Visual Output Weight Scale
For Wheelchair Users

Alternative Design #3

Team # 3

Fatima Muñoz
Chris Liebler

12/05/03
Project Description

Objective

The scale will use four Linear Variable Differential Transformers, or LVDTs, to measure the weight on the scale. The analog output of each LVDT will be connected to the Analog to Digital, or A/D, input of the microprocessor. From these inputs, the weight is calculated. This design will measure weight accurately without needing an exact system to position the center of gravity.

The user will be able to compensate for the weight of the wheelchair in one of two ways. The user may choose to enter the weight of the wheelchair manually through a user interface which employs three momentary pushbutton switches and a LCD display. The user also will have the option to calibrate the scale by placing the empty wheelchair on the scale and then weighing the subject and the wheelchair. These methods will allow the microprocessor to subtract the weight of the wheelchair from the total measured weight and display the weight of the subject.

The scale will be constructed of aluminum. The top surface will be diamond plate aluminum to provide a no slip surface. One of four LVDTs will be mounted in each corner of the scale. A ramp will allow the user to position the wheelchair on top of the scale platform.

Methods

This system will use four Linear Variable Differential Transformers, or LVDTs, to measure the weight on the scale. The LVDT measures small changes in displacement. The DC voltage at the output of the LVDT is directly proportional to displacement of the transducer. The ratio of change in output voltage to change in displacement is given by the manufacturer.

The weight will be determined by the displacement of four LVDTs. Each LVDT will be positioned next to one of the four springs in the scale. Since the spring constant \( k \) of the springs is known the force applied to the spring can be calculated using the displacement of the spring according to Hooke’s Law.

The DC analog output of each of the LVDTs will be connected to a low pass active filter. This will filter out 60 Hz line noise as well as vibration noise from small movements of the scale. The filtered signal is then passed on to the A/D input of the microprocessor. The microprocessor will perform an 8 bit A/D conversion. The change in voltage can be calculated. The voltage is used to calculate displacement. Then the force can be calculated using the ratio of
change in output voltage to change in displacement given by the manufacturer of the LVDT. Static analysis is used to calculate the sum of the forces on the LVDTs.

An LCD interface will prompt the user for input and display the weight. Since it is necessary to compensate for the weight of the wheelchair in the total weight measurement, two methods were developed to obtain the wheelchair weight.

The first method will prompt the user to enter the weight manually using the LCD interface. This interface shown in figure 2 below, will allow the user to adjust the weight of the wheelchair by pressing the + or – select buttons. When the displayed weight is correct the user will press the enter button to proceed to the weight measurement.

Figure 1. LCD interface

Enter Weight  +

-  

The second method requires the wheelchair to be weighed without the subject. The wheelchair is placed on the scale and the user presses enter. The weight is recorded and the user is prompted to proceed with the weight measurement.

With the weight of the wheelchair recorded by either the first or second method, the total weight is measured and recorded by pressing enter. The wheelchair weight is then subtracted from the total weight to give the weight of the subject.
Analysis

Force analysis of scale

Figure 2. Free body diagram of weight scale platform
\[ \Sigma F_y = B + A = 4P \]
\[ P = B/4 + A/4 \]

Therefore

\[ \Sigma My_{axis} = B*17" + A*d - 2P*34" = 0 \]
\[ = 17B + Ad - 68P = 0 \]
\[ d = -(17B)/A + (68P)/A \]

where, 
- B = weight of platform
- A = weight of wheel chair and person
- P = force exerted at each spring
- d = desire distance of positioning of the wheel chair on the scale (center of gravity)

For example:

A subject that weights 140 lbs sits on a wheel chair that has a mass of 100 lb gets on the weight scale. Given that the platform weights 20 lb. then A = 240 lb and B = 20lb.

\[ \Sigma F_y = 20 + 240 = 4P \]
\[ P = 20/4 + 240/4 = 65 \text{ lb.} \]
\[ \Sigma My_{axis} = B*17" + A*d - 2P*34" = 0 \]
\[ = 17B + Ad - 68P = 0 \]
\[ d = -(17B)/A + (68P)/A \]
\[ d = -340/240 + 4420/240 = 17" \]

Since Platform is symmetrical there is no need to find the “d” for the y direction, we just assume that is also 17”.

Ultimately theoretically is found that, the center of gravity of the total weight of the wheel chair with the subject on it should be placed right at the center of the platform for each reading at the LVDT to be equal.
The LVDT will measure the force exerted at each point. See Figure 3 below.

**Figure 3. Diagram of force exerting at each spring**

According to Hook’s Law:

\[ F = kx \]

Where,

- \( k \) = spring constant
- \( x \) = displacement of spring
- \( F \) = force exerted at each spring

Given a desired spring \( k \) can be calculated by analyzing the maximum force and the maximum room for displacement of the LVDT. That is:

\[ k = \frac{F_{\text{max}}}{X_{\text{max}}} \]

The maximum force is obtained from the specifications of the desired LVDT, the displacement maximum is specified when buying the LVDT. Once \( k \) has been found, further force findings can be made only with the information of the displacement.

In this way, a specific positioning of the wheelchair user is not critical since each reading of the LVDT at the springs will be independent from each other and the sum of the forces will add up to the total weight.
Analysis of Electronics

Figure 4 below shows the schematic diagram for the LVDT scale system. Calculations for all component values are shown after the schematic. Components that have identical values have been given the same component number to simplify the diagram.

Figure 4. Schematic Diagram
• Calculations for the low pass filters.

Assume \( f_0 = 5 \text{ Hz} \) Choose \( C_1 = 3.3 \mu \text{f} \)

\[
f_0 = \frac{1}{2\pi R_1 C_1}
\]

\[
5\text{Hz} = \frac{1}{2\pi R_1 (3.3 \mu \text{f})}
\]

\( R_1 = 9.65K \Omega \approx 10.0K \Omega \)

A value of 10K is chosen because it is more commercially available.

Choose Gain = 1 and \( R_2 = 100 \)

\[
Gain = 1 + \frac{R_f}{R_2} = 1 + \frac{100}{R_2}
\]

\( R_2 \approx 10.0K \Omega \)

\[
P = \frac{V^2}{R}
\]

\[
P_{R_1} = \frac{5V^2}{10.0K \Omega} = 5.0mW
\]

\[
P_{R_2} = \frac{5V^2}{10.0K \Omega} = 5.0mW
\]

\[
P_{R_f} = \frac{5V^2}{100\Omega} = 100mW
\]

• Calculations for A/D input current limiting resistors

The maximum current for the A/D port is 25 ma.

Choose a current of 1.0 ma for each input

The maximum voltage will be the supply voltage of 5.0v.

\[
R_3 = \frac{5.0V}{1.0 \text{ma}} = 5.0K \Omega
\]

\[
P_{R_3} = 1.0\text{ma} \cdot 5.0V = 5.0mW
\]

• Calculations for pull up resistors.

The suggested input current for a high input on Port B is 0.05ma.
A digital high is 5v.

\[
R_4 = \frac{5.0V}{0.050 \text{ma}} = 10K \Omega
\]
$P_{R_i} = 0.050mA \cdot 5.0V = 0.25mW$

- Microprocessor input voltage calculation

$V_{in} = b \cdot \frac{5.0V}{255}$

$b$ is value of the stored voltage value. 255 is the number of binary combinations possible for an 8 bit value.

The displacement $x$ is calculated using the constant of the LVDT which is given in in./v and $V_{in}$

$x = V_{in} \cdot \frac{1,000\text{mV}}{v} \cdot \frac{\text{in.}}{\text{mV}} = \text{in.}$

The displacement value is used to calculate the force on each sensor using the spring constant $k$. $f_n$ is the force on LVDT $n$.

$f_n = k \cdot x$

This calculation is performed for each load cell. The total force is equal to the sum of the forces at each sensor.

$\sum_{n=1}^{4} f_n = f_1 + f_2 + f_3 + f_4 = f$
Microprocessor Code
Figure 5. Microprocessor Flow Diagram

Power on / Reset

Display "Select mode"

Mode A

Input?

Display "TARE Mode
Place Chair on
Scale and Press
Enter"

No

Yes

Calculate force &
Store Value XVAR

Display "Get on
Scale and Press
Enter"

Input?

No

Yes

Display "Value of
YVAR-XVAR"

Mode B

No Input

Display "Manual Mode
adjust weight and
Press Enter"

No

Yes

Increment or
Decrement value
and Store Value
YVAR

Input?

No

Yes

Display "Press Enter"

Input?

No

Yes

Calculate force &
Store Value YVAR

Display "Value of
YVAR-XVAR"
Budget

The cost of the project is estimated below in table 1. The total cost of the project has been estimated at $1,135.74

Table 1. Projected cost

<table>
<thead>
<tr>
<th>Part</th>
<th>Metals Depot</th>
<th>Manufacturer</th>
<th>Description</th>
<th>Unit Price</th>
<th>#</th>
<th>Extended Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 K resistor</td>
<td>1.0KQBK-ND</td>
<td>Yageo</td>
<td>1.0K OHM 1/4W 5% CARBON Film</td>
<td>$0.02</td>
<td>2</td>
<td>$0.04</td>
</tr>
<tr>
<td>1M resistor</td>
<td>1.0MQBK-ND</td>
<td>Yageo</td>
<td>1.0M OHM 1/4W 5% CARBON FILM</td>
<td>$0.02</td>
<td>4</td>
<td>$0.08</td>
</tr>
<tr>
<td>Rocker Switch</td>
<td>EG1890-ND</td>
<td>E-Switch</td>
<td>ROCKER SWITCH DPDT 10A</td>
<td>$4.73</td>
<td>1</td>
<td>$4.73</td>
</tr>
<tr>
<td>IC Socket</td>
<td>2-641268-1-ND</td>
<td>AMP/Tyco Electronics</td>
<td>40 Pin DIP Socket</td>
<td>$1.29</td>
<td>1</td>
<td>$1.29</td>
</tr>
<tr>
<td>Capacitor</td>
<td>P10321-ND</td>
<td>Panasonic - ECG</td>
<td>CAPACITOR 25V 47UF ELECTROLYTIC AXIAL</td>
<td>$0.42</td>
<td>2</td>
<td>$0.84</td>
</tr>
<tr>
<td>Resonator</td>
<td>X902-ND</td>
<td>ECS Inc.</td>
<td>RESONATOR 4.00MHZ CERAMIC W/CAP</td>
<td>$0.68</td>
<td>1</td>
<td>$0.68</td>
</tr>
<tr>
<td>Voltage Regulator</td>
<td>296-1974-5-ND</td>
<td>Texas Instruments</td>
<td>IC 5.0V 1.5A REGULATOR TO-220AB</td>
<td>$0.76</td>
<td>1</td>
<td>$0.76</td>
</tr>
<tr>
<td>Box</td>
<td>377-1216-ND</td>
<td>Bud Industries</td>
<td>BOX ABS TEXT TOP 4.6X3.1 X 1.87&quot;</td>
<td>$7.20</td>
<td>1</td>
<td>$7.20</td>
</tr>
<tr>
<td>PCB</td>
<td></td>
<td>ExpressPCB</td>
<td>PCB</td>
<td>$98.62</td>
<td>1</td>
<td>$98.62</td>
</tr>
<tr>
<td>Microprocessor</td>
<td>PIC16F874-04/P-ND</td>
<td>Microchip Technology</td>
<td>PIC16F87x 8-Bit CMOS FLASH with 10-Bit A/D</td>
<td>$7.78</td>
<td>1</td>
<td>$7.78</td>
</tr>
<tr>
<td>LED</td>
<td>L10001-ND</td>
<td>Chicago Miniature Lamp, Inc</td>
<td>LEDs - PCB &amp; Panel Mount</td>
<td>$1.33</td>
<td>1</td>
<td>$1.33</td>
</tr>
<tr>
<td>LCD</td>
<td>67-1758-ND</td>
<td>Lumex Opto/Components Inc</td>
<td>LCD Display 16 x2</td>
<td>$13.36</td>
<td>1</td>
<td>$13.36</td>
</tr>
<tr>
<td>Power Supply</td>
<td>T920-P5P-ND</td>
<td>CUI Inc</td>
<td>TRANSFORMER 5V 2.4A</td>
<td>$14.03</td>
<td>1</td>
<td>$14.03</td>
</tr>
<tr>
<td>LVDTs</td>
<td>356-1002-ND</td>
<td>Schaevitz Sensors</td>
<td>SENSOR GAGE HEAD PCA-116 2.5MM</td>
<td>$100.00</td>
<td>4</td>
<td>$400.00</td>
</tr>
<tr>
<td>Plate Aluminum</td>
<td>P418</td>
<td><a href="https://www.metalsdepot.com">https://www.metalsdepot.com</a></td>
<td>1/8&quot; Diamond Plate Aluminum 2'x4&quot;</td>
<td>$72.00</td>
<td>1</td>
<td>$72.00</td>
</tr>
<tr>
<td>Labor</td>
<td></td>
<td>Machine shop</td>
<td>Machine shop labor and supplies</td>
<td>$500.00</td>
<td>1</td>
<td>$500.00</td>
</tr>
<tr>
<td>Wheel</td>
<td>1G025 1G027</td>
<td>Grainer-Wagnerer</td>
<td></td>
<td>$13.00</td>
<td>1</td>
<td>$13.00</td>
</tr>
</tbody>
</table>

Total cost $1,135.74
Conclusion

The LVDT design will take accurate weight measurements regardless of where the subject is positioned on the platform. This is due to the force measurement at four points instead of one or two points. The calculated ramp angle will only have a magnitude of $10.62^\circ$, which is very small and facilitates the access of the wheelchair user onto the ramp. This device will have two wheels and a handle to facilitate transportation.

The electronic portion of this design would accept input from four LVDTs and display the output in an easily read format. The cost of parts is very low. Keeping the electronics to a minimum would also keep the design light enough to be easily transported. Since the cost to build this design would be less than the total budget, there will be room in the budget for additional features if there is available development time. There will also be money for unexpected development costs.