load Cells

The use of load cells in electronic weight systems is nearly ubiquitous. At its most basic form, a load cell is simply a force transducer that converts a load into an electrical signal via a strain gauge. The strain gauge consists of a thin metallic foil that has been bonded to a dielectric layer. Dielectric materials transmit electrical force using induction rather than conduction. They do not make good conductors but can support an electrostatic field.
The resistance of the gauge changes proportionally when a force is applied to a strain gauge. If a voltage is applied during loading the change in resistance will alter the output voltage in a linear manner and the output can be used to calculate the applied force. However, the strain gauge is a delicate thin piece of wire and it cannot be deformed directly without failing. It must be mounted to a strain element using an adhesive. The shape of the strain element can vary; typically beams, rings, or columns are used depending on the function. The adhesives used and the mounting method will have the greatest effect on the quality of the load cell. If there is not a good bond between the two it will introduce errors into the calculations. The strain element and gauge are usually housed in a metal casing to prevent damage during use. Force is transferred inside via a button or similar part. Once the force is applied to the button it pushes on the strain element which deforms along with the strain gauge. Switching the position of the gauge allows the force to be measured under tension or compression.

A Wheatstone-Bridge is the only internal electrical component of the load cell. Each of the four legs is connected to a separate strain gauge and when an input voltage is applied the gain in the output becomes proportional to the load. The Wheatstone-bridge also serves to make the voltage output semi-linear.

In addition to the cell there are some peripheral components that allow the device to interface with a computer. The most common addition is an analog to digital converter that allows the cell to communicate directly with the computer. There may also be indicators, extra cables, printers and scoreboards that are used with the cell.\(^3\)
There are myriad types of load cells on the market but for the aforementioned design a miniature button load cell would be most suitable. Several different types of miniature cells are available, however, many are quite expensive. Ultimately the two main concerns for the load cell selection are cost and dimensions. The height of the scale is critical because, as stated before, the length of the ramp must be 12 to 1. Most of the cells researched were more than capable of accurately measuring the maximum weight outlined in the specifications. Based on these criteria, the final decision was an LCM302 series stainless steel compression load cell offered by Omega. Combining a low .5" profile with a comparatively low cost of $295 made this cell an ideal choice. There are several varieties of this cell that differ in maximum measurable weight but the 2kN, 450 Ibf, model is the most appropriate for this design. Other desirable features include a built-in button for simple operation, a five-point traceable calibration, and relatively high overload capacities. This cell functions in compression which is desirable for most scale types. Additional specifications and descriptions are:

![Figure 1.0 Miniature Button Cell](image-url)
SPECIFICATIONS

Excitation: 10 Vdc, 15 Vdc max - The voltage needed to run the cell.
Output: 1 mV/V (nominal) - A ratio of max output/input. Accuracy:
±0.5% FSO (linearity, hysteresis and repeatability combined) Zero
Balance: ±2% FSO - The amount of error with no load. Deflection:
0.025 to 0.075 mm - How far the cell button moves.
Operating Temp Range: -54 to 107°C (-65 to 225°F) - temperature limits.
Compensated Temp Range: 16 to 71 °C (60 to 160°F) - temperature for safe operation.
Thermal Effects: Zero: 0.009% FSO/°C Span: 0.036% FSO/°C -
Safe Overload: 150% of Capacity - The amount of sustainable overload that the cell can take with no resulting damage.
Ultimate Overload: 300% of Capacity - The maximum amount of overload the cell can take.
Bridge Resistance: 350 Ohms minimum - The minimum resistance in the Wheatstone-Bridge variable resistor.
Construction: Stainless Steel
Electrical: 1.5 m (5 ft) 4 Conductor Shielded Cable

There will be four load cells incorporated into the scale design. While it is only necessary to have three in order to calculate the applied force, four will be needed to maintain stability during loading. The cells will be positioned at the corners of the square plate as seen in the design schematics. To function properly
the cells require a rigid surface. Adding an entire second plate would be a waste of materials however, and four smaller square plates can function equally well.

**Power Systems**

The specifications for the wheelchair scale call for a device capable of operating on both AC and DC power. Therefore, a method must be determined to step down the voltage from both these sources to a voltage compatible with the electronics of the device. With the exception of the load cells, every chip should operate with a +5V power supply. Also, the fluctuation in the +5V supply should not be large enough to damage the electronic components.

To achieve a DC power level from an AC wall outlet, a power supply transformer will convert the 120 V 60 Hz signal into a 12V signal. The Phihong PSA-31U is a 20-30 Watt power supply with a DC output of 12V and a maximum output current of 2.5 A. The peak to peak ripple of this device is
only 120 mV, which is very stable, however an additional regulator can step the voltage down to the final 5V and provide additional power signal stability. In order to connect to the wall, the device requires an AC cord that is compliant with the IEC320 C13 grounded input terminal and a typical American wall outlet. Connecting the DC output of the supply to an electronic board requires a standard 2.1 mm ID, 5.5 OD, and 10mm length coaxial power connector.

The DC battery requirements of the system have not yet been determined. While at least 9V batteries are required for the electronic components, the load cells may require two batteries in series in order to maintain a 10V supply. Also, while the majority of the electronic should be capable of running off a single 9V battery, the LED backlight of the LCD display draws an unusually large amount of current and may require two 9V batteries in parallel. This uncertainty of the DC requirements can be better addressed when the device is assembled and the supply current can be measured. At this stage of design, the DC power systems simply need to be design with the proper voltage requirements and a significantly large current accommodation.

Linear voltage regulators are offered by a variety of companies and are available in many different output voltages. ON Semiconductor produces a 5V regulator with a 3A maximum output current capability. Since, the AC power supply can only provide a maximum of 2.5A the regulator adequately suits our output requirements. The regulator provides a line regulation of 1mV and a load regulation of 10 mV; these values are significantly small enough to prevent damage to the electronic components. Input into the voltage regulator will require a .33 uF capacitor since the AC power supply
filter could be a significant distance from the linear regulator. Also to prevent back current from damaging the batteries or the AC supply, 6A diodes will be placed to allow current to flow only from the batteries to the linear regulator or from the AC supply to the linear regulator. After the current limiting diodes, a SPDT slide switch will provide a power switch functionality to disconnect the power input to the linear regulator. The output of the linear regulator will have a 10 uF electrolytic capacitor which improves the transient response of the system during power-up and avoids harmful voltage spikes. It is also important that the inputs and output of the voltage regulator share a common ground, otherwise the regulator may not function within the specifications listed on the datasheet. Additional .1 uF capacitors will be connected between the power and ground pins of the electronic components to provide additional regulation of voltage spikes. This configuration should adequately convert either an AC or DC power signal to a 5V power signal compatible with the chips used in our design.
A PIC16F737 microcontroller was selected for this device for a variety of reasons. It contains eleven on board A/D converters which allows for multiple load cells if required. An internal oscillator block simplifies oscillator selection to a simple programmable selection. A USART interface allows the processor to access a computer through a serial port when the proper RS-232 interface chip is used. The SPI bus permits expansion of the device by allowing it to communicate with peripheral devices. And the multitude of general purpose I/O ports allows for an interface to the keypad and LCD display. Additionally, the 16F737 is equipped with microchips low power nanowatt technology to limit the power dissipation and increase electrical life when operating on battery power.

Interfacing the load cells with the PIC requires only four A/D converter ports. The output signal of the load cells must be limited to between zero and five volts in order to be compatible with the A/D converter. Therefore the output of the load cells must be examined and a suitable voltage divider network determined. Also, to allow the PIC to minimize power requirements of the entire scale, a block of four relays will connect to four of the general purpose I/O ports. When activated, these relays will connect a given load cell to its power source. Thus the load cells are only consuming power during a measurement operation. The program must wait a sufficient amount of time prior to executing the A/D converted cycle to avoid the transient response of the device. Also, the repeatability of measurements between power-up and power-down must be examined in order to determine whether the load cells must be constantly power between tare and measurement cycles.
The keypad will consist of up to sixteen over-travel pushbutton momentary switches. The over-travel functionality of the keys will allow filter unwanted keystrokes when a person with weaker motor control is accessing the device. The actual key is simple a small rod with a panel mount thread, therefore we must machine some sort of plastic key face that meets our specifications. Electrically, the keypad will be divided into a matrix with each row of four buttons connected to an output port on the PIC. Four PIC input ports will be connected to a 100Kohm pull-up resistor and a column of switch outputs. When one of the output ports is held high, if one of the keys is pressed, the signal on the corresponding input port will be pulled high. Therefore, pulsing the four output ports and listening to the four input ports can determine which of the sixteen buttons has been pressed. A potential problem may exist when keys from the same column but different rows are pressed since the current pulse will be driving the input line high but a different channel will be driving the line low. This will result in unexpected key decryption and the PIC may not decode the proper key value. Hopefully, the over-travel functionality of the keys selected will reduce the chances of this situation occurring.

An LCD display can require a large number of interface lines, however proper multiplexing design can reduce this value to a manageable value for the low pin count microcontroller we have selected. The Lumex LCD we selected has sixteen .4" characters on two lines with a yellow LED backlight. Contrast of the LCD is controlled using a potentiometer connected between the power supply and ground. Three control lines determine the register select, read/write, and enable functions of the LCD and must have dedicated input lines from the microcontroller. Data lines DB0 through DB7 can be
configured to only read the four rather than eight data lines. When only using four lines the other four lines are tied to ground. The four remaining data lines can actually be multiplexed with the four output lines going to the switches. As long as the LCD enable line does not go from high to low while the keys are being scanned, the data will not be clocked into the LCD. A fourth dedicated output line from the microcontroller will control a relay that activates the LCD’s backlight LED. Since the Backlight consumes 220 mA at 4.2V, the time that the backlight is enabled should be minimized.

Connecting the PIC to a serial port requires a RS-232 interface chip. The MAX220 offered by MAXIM electronics is a low power device capable of boosting the microcontroller output to the proper RS-232 signal levels using only a +5V supply. This chip only requires the USART Rx and Tx lines from the microcontroller.

Programming the PIC16F737 will be accomplished using the Microchip MPLAB ICD 2 module. This device requires two data lines from the microcontroller as well as a connection to the master clear port. If the device is designed with a socket for the microcontroller, a header connected can be place between the socket and the processor to debug and program the device. The socket can then be removed to restore functionality to the two pins lost to program the PIC.
Software Design

1. Initialize System
2. A/D conversion from load cells
3. Convert binary value to desired weight units
4. Decode keyed input
5. Decide to store data
   - True: Store weight data for a given patient
   - False: Decide output
     - Output data to LCD
     - Output data to Serial port
The program for the microcontroller will simply consist of an infinite loop that switches through various subroutines. First, the A/D converters digitize the signals from the four load cells and convert the signal into a weight. Second, a keypad algorithm decodes the user input from the keypad and translates that input into the proper action. Finally, the desired output in pounds or kilograms is sent to the LCD display and the serial port if those functions are enabled. After a given time interval of inactivity, the entire system should switch to a low power standby mode in which the contents of the system memory are saved, but power consumption is minimized. An interrupt will most likely be tied to one of the A/D converter ports connected to a load cell. When the value of the conversion switches beyond some threshold point the system will exit standby and resume normal operation.
**Mechanical Parts Budget:**

The following chart indicates the materials selected for our scale design that complied with our design specifications. **Total Mechanical Cost:**

$355.62

<table>
<thead>
<tr>
<th>Part's Name</th>
<th>Manufacturer</th>
<th>Material</th>
<th>Description</th>
<th>Part's Number</th>
<th>Yield Strength (psi)</th>
<th>Density (lb/in^3)</th>
<th>Dimensions</th>
<th>Units</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Platform</td>
<td>McMaster-Carr</td>
<td>Aluminum/ Thermoplastic Composite</td>
<td>Aluminum Sheet</td>
<td>2888K14</td>
<td>40,000</td>
<td>0.1</td>
<td>.118&quot; T, 48&quot; X 48&quot;</td>
<td>1</td>
<td>100.35</td>
</tr>
<tr>
<td>Bottom Platform</td>
<td>McMaster-Carr</td>
<td>Alloy 6061</td>
<td>Aluminum Sheet</td>
<td>89015K52</td>
<td>40,000</td>
<td>0.098</td>
<td>.063&quot; T, 36&quot; X 36&quot;</td>
<td>1</td>
<td>50.18</td>
</tr>
<tr>
<td>Ramp</td>
<td>McMaster-Carr</td>
<td>Alloy 6061</td>
<td>Aluminum Rectangular Bar</td>
<td>8975K444</td>
<td>35,000</td>
<td>0.098</td>
<td>1/4&quot; T, 8&quot; L, 3&quot; W</td>
<td>1</td>
<td>39.47</td>
</tr>
<tr>
<td>Side Bar</td>
<td>McMaster-Carr</td>
<td>Alloy 4130</td>
<td>Steel Shim Bushing Stock</td>
<td>8305T12</td>
<td>54,000</td>
<td>0.284</td>
<td>1&quot; ID, 1.47&quot; OD, 10' L</td>
<td>1</td>
<td>60.00</td>
</tr>
<tr>
<td>Stop</td>
<td>McMaster-Carr</td>
<td>Alloy 6061</td>
<td>Aluminum Rectangular Bar</td>
<td>8975K833</td>
<td>35,000</td>
<td>0.098</td>
<td>1/8&quot; T, 3&quot; W, 3' L</td>
<td>3</td>
<td>30.45</td>
</tr>
<tr>
<td>LCD Bar</td>
<td>McMaster-Carr</td>
<td>Alloy 6063</td>
<td>Aluminum Square Tube</td>
<td>88875K46</td>
<td>16,000</td>
<td>0.098</td>
<td>3&quot; X 3&quot;, .125&quot; Wall, 6' L</td>
<td>1</td>
<td>40.17</td>
</tr>
<tr>
<td>Rubber Coat</td>
<td>Premium Coatings</td>
<td>Asphalt emulsion, halogenated elastomer &amp; water</td>
<td>Liquid Spray Rubber</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>1</td>
<td>35.00</td>
</tr>
</tbody>
</table>

**Electronics Budget**

<table>
<thead>
<tr>
<th>Description</th>
<th>Stock num</th>
<th>Cost</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 V 2.5A External Power supply</td>
<td>(Allied) 653-0348</td>
<td>$27.59</td>
<td>1</td>
</tr>
<tr>
<td>Coaxial DC power connector</td>
<td>(Allied) 283-1510</td>
<td>$1.11</td>
<td>2</td>
</tr>
<tr>
<td>Item</td>
<td>Supplier</td>
<td>Part Number</td>
<td>Price</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>----------</td>
<td>-----------------</td>
<td>--------</td>
</tr>
<tr>
<td>Detachable Power Cord 9 10&quot;</td>
<td>(Digi-Key)</td>
<td>Q105-ND</td>
<td>$4.50</td>
</tr>
<tr>
<td>6A diode</td>
<td>(Allied)</td>
<td>266-0086</td>
<td>$0.46</td>
</tr>
<tr>
<td>6A 28VDC slide switch SPDT (power)</td>
<td>(Allied)</td>
<td>676-0250</td>
<td>$3.13</td>
</tr>
<tr>
<td>+3V 3A linear regulator</td>
<td>(Allied)</td>
<td>568-4682</td>
<td>$3.12</td>
</tr>
<tr>
<td>.33 uF ceramic axial</td>
<td>(Digikey)</td>
<td>1213phpct-nd</td>
<td>$3.06</td>
</tr>
<tr>
<td>.1 uF ceramic axial</td>
<td>(Digikey)</td>
<td>1210phpct-nd</td>
<td>$1.15</td>
</tr>
<tr>
<td>+8V 3A linear regulator</td>
<td>(Allied)</td>
<td>568-4690</td>
<td>$3.28</td>
</tr>
<tr>
<td>9V battery holder</td>
<td>(Allied)</td>
<td>839-1294</td>
<td>$1.05</td>
</tr>
<tr>
<td>10 uF aluminum electrolytic capacitor</td>
<td>(Allied)</td>
<td>613-0124</td>
<td>$0.05</td>
</tr>
<tr>
<td>Overtravel Pushbutton switch SPST?</td>
<td>(Allied)</td>
<td>676-9350</td>
<td>$5.25</td>
</tr>
<tr>
<td>DC relay 3-60V .02-1A</td>
<td>(Allied)</td>
<td>682-2102</td>
<td>$8.17</td>
</tr>
<tr>
<td>LCD</td>
<td>(Digikey)</td>
<td>LCM-S01602DSF/D-ND</td>
<td>$25.75</td>
</tr>
<tr>
<td>Single turn pot 10K</td>
<td>(Allied)</td>
<td>970-1031</td>
<td>$8.94</td>
</tr>
<tr>
<td>Wireless 916MHz antenna</td>
<td>(Digikey)</td>
<td>ANT-916-PML-ND</td>
<td>$7.61</td>
</tr>
<tr>
<td>Wireless TX</td>
<td>(Digikey)</td>
<td>TXM-900-HP3-PPQ-ND</td>
<td>$29.45</td>
</tr>
<tr>
<td>Wireless RX</td>
<td>(Digikey)</td>
<td>RXM-900-HP3-PPQ-ND</td>
<td>$45.15</td>
</tr>
<tr>
<td>DIP switches bank of 3</td>
<td>(Allied)</td>
<td>948-7638</td>
<td>$0.38</td>
</tr>
<tr>
<td>100k pot</td>
<td>(Allied)</td>
<td>754-3172</td>
<td>$2.31</td>
</tr>
<tr>
<td>100 resistor</td>
<td>(Allied)</td>
<td>296-0007</td>
<td>$2.31</td>
</tr>
<tr>
<td>MCP616</td>
<td>(microchip)</td>
<td></td>
<td>$0.61</td>
</tr>
<tr>
<td>MCP619</td>
<td>(microchip)</td>
<td></td>
<td>$1.20</td>
</tr>
<tr>
<td>PIC16F737</td>
<td>(microchip)</td>
<td></td>
<td>$3.35</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td><strong>$296.91</strong></td>
</tr>
</tbody>
</table>