Accessible Weight Scale for Seated Users

By James I. Johnson
Patrick Tshilenge
Gregory Whitehouse
Team 9

Client: RERC-AMI
Client Contact: Dr. Enderle
University of Connecticut
Bronwell Building, Room 217C
260 Glenbrook Road
Storrs, Connecticut 06269-2247
Phone: (860) 486-5521

1. *Alternative Design Project # 3*

Introduction

The clients for the accessible weight scale for seated users all have mobility problems that make it difficult for them to use a standing scale. These clients may want to measure their weight several times a day in order to ensure that they are remaining healthy. The design for the accessible weight scale for seated users will integrate a weight scale into an elevated toilet seat allowing the user to easily and independently measure their weight. The elevated toilet seat scale will have several main components an elevated toilet seat, load cells, a microcontroller, a mounted user interface, and adjustable and removable posture support.

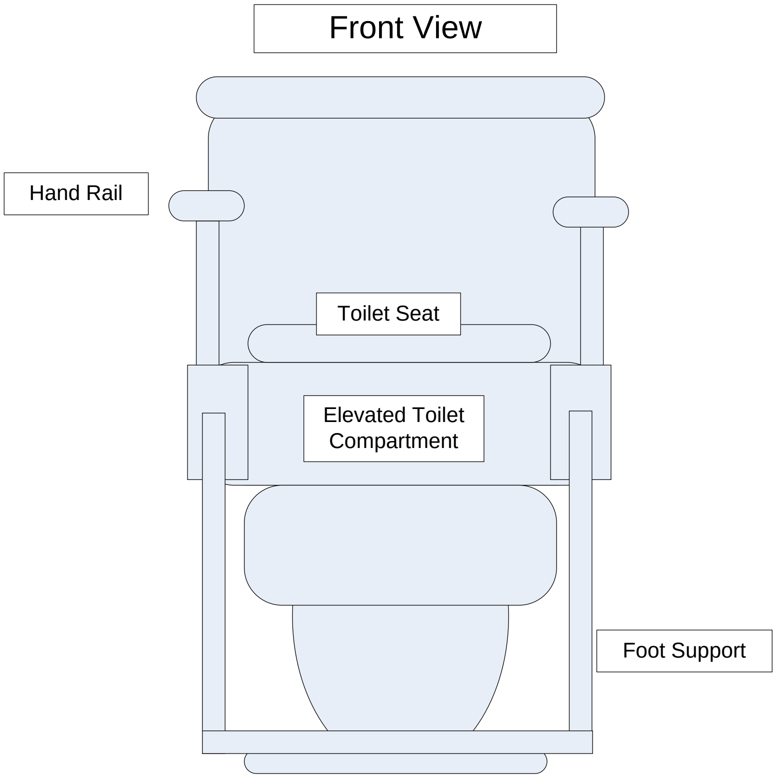

Figure 1 – Alternative Design 3 Elevated Toilet Seat Scale

Figure 1 shows the overall appearance of the elevated toilet seat scale. The scale will have a total capacity of over 500 pounds, an accuracy of 1/5 of a pound, and enough memory to store 15 readings for five different users. The scale will also be able to take a measurement in less than 10 seconds and it will provide visual and audio outputs.

This alternative design makes use of adjustable and removable handrails and foot support. By making the handrails and foot support adjustable the device will be more convenient for a wide range of users. By making the handrails and foot support removable the device will be easier to move from one toilet to another. Also many clinical settings already have grab bars mounted on the wall, which may be more convenient to use than the hand rails mounted on the toilet seat. Once the removable handrails are removed the user can use the mounted grab bars more conveniently.

The elevated toilet seat serves several purposes. By being elevated it puts the toilet at a similar height to a wheelchair seat allowing the user for easier transfer on and off of the toilet. Similar to other elevated toilet seats currently on the market, this elevated toilet seat will be 5 inches tall. The elevated toilet seat will also house the electronic components in this design as well as acting as the support structure for the handrails and foot support. A third purpose for the elevated toilet seat is to act as the comfortable seat for the user and mounting surface for the load cells.

Three load cells will be used to measure the weight of the user. They will be loaded on the bottom of the elevated toilet seat similar to the first design. The load cells will measure the compression force applied by the user on the elevated toilet seat and send the signal through wires to the printed circuit board (PCB) inside the elevated toilet seat. A waterproof plastic will be used to cover the load cells to prevent them from becoming wet.

Also incorporated into the elevated toilet seat compartment will be the microcontroller, which will be responsible for converting the signal from the load cells into a weight measurement that can be stored in the microcontroller and outputted in both kilograms and pounds. These outputs will be sent to the mounted display via a wireless transmitter.

The purpose of the mounted display is to act as the user interface for the accessible weight scale for seated users. The user can use this component to take a measurement or to view past readings. The mounted display can be mounted on either of the two handrails, whichever is more convenient for the user. It can also be mounted to the wall if a different attachment mechanism is used.

Figure 2 shows a block diagram of the operation procedure for the accessible weight scale for seated users below. The user inputs are shown in blue outlined rectangles with rounded edges and the actions completed by the accessible weight scale are shown in rectangular boxes with sharp edges.

Prior to using the device for the first time the user will have to turn the device on and press the “Tare” button on the mounted display. Pressing this button will cause the scale to take a measurement without the user on the device. This measurement will be stored in the microcontroller as the weight of the scale alone. This weight will be subtracted from the user’s weight when a measurement is taken so that the weight outputted by the device is the weight of the user alone. To provide the most accurate measurement the user could tare the device prior to every use, but it is not necessary if a small amount of error is allowable.

To operate the device the user will simply get on the device. When the user gets on it will cause compression of the load cells which will result in the device powering on. Next the liquid-crystal display (LCD) screen interface will display the message “Please press user number button.” Once the user presses one of the five user number buttons located on the mounted display the LCD screen will tell the user, which user number has been selected and prompt the user to press the measure button if this number is correct or to press another user number button if it is not correct. If the user presses another user number button then the prompt will reappear with the new user number. These prompts will also be given in the form of audio output by the text to speech device housed within the mounted display. The user with impaired vision will receive the prompt as well.

If the user number is correct the user now has two choices. He or she can press the “Measure” button or they can press the “Up” or “Down” arrows to view past measurements.

To take a new measurement the user will press the “Measure” button. At this point the load cells underneath the elevated toilet seat will send the reading to the microprocessor, which will subtract the current weight from the weight of the scale. This will be the measurement of the user’s weight, which will be converted into kilograms and pounds, stored in the memory, and displayed for the user on the LCD screen as well as the audio output through the speaker. The user now has the option of turning off the device or viewing past measurements.

The user can scroll through past measurements by pressing the up or down arrow on the user interface. These weights will be displayed in both kilograms and pounds on the LCD screen and the measurements will be outputted by the text to speech device as well. Figure 2 shows the block diagram of the process outlined above.

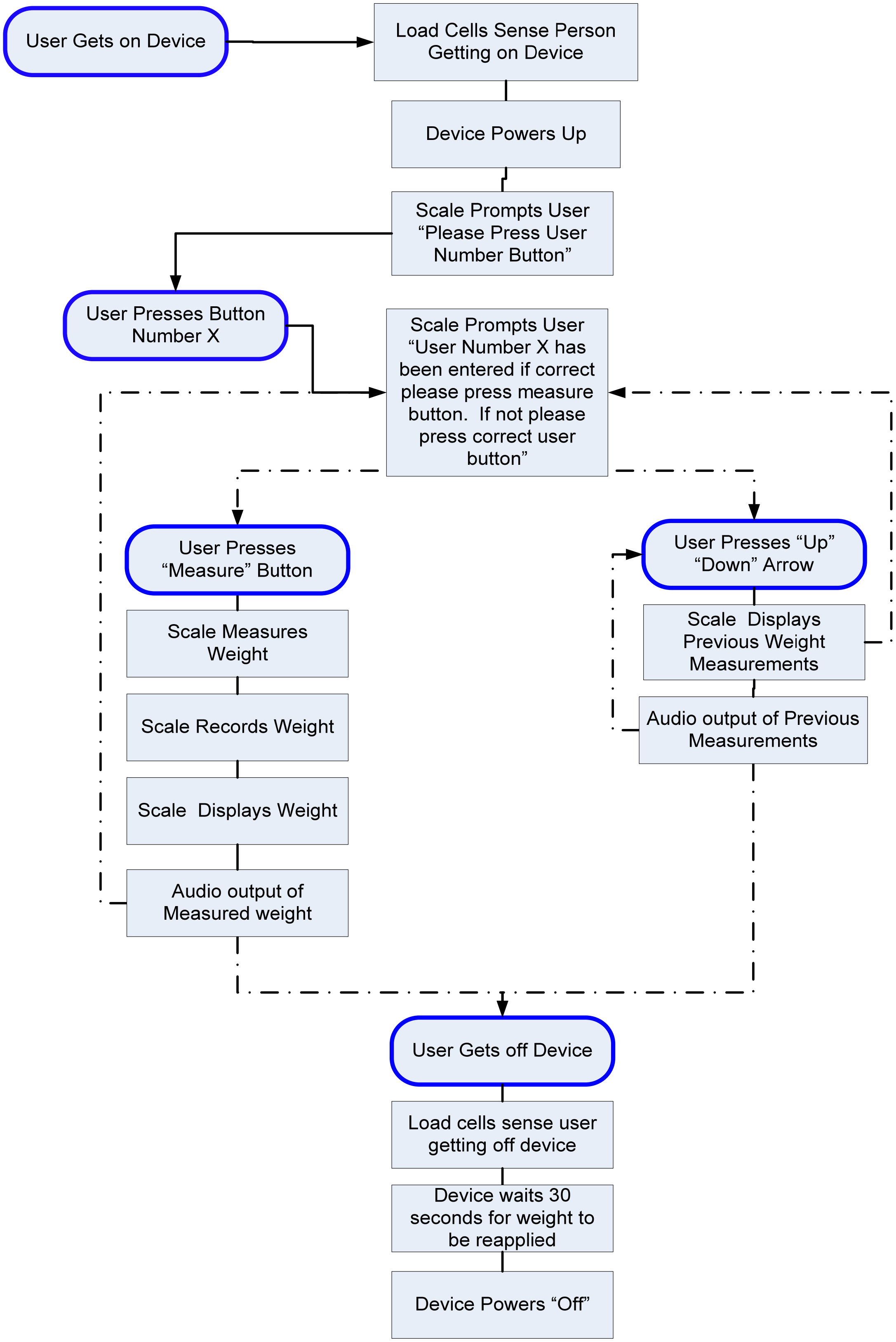

Figure 2 – Block Diagram of Operation Procedure

The elevated toilet seat scale is different from the other two accessible weight scales for seated users in that it makes use of an elevated toilet seat, adjustable and removable posture support, a mounted display, and it turns on as soon as the user gets on the device. Probably the largest difference between this design and previous designs is that it will be able to store readings for up to five different users.

1.2 Subunits

Load cells

The function of the load cells is to measure the compression force of the user sitting on the toilet seat. This compression force is changed into an electrical signal which is then sent to the electrical toilet compartment via wires, and input into the A/D conversion ports on the microprocessor for conversion of the analog signal to a digital signal. Most load cells are based off of traditional strain gauges, and utilize strain gauges to provide accurate measurements. The strain gauge has a thin metallic foil that is bonded to a dielectric layer, which transmits the electrical signal using induction. This involves the electrically charged film to create an additional electrical charge, which is sensed by the strain gauge. When a force is applied to the strain gauge, the foil is deformed causing a change in its electrical resistance. A Wheatstone Bridge then measures the changes in resistance, and relates this value to the gauge factor, where GF = (ΔR/R)/(ΔL/L). A figure showing the related forces and dimensions of strain is shown on the following page:

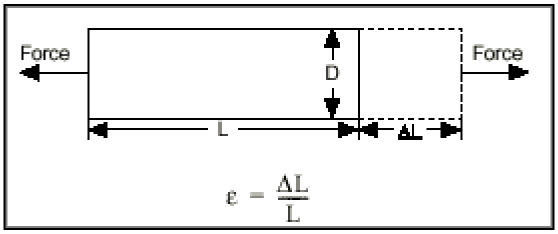

Figure 3 – Strain Specification [1]

The Wheatstone Bridge consists of four resistive arms with a voltage excitation source. When the excitation voltage is applied across the bridge the output voltage will equal the following equation:

$$V_O = \left[\frac{R_3}{R_3 + R_4} - \frac{R_2}{R_1 + R_2}\right] \bullet V_{EX}$$ [2]

The output voltage can then be used to calculate the applied force onto the strain gauge. The output voltages of strain gauges is usually quite small; therefore, the output signal will have to be amplified to boost the signal level for an increase of measurement resolution and improved signal to noise ratios. The amplification will also allow for the microprocessor to receive the appropriate minimum current for A/D conversion of the signal. Also, as with many electronics, there will be noise that can couple to the strain gauges. Therefore, a low-pass filter will have to be implemented to remove the high frequency noise associated with the electronics and environment.

In order to function correctly, the strain gauge must be mounted to a strain element using an adhesive due to the delicacy of the thin piece of wire within the gauge. The strain gauges that are intended for use in the project utilize a simple beam mounting configuration. This configuration, along with the proper adhesive, should allow for high accuracy and little error in the calculations. The strain gauge and element will have to be housed in either a laminate material or metal casing in order to prevent shock to the load cell, as well as adequate prevention of contact with liquids.

There are numerous different load cells available on the market, but for the design project the SMD Sensors S400 Button Cell load cell has been chosen in order to provide optimal functionality while being relatively cost-effective. An initial search for load cells resulted in many high capacity rated load cells that were very expensive. The S400 Button Cell, rated at a capacity of 500 pounds, has a cost of $350 per load cell. The group intends to implement three load cells for the design and manufacture of the device. Three of the load cells, all rated at 500 pounds capacity, will provide optimum weight measuring capacity and accuracy. Also, the S400 Button Cells are quite small and have a low-profile appearance, which will allow for the placement of the load cells on the bottom of the elevated toilet compartment; thereby, mimicking the actual stops or cushions on the underside of a toilet seat. As previously mentioned, proper adhesive will have to be used to mount the load cells to the bottom of the elevated toilet compartment, and small circular stops will have to be placed on the top, flat portion of the toilet bowl where the load cells will undergo compression when the user is seated on the seat. This will result in unwanted slippage of the elevated toilet compartment, and consequently the load cells, when the toilet seat is down and weighing is taking place. It will also provide accurate calibration of the load cells when the user tares the weight scale. A picture of the load cell and its related specifications are shown below and on the following page:

Figure 4 – S400 Button Cell Load Cell

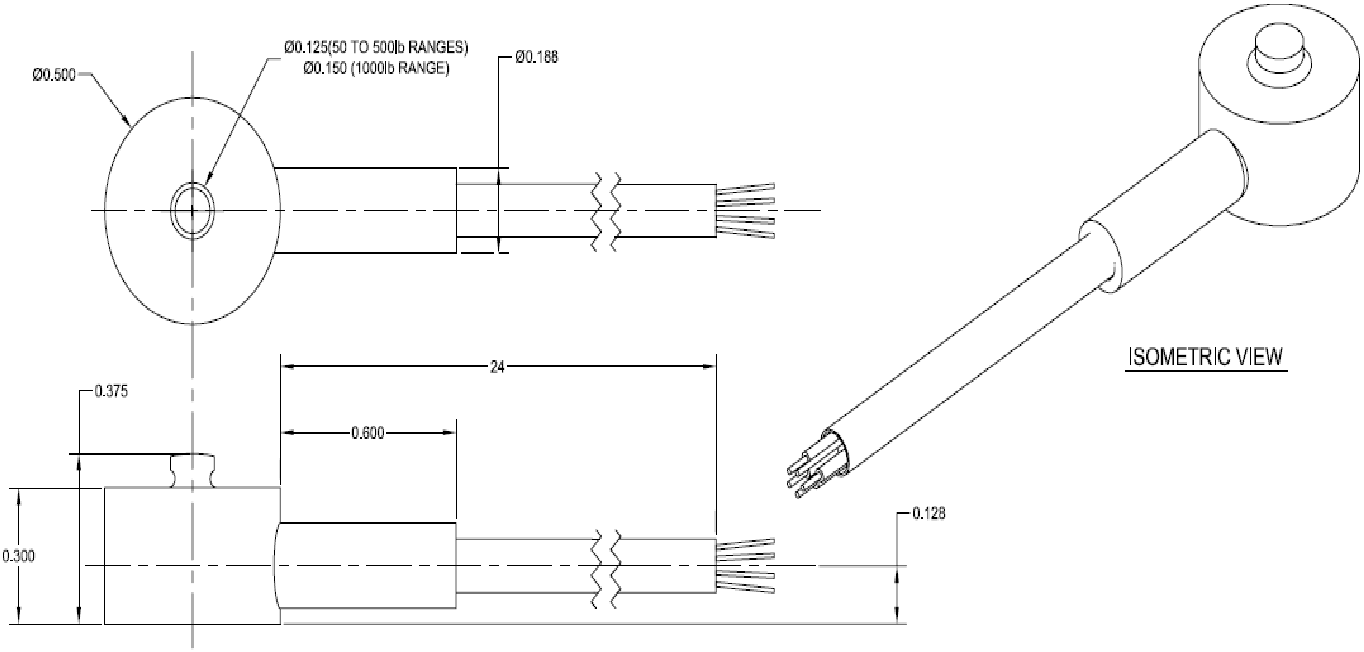

Figure 5 – S400 Button Cell Isometric View and Dimensions

Specifications

Performance	
Nonlinearity	< 0.1 % Rated Output (R.O.)
Hysteresis	< 0.05 % Rated Output (R.O.)
Nonrepeatability	< 0.03 % R.O.
Static Overload	
Safe	150 % Rated Capacity (R.C.)
Temp. Effect on Zero Balance	
Standard	< 0.038 % R.O. / °C
Temp. Effect on Output	
Standard	< 0.025 % Reading / °C
Body Material	17-4 PH stainless steel
Electrical	
Rated Output (R.O.)	2 mV / V nominal
Excitation	
Recommended	10 Vdc
Maximum	15 Vdc
Bridge Configuration	Full Wheatstone Bridge

Bridge Resistance	350 ohms
Insulation Resistance	>1,000 MΩ @ 50Vdc
Electrical Termination	Shielded 28AWG 4C cable with drain wire, 24" long
Mechanical (Please order in lbs,	e.g. S400-250 lb)
Rated Capacity, Newtons	245, 445, 1,130, 2,255, 4,500
Rated Capacity, kg-force	25, 45, 115, 230, 460
Rated Capacity, lb-force	50, 100, 250, 500, 1,000

Table 1 – Specifications for S400 Button Cell Load Cell [3]

A very significant part of the third alternative design, especially concerning electronics and electrical components, is keeping the elevated toilet seat scale as waterproof as possible. This is quite necessary when considering the mounting and placements of the three load cells. As previously mentioned, the load cells will be mounted to the bottom of the elevated toilet compartment. They will have to be fastened, with waterproof adhesive and sealant, into circular holes that meet the radiuses of the button cells. This setup will allow for the button parts of the load cells to face down and undergo the compression of the user sitting on the elevated toilet seat, which will then result in the weight measurement. The S400 Button Cells will have to be covered with a thin plastic film in order to keep water or condensation from contacting the load cells. The plastic covering will have to be thin enough to allow for accurate load cell measurements, while not disrupting the distribution of forces when the user is sitting on the toilet seat. The shielded wires from the load cells will enter directly into the elevated toilet compartment for input into the A/D pins on the microcontroller, and the compartment will ultimately be the housing of the electronics and electrical components.

Elevated Toilet Seat Component

The elevated toilet seat will be mostly constructed in the machine shop. It will consist of several different parts. The elevated toilet seat will have a normal toilet seat with hinged cover for the user to comfortably sit on. This will be attached as a normal toilet seat would with a hinge and a toilet seat cover. The toilet seat that will be purchased for this design is shown below in Figure 6. It comes with non-corrosive hardware to attach the seat on top of the rest of the device.

Figure 6 – Bemis 500PRO Round Wood Toilet Seat

Figure 7 below is a diagram of how the elevated toilet seat will appear. The toilet seat will be fastened to the top of the device using a hinge similar to how a toilet seat is normally fastened to a toilet. The prototype for this device will incorporate all of the electrical components inside the elevated toilet. The elevated toilet encasing will be made of thick Plexiglass encasement with high tensile strength and bend modulus. Having a clear casing will allow people to view the electronics housed within without taking the device apart. When the device is made for market it will use a different material for the encasement that is equally sturdy, but more aesthetically pleasing. The encasement will have a hole in the middle the same size as the Bemis toilet seat. The sides of the encasement will extend farther than the sides of the toilet seat. The handrails and foot support will fit into slots in the extended portion of the encasement. How the handrails and foot support will be fastened in these slots is discussed in the posture support section of this paper. As described above the load cells will be attached to the bottom of the encasement in between the encasement and the toilet.

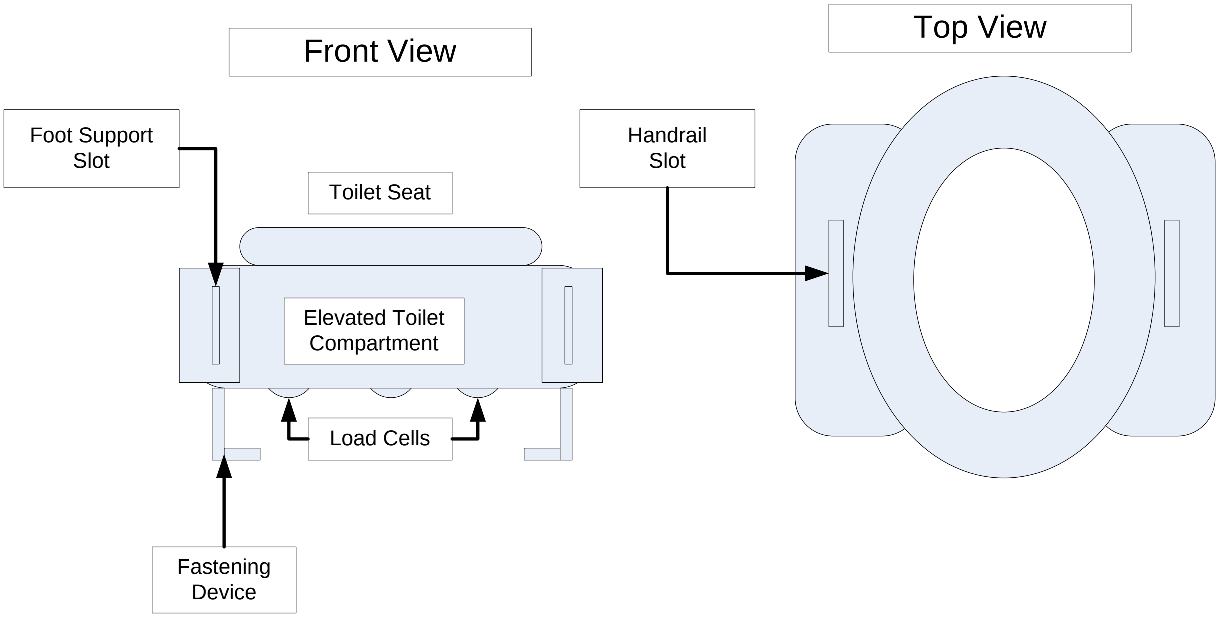

Figure 7 – Elevated Toilet Seat Design

The encasement will be fastened to the sides of the toilet using four fastening mechanisms located at the four corners of the elevated toilet seat. The fastening mechanism is shown below in Figure 8. The rubber stopper will act as the interface between the fastening mechanism and the toilet. The fastening device will hold the seat in place without affecting the readings from the load cells. The fastening mechanism will be attached to the toilet seat using a two screws and a metal plate. The handle will go through a hole in the screw and will be turned to extend the rubber stopper toward the toilet seat or retract it from the toilet seat.

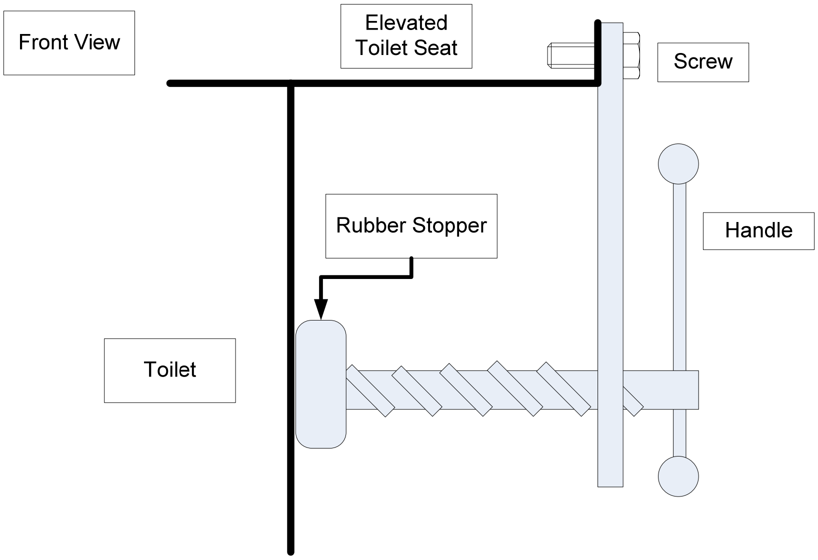

Figure 8 – Fastening Mechanism for Elevated Toilet Seat

The elevated toilet seat will contain the “guts” of the device, including the printed circuit board (PCB) and related electrical components, batteries, wires, and wireless transmitter that will communicate to the mounted display. The bottom panel of the elevated toilet seat will be removable to allow for easy access to the circuit within; thereby, allowing for necessary modifications or repairs to the electrical circuit board or PCB. This part of the electrical component compartment will not be accessed by the user, but by an individual who is familiar with electronics and electrical components in the event that a modification or repair is needed. It will also need to be lined with a weather stripping in order to prevent water from entering into the electrical component compartment. There will also be another easily accessible compartment on the front of the elevated toilet seat compartment that will allow the user to easily change the batteries when necessary. This accessible battery compartment will also need to be lined with weather stripping in order to prevent liquid or condensation from entering the compartment and subsequently damaging the batteries. An example of the circuit schematic for the power supply to the microcontroller is shown and explained on the following page:

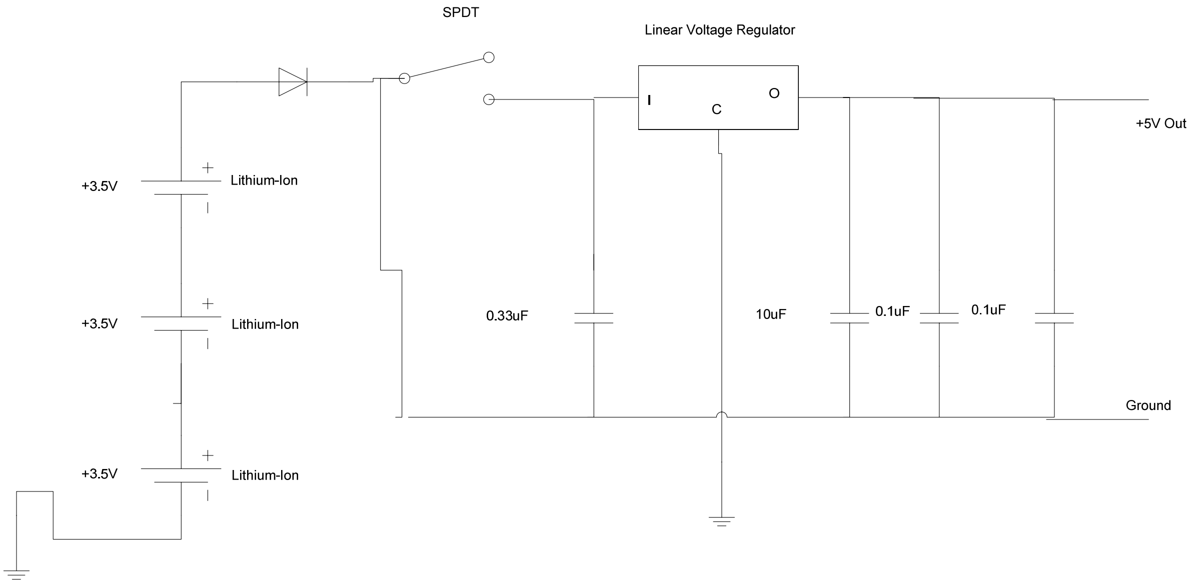

Figure 9 – Example of Power Supply to PIC Circuit

Three lithium-ion batteries will be wired in series and used as the power supply for the device. They are rated at approximately 3.5V a piece; therefore, a voltage of about 11.5V will be output from the three batteries mimicking a 12V DC power supply. A current limiting diode will be placed after the batteries and before the switch for prevention of electrical damage to the batteries. A single-pull-double-throw switch (SPDT) will be placed after the diode in order to function as a disconnection of power to the linear regulator. Since the device will be turning on automatically when the user sits on the toilet seat, the excitation of the load cells will trigger a flow of voltage to the SPDT switch, which will then power on all of the components of the device. For input into the voltage regulator, a 0.33uF capacitor will be necessary to filter out unwanted spikes or noise in the signal that could occur after the switching. After the linear voltage regulator will be a 10uF capacitor that will filter out any more unwanted voltage spikes that could occur after the switching and power up. Also, the input and output pins of the linear voltage regulator will have to be grounded to a common ground to provide the true functionality of the regulator, thereby supplying the desired 5V output. Finally, two 0.1uF capacitors will be placed after the 10uF and will be connected to the power and ground pins of the electrical components to filter out additional noise and voltage spikes. The circuit will be necessary and will work to down regulate the 11.5V from the lithium-ion batteries to provide the 5V output necessary for supply to the microcontroller and electrical components.

All of the electrical components included in the elevated toilet compartment will need to be tested on a protoboard prior to ordering the printed circuit board so that the group is ensured the correct PCB schematic is sent. A standard smoke test will have to be performed to make sure that all of the electrical components are functioning correctly and will function correctly when eventually connected to the PCB. A digital multi-meter will be used to check voltages, currents, and resistances throughout the protoboard to make sure that they meet the specifications of the various chips and linear voltage regulator, and so that there are no short circuits throughout the circuit.

The structural integrity of the elevated toilet seat will be tested similarly to the toilet seat in the first alternative design. The device will be tested with varying weights to ensure that the device can hold over 500 pounds and that the load cells will be able to measure that weight accurately and efficiently.

Handrails

The purpose of the handrails is to aid the user in getting on and off of the device and to maintain their posture while the device is in use. Some of the users have limited strength in their legs. The handrails will allow them to grip a component of the device and support their weight while transferring on and off of the scale. Users who have trouble sitting straight up may need this added support. The hand rails will be adjustable to accommodate the multiple types of users. The handrails will also be removable to allow the user to more easily transport the whole device to other settings. The user may also wish to use previously installed grab bars and transfer bars in a handicap accessible water closet. Thus, the added handrails of this device could be inconvenient and the user may wish to remove them.

The handrails will most likely be constructed in the machine shop. They will be made of steel because of steels high tensile strength and corrosion resistance. The handrails will be inserted into the top slots of the elevated toilet seat. The handrails will have periodic holes in the center of bar. When the handrails pass through the slots it will be possible to match up these holes with holes made in the side of the elevated toilet compartment. A steel pin can be placed through these holes in order to fasten the handrails into position and make the handrails adjustable. The holes in the elevated toilet compartment will not go all the way through to where the electrical components are stored. That compartment will remain water resistant.

The handrails will also have a rubber gripping surface at the top in order to allow for comfortable gripping. This rubber surface will also help with the comfort of the user since metal tends to be cool if the surrounding temperature in the bathroom is cool.

The handrails will apply a vertical downward force on the toilet seat. When in use the weight applied to the handrails will be incorporated with the rest of the weight of the user. The vertical resistance of the hand rail will be tested by applying 250 lbs on each hand support. For the lateral resistance test a hook will be attached to 250 lbs and it will be hanged from the side of the hand rail in order to ensure compliance with the Americans with Disabilities Act (ADA) requirements.

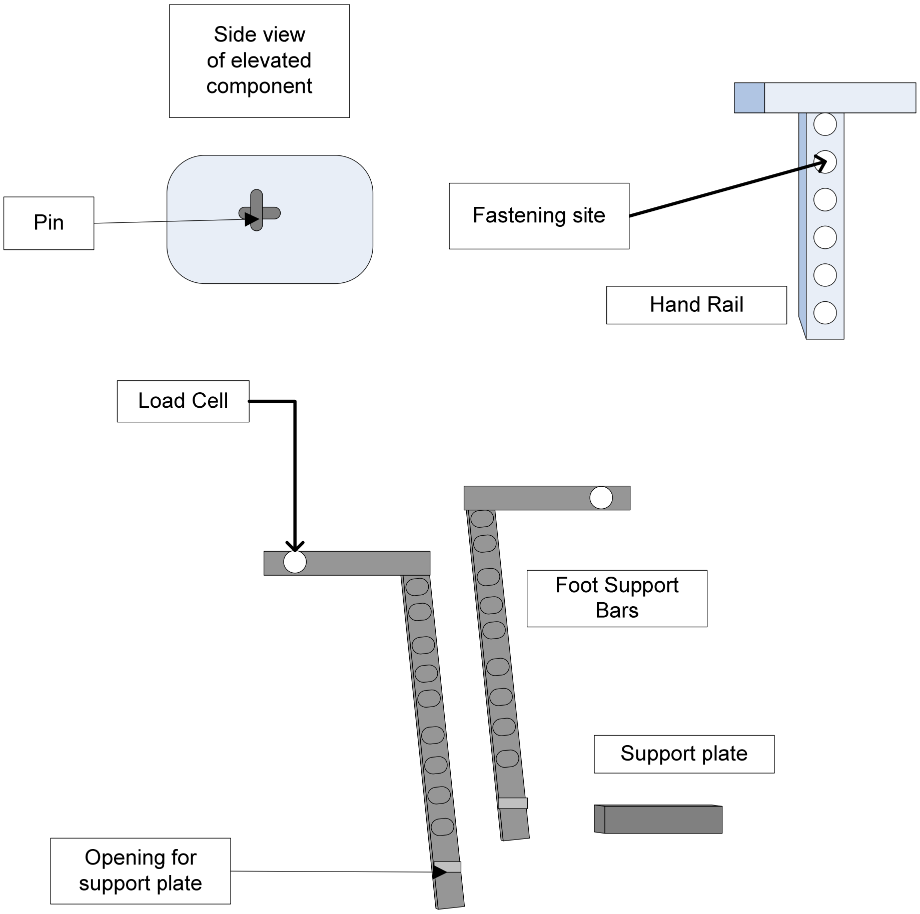

Figure 10 – Components of foot support and hand rail

Foot Support

The function of the foot support is to keep the user's feet off the ground. The weight applied to the foot support is distributed to the elevated toilet seat. This will ensure that all of the user's weight is distributed onto the elevated toilet seat and incorporated into the measurement.

The foot support will be adjustable and detachable for the user's convenience. It will consist of two adjustable and removable support bars and a removable support plate in the middle. All these components will be made of aluminum to reduce the weight of the foot support and resist corrosion. The support plate will be rectangular and it will be attached to two bars with a spring locking mechanism. It will consist of a circular bar, which will be welded to the two supporting bars. The supporting bars will be adjustable in length. It will also have a spring pin locking mechanism. The user can adjust the foot support to the optimal height prior to getting on the device. When the user applies the weight of their legs on the support their weight will be supported.

The strength of the foot support will be tested by applying 550 lbs on the support. The device should be able to withstand a weight of up to 500 lbs. this test is essential to avoid any injury to the user and or damage to the device because the 500 lb user might stand on the foot support while getting on the device.

Force Equations

Toilet seat

Force 1: Weight of right hand support plus half of the leg support
Force 2: Weight of right tight segment
Force 3: Weight of the head, neck and back segment
Force 4: Weight of left tight segment
Force 5: Weight of left hand support plus half of the leg support

Hand Support

Force 6: Weight of right arm
Force 7: Weight of left arm

Foot support

Force 8: Weight of right lower leg plus right feet
Force 9: Weight of left lower leg plus left feet
Sum of force equation
1. $\sum F_y$ = Force 1 + Force 2 + Force 3 + Force 4 + Force 5 – Load Cell 1 – Load Cell 2 – Load Cell 3;
2. $\sum F_z = 0$
3. $\sum F_x = 0$

Sum of Moment equation
1. $\sum M_y = 0$
2. $\sum M_z$ = Force 1*d1 + Force 2*d2 + Force 3*d3 – Force*d4 – Force 5 *d5 + Load Cell 2 *d6 – Load Cell 3 *d7 – Load Cell 1 *d8;
3. $\sum M_x$ = Force 1*d9 + Force 3*d10 + Force 4*d11 – Load cell 1*d12

Distances
d1: distance from Force 1 to Z axis
d2: distance from Force 2 to Z axis
d3: distance from Force 3 to Z axis
d4: distance from Force 4 to Z axis
d5: distance from Force 5 to Z axis
d6: distance from Load Cell 2 to Z axis
d7: distance from Load Cell 3 to Z axis
d8: distance from Load Cell 1 to Z axis
d9: distance from Force 2 to X axis

d10: distance from Force 3 to X axis
d11: distance from Force 4 to X axis
d12: distance from Load Cell 1 to X axis

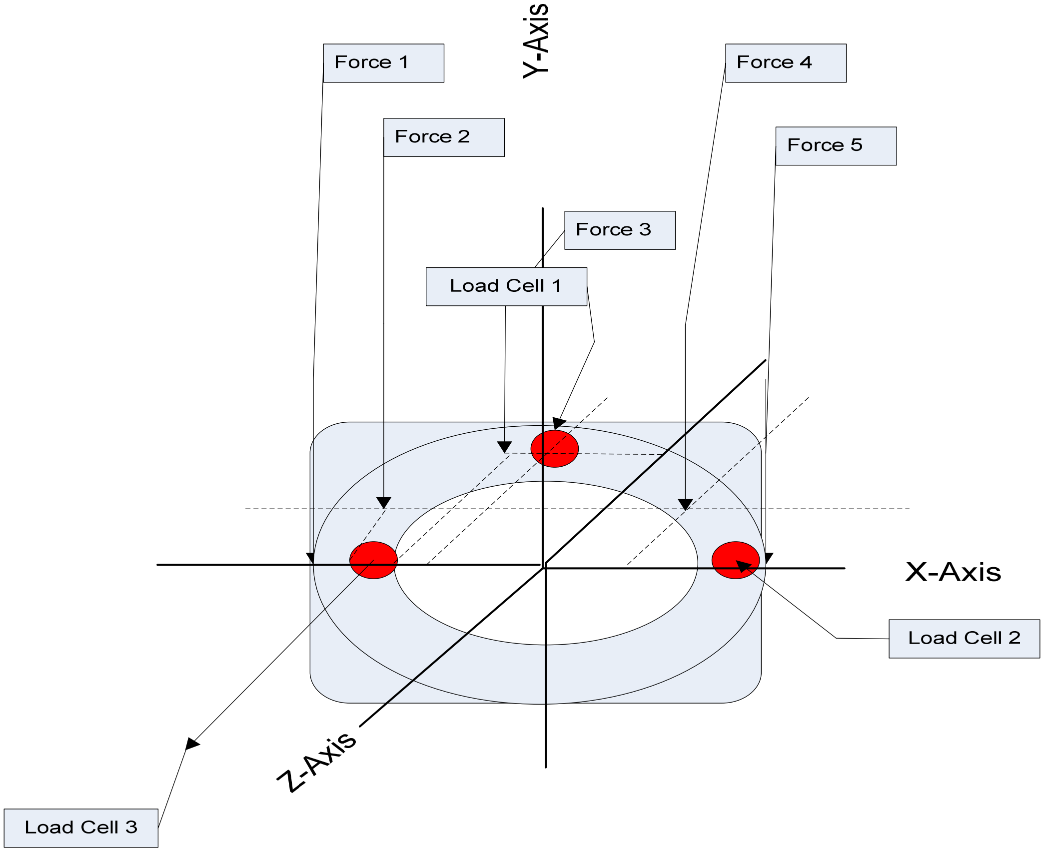

Figure 11– Free body diagram of device

Microcontroller

The microcontroller is responsible for converting the electrical signal from the load cells into a weight measurement given in kilograms (Kg) and pounds (lbs). It is also responsible for storing the data of the collected weight measurements, and incorporating a wireless transmitter and receiver for communication between devices.

The PIC18F6723 microcontroller, made by the Microchip Corporation, will be used for the accessible weight scale for seated users project, and will be used in the elevated toilet compartment. The PIC18F6723 microcontroller was chosen for the project for numerous, various reasons. A main reason is that it has 128 kilobytes of program memory as well as 3936 bytes of data memory, which will be essential for storing multiple readings taken from numerous weight measurements. It also has twelve onboard, 12 bit analog-to-digital module inputs, which is an amount that is higher than what is needed for the project, the device only requiring three inputs for the load sensors; however, if more load sensors were later required for some reason, then the microcontroller would easily allow for the implementation of those sensors. A USART output pin will be used to transmit serial communications via a wireless transmitter to the microcontroller within the handheld console.

For the third design of the project, it was determined that a second microcontroller would need to be implemented in order to incorporate a wireless handheld console. Therefore, the PIC16F874A microcontroller was chosen due to a familiarity with programming, debugging, and utilization of this microcontroller in past projects. The LCD screen and buttons will be connected to the input I/O pins of the microcontroller, and the wireless receiver will be connected to one of the USART input pins for serial communication with the elevated toilet compartment.

As just mentioned, the PIC microcontroller employs USART serial communications, and it can allow for access to a computer through a serial port when a proper RS232 chip is used. The Microchip MPLAB Integrated Developer's Environment can also be used for the programming and debugging of the PIC microcontroller. It is also capable of parallel communications (PSP), thereby allowing for compatibility with peripheral devices and wireless applications. Furthermore, both the PIC18F6723 and PIC16F874A are stocked with Microchip's nanowatt technology, which limits power dissipation while increasing the electrical life when the PIC and device are operating on battery power; this will be useful for the group's device, which will be operating solely on battery power.

As previously stated, the analog-to-digital conversion ports will be used for the output signals of the load sensors, in order to convert the electrical signals into actual values of weight, in pounds and kilograms, for display on the LCD screen. There are in-circuit-debugger (ICD) ports which will be used for the programming and debugging of the microcontroller. The programming and debugging can be done using the MPLAB IDE in conjunction with the Microchip ICD 2 or PICSTART Plus. Programming will either be done in the assembly language (ASL) or C++ language. It is much easier to program in C++, mainly due to the simpler use of loops in C++ in comparison to the numerous bundles of programming in ASL. However, each programming language can be converted to the other for greater ease of programming. Testing the microcontroller will be done by setting up a protoboard circuit that has a power supply and telephone type data connect, which will plug into the Microchip ICD 2 for debugging and eventual programming. Showing that the microcontroller is actually functioning will require the use of an oscilloscope and probe, which should show a 5V peak to peak sinusoidal wave assuming that the protoboard is wired correctly. The following figures are connection diagrams for the PIC18F6723 microcontroller and the PIC16F874A microcontroller, showing certain pin connections for supply voltages, grounds, A/D conversions, data output, and digital output:

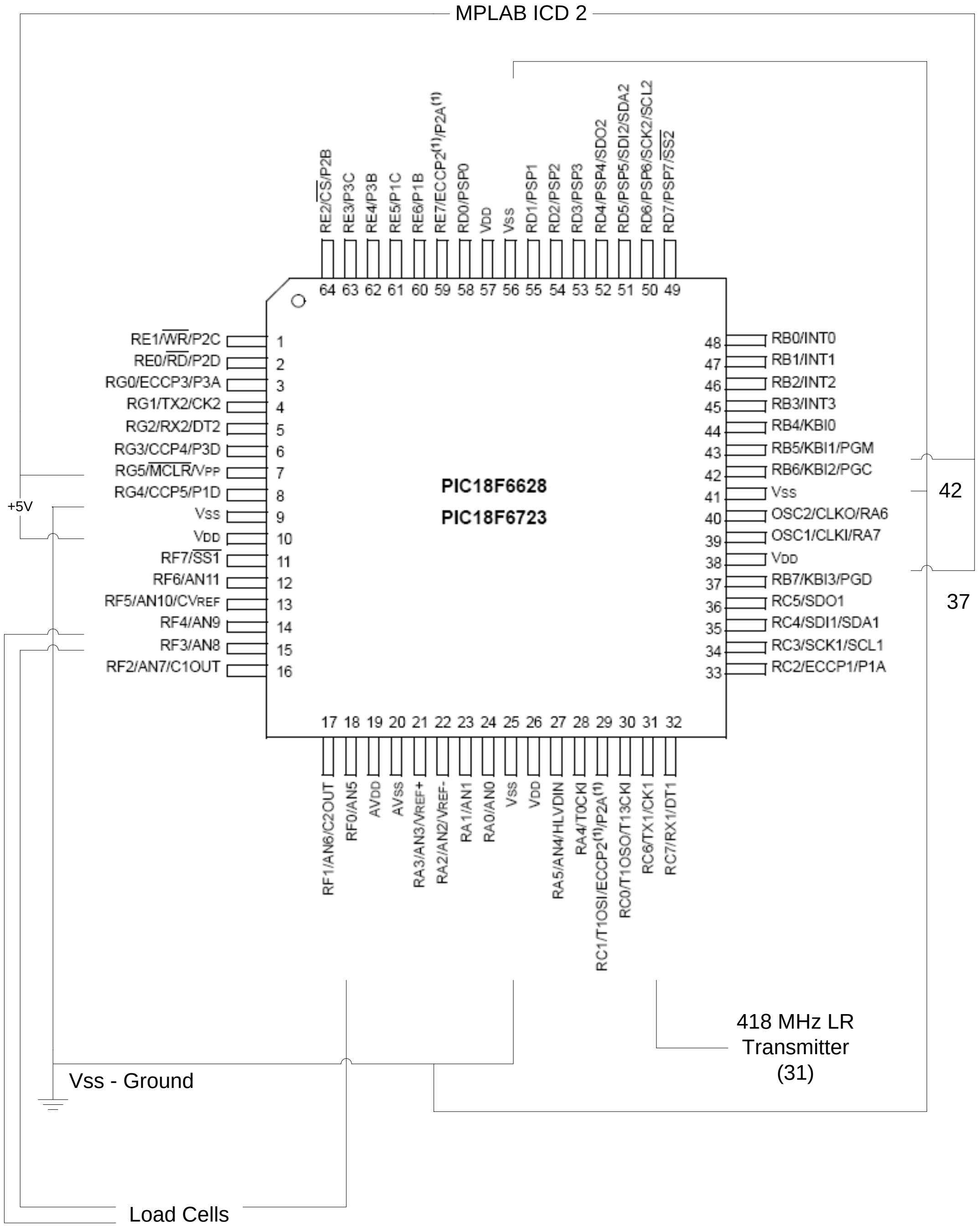

Figure 12 – PIC18F6723 Connection Diagram

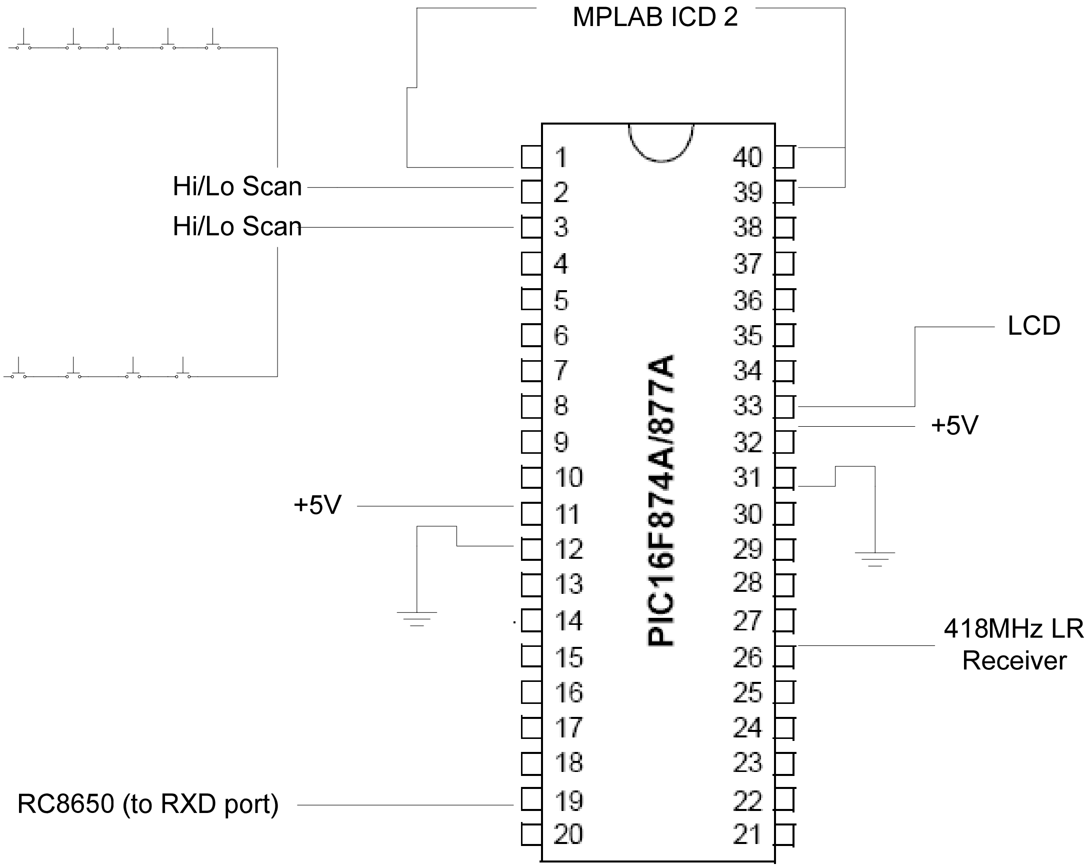

Figure 13 – PIC16F874A Connection Diagram

A significant upgrade to the accessible weight scale, which largely incorporates a further implementation of the PIC16F874A, is the inclusion of five user buttons (1-5) on the handheld console for the storage of weight data for up to five users. This inclusion results in an expansion of programming for the PIC16F874A in which the analog input pins will have to be scanned for when a button is being pressed. The programming will accomplish this by setting a low bit and a high bit. All of the buttons will remain low when they are not pressed, yet, when one of the buttons is pressed, the microcontroller will sense the pulse and acknowledge the button that is being pressed (one of the users in this case). The user that presses their button will then be able to scroll through his or her weight measurement readings using the up and down arrows. Each user will have their own storage in parts of the memory banks on the microcontroller. There should be enough space for more than one user on a given bank; however, multiple users will require storage memory on two to three banks which reside in the RP0 and RP1 registers. Examples of assembly language source code for A/D conversion, initialization of an LCD, and button pressing are included as appendices A, B, and C respectively. The source code was programmed to a PIC16F874A on a student education board.

Mounted Display Component

The user interface will contain all of the buttons necessary for the user to operate the device. It will contain 5 buttons numbered 1-5; these buttons will identify the different users. The interface will also have a "Tare" button that will allow the user to tare the device while the device is not in use. It will contain a "Measure" button that will allow the user to easily take a measurement. There will be a scroll up and down button that will allow the user to scroll through previous readings. There user interface will also contain a liquid crystal display (LCD) screen that will have characters about half of an inch in height in order to output readings visually. For audio output the user interface will contain a speaker and text to speech device.

The mounting mechanism of the user interface will be attached to one of the hand rails or the foot support with a C shape rubber stopper. It will consist of the user interface and a supporting element which will attach the interface to the support. The supporting element will medially move the interface and will interlock at the midpoint between the left and right support. This will allow the user to attach it on either side for their personal convenience.

The user interface console will be connected to the other electrical components housed within the elevated toilet seat via wireless transmission and serial communication. The mounted display will take 9 V batteries that will be easily accessible from the back of the console. A linear voltage regulator circuit will have to be implemented in order to down regulate the 9 V battery output to a 5 V LCD input. The LM317L linear voltage regulator manufactured by ON Semiconductor Corporation will be used as the linear voltage regulator for 5V input into the LCD screen. These voltage regulators have a variable voltage output of 1.2V to 37V, which will incorporate the needed 5V output and input into the LCD, and will work well considering the use of 9V battery power supply. The current output for the LM317L is in excess of 100mA, which is not too high of a current, but will still make it necessary to put a current limiting diode in series with the 9V battery in order to prevent backflow of current, which could damage the battery and possibly other electrical components (shown in Figure 15). A circuit diagram of the external components wired to the LM317L is shown below, and will be wired as so for the design of the device:

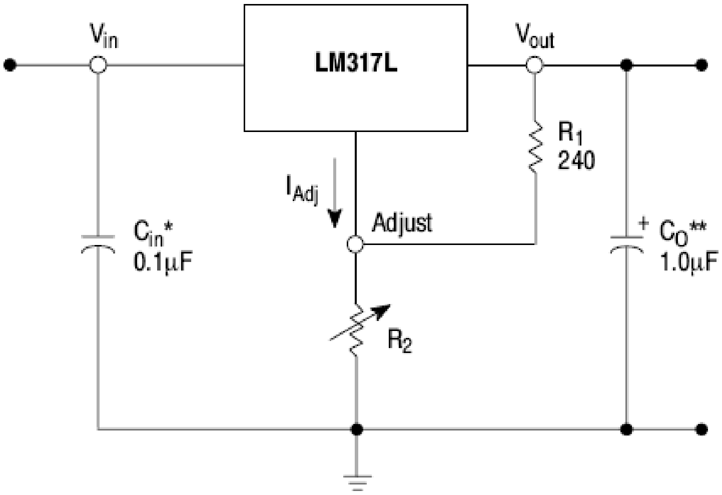

Figure 14 – LM317L Linear Regulator Circuit Setup [3]

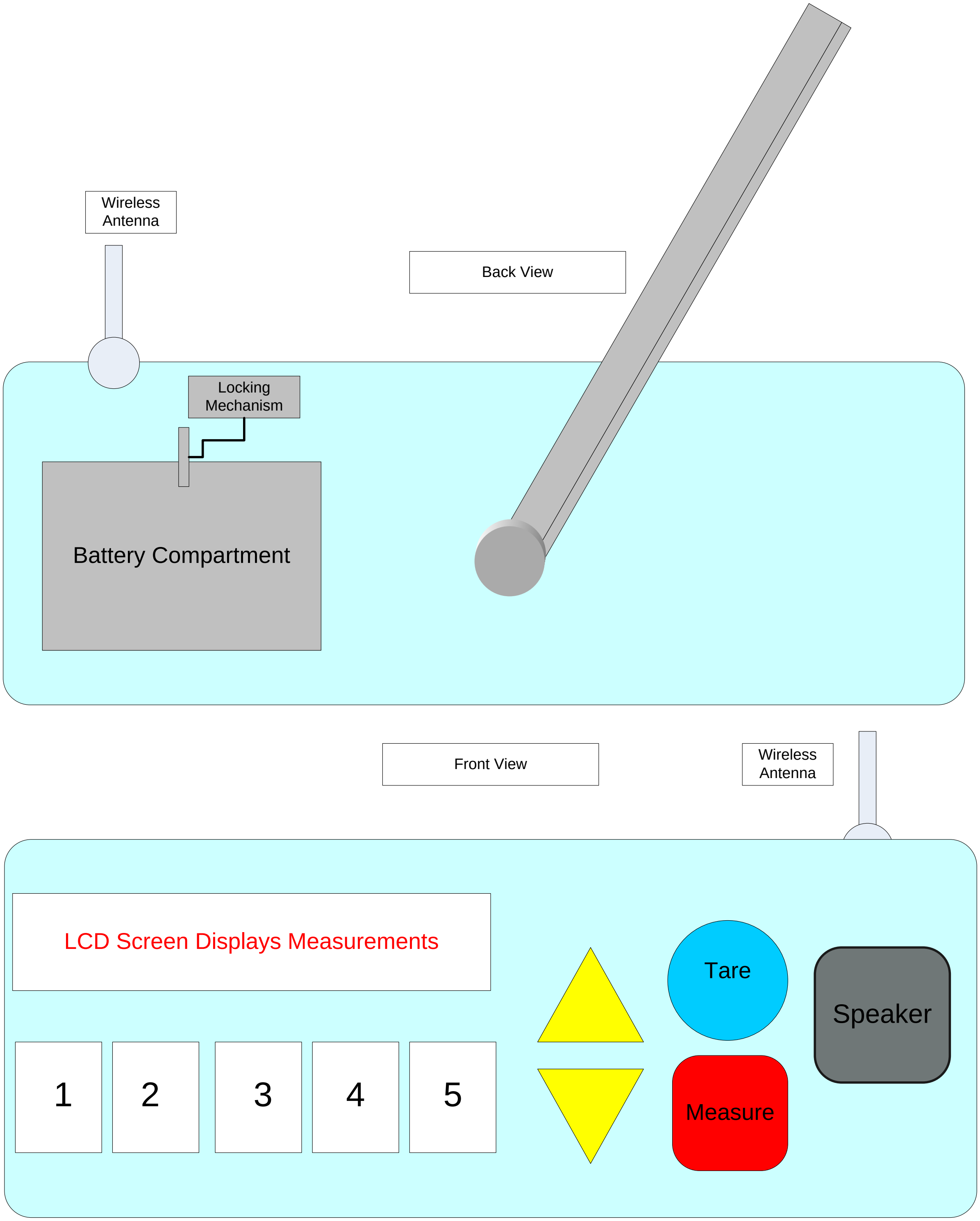

Figure 15 – Mounted Display Component

The LCD that the design group intends to use is the LCM-S01602DSR/D manufactured by Lumex Inc., and a picture of the LCD screen is shown below:

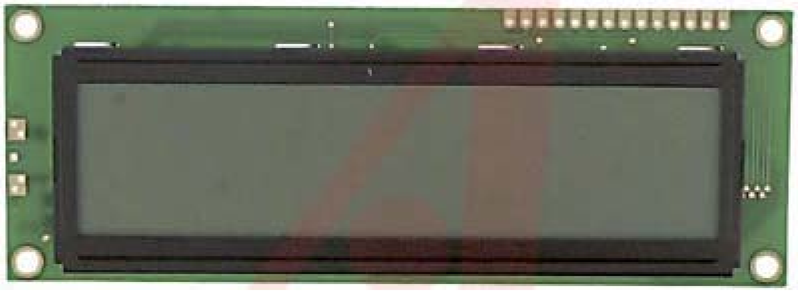

Figure 16 – LCM-S01602DSR/D [4]

The LCM-S01602DSR/D screen, shown above, is ideal for the group's design for a few reasons. The first reason is that it has sixteen characters X two lines, which will be useful when sending messages to the users from the microcontroller, as well as when displaying the weight measurement readings. Another reason is that is has a large viewing area with a dimension of 99 X 24 mm, providing a fairly big view to the users. The LCD also has a character size of 4.84 X 9.63 mm, which will make it easier for any user with vision impairments to read the screen. It has a wide viewing angle, which will easily compensate for viewing if a user is holding the handheld console at an angle. The backlight on the LCD will make it easier to read in dimly lit settings. Lumex states that the LCD has low power consumption with long operational life and that will be vital to the accessible weight scale, as batteries will be used and replacing them often is not desired. It must also have a voltage input of 5V and a 12mA current. A schematic for the power supply to the LCD screen is shown below:

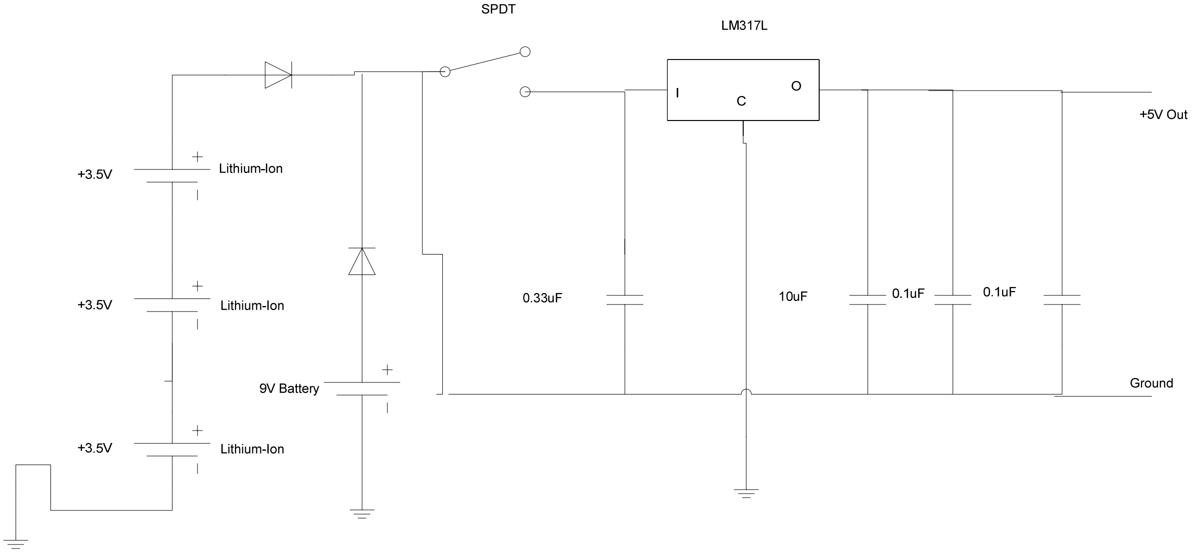

Figure 17 – Example of Power Supply to LCD Circuit

The power supply to the LCD screen should resemble the schematic shown above in order to meet the voltage and current requirements for input into the LCD. However, due to the incorporation of a backlight on the LCD, there may need to be another 9V battery added to the initial battery to meet the power requirements of the backlight. If need be, the 9V batteries could be put in parallel to ramp up the current to meet all of the current specifications.

Another important component of the mounted display will be the text-to-speech device. This device's incorporation into the design is vital to the user(s) that has extreme vision impairment or possible blindness. The group will be implementing the RC8650 Voice Synthesizer® Chipset made by RC Systems in order to accommodate the text-to-speech functionality. The RC8650 can store up to 3.5MB of memory and includes playback of fifteen minutes of pre-recorded messages. This is more than enough memory to include the speech output that is necessary for the device. The chip is available in 3.3V and 5V operating voltage packages, and the 5V operating voltage chip will most likely be chosen for the voltage specifications of the device. The RC8650 will connect to three ports on the microcontroller for input, output, and clear functionality. The RXD port of the chip will receive data (text) and commands from the microcontroller. The TXD port will be used to read information out of the RC8650, and CTS# port will acknowledge each byte received on the RXD pin by going high (it is initially low) and allowing the data flow. The $A0_0$ and TS_0 pins will transmit the analog output and talk status output from the RC8650 to a low-pass filter operational amplifier circuit, which will then output to an 8 ohm speaker for audible speech output of the weight measurement to the user. Testing of the chipset will be done using a protoboard setup to connect a set of inputs to make sure that the outputs match the data and commands of the inputs. This can be done by setting up the RC8650 chipset testing circuit (given in the datasheet) on a protoboard to see if the DC characteristics match up to those provided in the datasheet. A figure showing a picture of the RC8650 chipset is shown below:

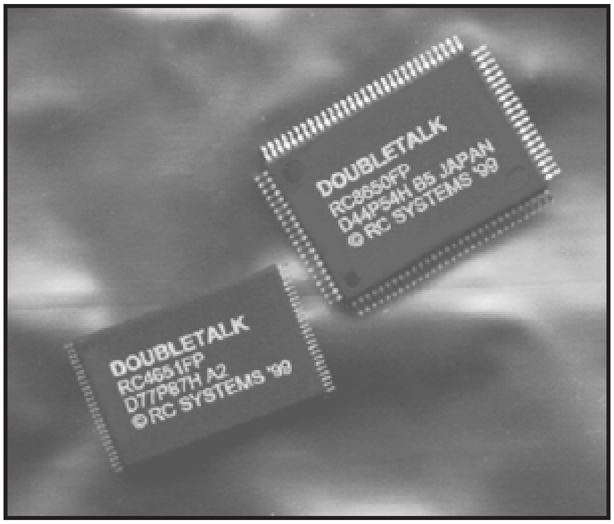

Figure 18 – RC8650 Chipset [5]

The outer casing of the console will be made of hard plastic. It will need to be big enough in size to safely fit the LCD, push buttons, batteries, and electrical components. Yet, it also must not be bulky in order to make it comfortable to the user. All of the buttons will be clearly labeled, either directly on the buttons or directly above or below the buttons. They will be labeled in English text as well as Braille for users with vision impairment. The "Measure" and "Tare" buttons will preferably be of the same size, but of different shapes and colors, making it even easier to distinguish between the two. The two arrow buttons will be the same size and color, but will be distinguished by the direction that they face (up/down, north/south). A number of push buttons were found that could be used in the design of the device; however, not many of the push buttons had an option to be bought with Braille incorporated into them. Grayhill Inc. is one manufacturer of push buttons that has an option for Braille on the push buttons, and an inquiry has been issued with them to see whether or not a word, such as “Measure”, can be put onto the push button. Innovation Industries Inc. is another company that actually manufactures push buttons with Braille already on them; however, these buttons are used for more commercial settings, like an elevator, and do not have Braille words on the push buttons that would be pertinent to the group’s device. Therefore, the best idea could be to purchase small “sticky sheets” of Braille words, such as “Measure” or “Tare”, which can then be put directly on the buttons.

As with the testing of the elevated toilet compartment circuitry, the mounted display circuitry will need to be tested on a protoboard. A standard smoke test will have to be performed to make sure that all of the electrical components are functioning correctly and will function correctly when eventually connected to the PCB. A digital multi-meter will be used to check voltages, currents, and resistances throughout the protoboard to make sure that they meet the specifications of the various chip, LM317L, LCD, and buttons. This will also make sure that there are no short circuits throughout the circuit.

A very important addition and upgrade to the third design of the accessible weight scale for seated users is the implementation of wireless/RF technology. The wireless/RF technology is necessary for the third design because of a need to minimize the amount of exposed wires. A large wire from the elevated toilet compartment to the handheld console, containing power and input/output wires, would be quite exposed and subject to contact with water, which is a danger to the user and cannot exist in the design. Therefore, the LR Series Long Range Wireless Communication Modules, made by Linx Technologies, were chosen to meet the wireless/RF technology demands. The 418MHz transmitter and receiver modules were chosen, which will hopefully reduce the amount of interference during transmission and provide accurate transmission of data between the two PIC microprocessors. They can incorporate a supply voltage of 5V, which is good for the power systems of the design since 5V supplies will be used. The modules have a direct serial interface and that will allow for accurate communications between USART pins of the PIC microprocessors. The 10,000 bits per second data rate of the LS modules is more than enough for the transmission of the data needed for the project; yet this will result in quicker communication between the handheld console and electrical component compartment, thereby resulting in quicker visual and audible weight readings. No external components are needed for the wireless modules, except for an antenna; therefore, the 418Mhz CW Series antenna was chosen for receiving of the data in the 418MHz frequency. These antennas are fully weatherized, which is optimal due to the environment in which the antenna will be used.

2 Realistic Constraints

The realistic constraints of the accessible weight scale for seated users include engineering standards put forth by the Americans with Disabilities Act (ADA), the economic, health and safety, social, sustainability, and manufacturability constraints. All of these constraints were determined by the team and addressed in designing this alternative design.

The most important engineering standard that should be met in the design of this project is the Americans with Disabilities Act (ADA) design standards for accessible design of water closets. The ADA is enforced by the Department of Justice of the United States. ADA was developed to protect the rights of Americans with disabilities. One ADA standard is that the handrails that will be used for this device have to have a diameter of 1-1/4 inches to 1-1/2 inches at the gripping site. The handrails have to be kept at least 1-1/2 inches from the wall. The handrail must not deform when a 250 pound bending stress or shear stress is applied to the handrail. Also the fastener or mounting device should be able to support a 250 pound lateral load or direct tension force. These are the only ADA requirements for this device. [6]

The economic constraints associated with this project will be the expense of the accessible weight scale for seated users. Our prototype costs cannot exceed $2000. Our projected cost for this alternative design prototype will be roughly $1700. This leaves only $300 cushion in the event one of the components is damaged during construction of the device. The future cost of the device is usually estimated as being 35% of the prototype costs making the device cost approximately $600. The market price of the device will be higher in order to make a profit, but the price of the device should still be significantly lower than current products on the market. Many of the currently available products that meet our specifications of accuracy within one fifth of a pound and total capacity of 600 pounds cost between $1,500 and $2000. These designs are not incorporated into an elevated toilet seat and are less convenient for the user, but they set the standard for the price range of this device. In order to compete with these products, the accessible weight scale for seated users should be less expensive than the currently available products. Many public hospitals and would appreciate a less expensive accessible weight scale for seated users given their tight budgets. Also it may be more beneficial for hospitals or private owners to have the scale incorporated into an elevated toilet seat because it is one less device to purchase and cheaper than purchasing two separate devices.

There are some definite constraints to the device in regards to health and safety. Similar to any electronic device there is an inherent risk of electric shock to the user. Because the device will be housed in a bathroom setting, this risk is even greater due to regular contact with water. This means that all electrical components will have to be safely housed to prevent electrical shock to the user when the device comes into contact with water.

Also the device will have to be easy to sanitize in order to prevent the user from coming into contact with harmful bacteria. The device will be used as a toilet as well as a scale. It should be easy to sanitize between uses especially in a clinical settings. In building the device it will be important to make sure that there are no crevices or hard to clean regions that bacteria could grow.

Another health and safety constraint is making sure there are no sharp edges on the device that could potentially injure the user. Cuts sustained from sharp edges could be painful and if the surface is not clean they could also result in infection of the wound. Any sharp edges will have to be filed down until they are smooth. This is especially important with the posture support and the electrical component encasement part of the elevated toilet seat since these components will be built in the machine shop by the group members.

Another health and safety constraint is ensuring the stability of the elevated toilet seat on the toilet. Bathrooms are a common place for the mobility challenged to have a fall. The elevated toilet seat will have four stoppers that will hold the elevated toilet seat securely ensuring that it will not slide off of the toilet. Normal toilet seats have hinges to secure the toilet seat, but the elevated toilet seat will not.

A definite social constraint of this project is ensuring that the device will increase the quality of life for the clients. The main objective of biomedical engineering is to engineer solutions that will increase the quality of life. This means that the user should be able to independently use the device without the help of another person. By making the device easy to use for a mobility impaired individual, the device will better the quality of life for the individual, allowing them to have control of monitoring their weight themselves without feeling embarrassed by a loved one seeing their weight or helping them use the device. Also it is important to make sure that the accessible weight scale does not prevent the user from using the toilet without the help of another person. This would significantly lower the quality of life of the user if they had to rely on another person to use the toilet if they did not previously have to do so.

Sustainability of the device is another constraint for this project. Most of the users are old and cannot be expected to repair the weight scale. The weight scale should require very little maintenance beyond sanitizing the device. The electrical and mechanical components should not in any way be subject to failure. This could be difficult because some of the users are obese and the scale will be exposed to substantial forces. Another concern for this device is that it should be capable of operating for a long period of time. The device should have a long battery life so that the user will not have to change the battery often and it should be easy for the user to change the battery when necessary. If the user has to dig through complicated wires in order to remove and replace the battery they will not replace the battery and the device will not work.

In the event that the accessible weight scale does need to be repaired, the device should be relatively easy to repair. The device should remain light weight so that it would not be too difficult for the users loved one to remove the device and bring it in for repairs. The posture support for this design is detachable, which will make it significantly easier to repair. Also the circuitry should be readily available. The bottom of the elevated toilet seat will have a removable panel to allow for easy access to the electrical components. The panel will be removed with a screwdriver to prevent the user from tampering with the electrical equipment.

One manufacturability constraint on this project is that the machine shop is not equipped with the machines required for working with plastics. This will drastically limit the choices of materials to be used for the accessible weight scale for seated users. Some of the materials might sacrifice aesthetics for functionality and manufacturability. When the actual device is manufactured there will be a greater number of machines available and the device may be produced with more aesthetically pleasing components.

It is important to keep in mind how these designs might be manufactured in the future. If one design would be more difficult to manufacture and require a large number of man hours to complete then it is possible a different alternative design would be a better choice in order to keep the cost of manufacturing down for the product.

3 Safety Issues

While designing this device it was important that the safety issues that are associated with the device were thought of, discussed and addressed within the design of the product. Many devices, especially electronic devices, have safety issues. These safety issues are not a problem for the user as long as they are properly addressed and accounted for in the design of the device. The different types of safety issues that have been determined for the accessible weight scale for seated users include electrical, biological and mechanical safety issues.

Any electronic device has an inherent possibility of causing electric shock to the user if constructed improperly. Electric shock is very dangerous and could cause pain, burns and even cardiac arrest. For this reason the accessible weight scale for seated users will be made water resistant in this design. The elevated toilet design could come into contact with water on a regular basis and must not endanger the safety of the user while in contact with water. The accessible weight scale will keep the wires and load cells from contact with water at all times. The mounted display will communicate with the rest of the device wirelessly so that there are no exposed wires. Also the display is mounted to prevent it from falling into the toilet and causing shock if the user tries to pull it out.

Another potential safety issue associated with the accessible weight scale for seated users is sanitizing the device. The scale will be integrated into an elevated toilet seat and will be used as such. Especially in a clinical setting the scale may be used by multiple users and will come into contact with germs and bacteria that could be spread from user to user. It is important that the weight scale be easy to clean and sanitize in order to limit the amount of risk to the users. This means that the device should not have a large number of crevices and hard to clean areas that could house bacteria and increase the risk of the user coming into contact with harmful bacteria.

One of the mechanical safety issues associated with the accessible weight scale for seated users is the stability of the elevated toilet seat on the toilet. If the seat were to fall off the toilet with the user on it, it could cause considerable injury to the user. The elevated toilet seat is not as easy to stabilize on the toilet since it will not be attached to the toilet as a normal toilet seat is. It will not have a hinge attachment. It will, however, have the four fastening mechanisms installed at the four corners of the device to ensure the stability of the elevated toilet seat on the toilet. These mechanisms will hold the seat from any lateral movement and will resist vertical movement without inhibiting the load cells from compressing and measuring the force applied by the seated user.

Another mechanical issue associated with this design is that it will have components built in the machine shop. It will be important to ensure that these components do not have any sharp metal edges that could injure the user. Any sharp edges will have to be filed down so that they are no longer sharp and no longer a danger to the user.

For each of the safety issues that have been determined for this project a solution has been made in order to ensure that the device is safe for the user. It will be important to keep these design solutions in mind while building the device if it becomes apparent that one of the safety solutions is not adequate to keep the user safe. At that time a new solution will have to be developed or the old solution will have to be improved. The safety of the user is paramount to the success of the accessible weight scale for seated users.

4 Impact of Engineering Solutions

As engineers it is important to consider the impact of our engineering solutions prior to starting a project. It is the engineer's responsibility to ensure that their engineering solutions are ethical and beneficial to society. The impacts of the accessible weight scale for seated users include economic, societal, environmental, and global impact.

There are two types of economic impact that the accessible weight scale for seated users would have. One type of economic impact would be the impact on the consumer, which would come in the form of a cheaper device. The second type of economic impact would be on the competing companies, which would come in the form of a competing device taking some of their market share.

By producing an accessible weight scale for seated users that is inexpensive, there will be an economic impact on the individual consumer. The individual consumer may have a fixed income, many expenses and limited savings. This consumer would save money by purchasing the accessible weight scale for seated users rather than purchasing other products that have the same capabilities, but are more expensive. The device would not only be cheaper, but it is an elevated toilet seat and weight scale combined. The consumer then only has to purchase this one device instead of spending more money by buying both a weight scale and an elevated toilet seat.

For competitors to the accessible weight scale for seated users the economic impact of the device will not be a good one. Competitors will have some of their market share taken by a less expensive and more convenient device. This means that competitors will lose money and be forced to drop prices in order to maintain their market share. They will also be forced to pour more money into research and development in order to design an accessible weight scale that is even better than their new competition. The companies' new products could be even cheaper and more convenient than the accessible weight scale for seated users, which will benefit the consumers. This benefit does not come to the consumers, however, unless new products are developed and introduced to the market.

The accessible weight scale for seated users could have a significant societal impact on people with limited mobility. It is currently quite difficult for seated users to monitor their weight. They often require another person's aid sometimes even having to travel to the hospital in order to measure their weight. This dependence on other people is sometimes very detrimental the psyche of a mobility challenged person. They can often feel that they are a burden on their loved ones. This depression can be especially detrimental to obese patients with limited mobility because their depression could cause them to eat more and monitor their weight less. By developing a weight scale that is convenient and easy to use without the help of another person, it will be possible to increase the seated user's independence from their loved one. This will allow them to feel less of a burden and to let them focus on monitoring their weight and ensuring their continued health.

In order to ensure that this product is environmentally friendly the accessible weight scale for seated users will not use lead based materials to operate. Restriction of Hazardous Substances (RoHS) came into force on July 1 2006. This directive restricts the amount of lead, cadmium, mercury and other hazardous substances that can be contained in an electronic devices sold within the European Union. In order to ensure that our device follows these standards, the electronic components for the accessible weight scale for seated users will only be purchased from RoHS compliant suppliers. In the event that the weight scale is thrown out it will not have as significant an impact on the environment as other electronic devices sometimes do. [7]

The design of the accessible weight scale for seated users can be easily adapted for a global market. It uses battery power and will not require power adaptors or power cords to work in different nations. Also the weight of the user is given in both pounds and kilograms. Allowing users everywhere to clearly understand how much it is they weigh. Also this design will be RoHS compliant, meaning no lead based materials, which will allow the product to be sold in the European Union.

There are several factors that will impede the global impact of the accessible weight scale for seated users. One reason for this is that selling a product in an international market takes more time than selling the product in the United States. An international patent should be applied for in order to protect the device from being adopted and sold by other companies. Also international distribution channels would need to be fostered and grown. Before entering a market a significant amount of market research should be conducted. There may be products sold in foreign nations that have not yet made it to the United States. These products may already have a sizable piece of the market and depending on their design it may be difficult to take some of that market share with a new product. Also determining pricing strategies in foreign nations could take time given fluctuating values of foreign currency and a lower standard of healthcare and living in other nations. In the future these impedances may fall away, but for the time being the global impact of the accessible weight scale for seated users will be slow in coming.

Taking all of these impacts of engineering solutions for the accessible weight scale for seated users into account, there are many reasons to build this device and few reasons not to. The device will have negligible impact on the environment when compared with other devices and the economic impact is a positive one. The societal impact is the driving force for this project and is the main reason for developing this device. The users will benefit from being able to independently monitor their weight.

5 Life-Long Learning

Life-long learning is a concept that is present in educational institutions all over the world. The Australian department of education has defined life-long learning as "the process of acquiring knowledge or skills throughout life via education, training, work and general life experiences." [8] The concept of life-long learning has made a large impact at the University of Connecticut. One of the program outcomes for the biomedical engineering program is, "a recognition of the need for, and an ability to engage in life-long learning." [9] Our senior design project is a principle component of our education to meet this program outcome. In this project a number of skills have been developed through life-long learning that would not have been achieved through normal educational means. Among these skills are working on a multidisciplinary team, applying education in a real world application, learning market research concepts, and machine shop training.

In our educational experiences at the University of Connecticut each of the three team members have worked on several engineering projects. None of these projects have been as challenging and none of these projects have required that our teammates be from different tracks within the biomedical engineering program. The three tracks that are represented in our team are chemical engineering, bioinstrumentation and biomechanics.

The most important skill that is developed when working on a multidisciplinary team is delegating tasks. These projects are so large and time consuming that in order to complete them, tasks have to be delegated to the various team members in such a way that plays to their strengths based on previous experiences. Each team member could probably complete any of the given tasks, but some are better than others because of their individual experiences at UConn. Determining which skills each person has and how best to implement those skills was probably the first challenge in this project and a skill that will be of great use in our careers.

The average engineering student has amassed a wealth of knowledge by their senior year of college, but may not have had many chances to apply that knowledge to real world problems. This is a skill that needs to be developed if the student is to succeed in his or her career. It is also a skill that is being developed in this senior design project. All of the seniors have to complete their senior design project in order to graduate with a degree in biomedical engineering from the University of Connecticut. Each team is asked to design a product that is needed in the world in order to increase the quality of life for their clients. In order to produce a successful project each team member has to apply the knowledge they have gained at UConn. Being able to apply that knowledge and skill is a lesson in and of itself.

These projects are all real world applications and that means that if it is going to be made for the real world it has to be able to be sold in the real world. This means that as engineers it is not acceptable to only develop a product that solves a problem. They must also develop a product that can compete in the market today. In order to do this it is necessary for the team to learn how to use market research in order to determine if there would be a market for their design project. The market research for these projects is limited to secondary research for the most part with the exception of the students who work on NSF projects and have a client with specific needs. For the rest it is imperative that they are able to see what other products are available and to design the project in a way that it can compete with the available products. This skill will inevitably be useful in future careers because it ensures that the product being engineered not only solves the problem, but can be sold as well.

Each senior design student is required to complete machine shop training. This training is necessary in order to ensure that the team can build the device in the second semester of senior design. This hands-on training is a skill that would not necessarily be learned at any other time in the student's life, but could be of definite benefit when working on future prototype designs at companies.

In working on the senior design project many different skills can be acquired. For example in this third alternative design the display is mounted for the user. In previous designs this had not been the case. It was important that all components of this device remain removable so that the device would be more portable than previous designs. In order to design this mounted display it was important to learn more about different attachment points and ways to adjust and lock the display easily for the user. Researching mounting mechanisms and having learned about mounted displays led to the current design for the mounted display. This understanding of the various mountings and there advantages and disadvantages would not have been acquired without this project.

All of these additional skills that the student learns while completing their senior design project are important in meeting the program outcomes that the biomedical engineering program has developed. These program outcomes prepare the students for their future careers in the field of biotechnology and prepare them to continue their education through life-long learning.

6 References

[1] National Instruments. http://zone.ni.com/devzone/cda/tut/p/id/3642

[2] SMD Sensors. http://smdsensors.com/detail_pgs/s290.htm

[3] ON Semiconductor Corp. http://www.onsemi.com/pub/Collateral/LM317L-D.PDF

[4] Allied Electronics. http://www.alliedelec.com/Search/ProductDetail.asp?SKU=670-1137&SEARCH=&ID=&DESC=LCM%2DS01602DSR%2FD&R=670%2D1137&sid=471550806480E17F#

[5] RC Systems. http://www.rcsys.com/Downloads/rc8650.pdf

[6] "ADA Standards for Accessible Design," Department of Justice, United States of America, available at, http://www.usdoj.gov/crt/ada/adastd94.pdf

[7] RoHS "Home" http://www.rohs.gov.uk/

[8] "Glossary of terms F to L" Department of Education, Science and Training Australian Government, available www.dest.gov.au/sectors/training_skills/policy_issues_reviews/key_issues/nts/glo/ftol.htm

[9] “Program Outcomes,” Department of Biomedical Engineering, University of Connecticut, Storrs, CT, available at, http://www.bme.uconn.edu/ugrad/bmeprgoc.htm

Appendix A

```
;;;;;;; ADConvert Subroutine ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

ADConvert
        MOVLF       rdAN1    ;load appropriate control for RA1 input
        movlw d'15'    ;RP1 goes to RA1 on NEW #905172 education board
        movwf ADCHARGETIME
waitSet1

        decfsz  ADCHARGETIME,F          ;delay 30 usec for settling
        goto    waitSet1

        bsf     startAD                 ;Start conversion

ADWait1

        btfsc   ADCON0,GO_DONE          ;check GO_DONE bit and continue if clear, i.e.
conv. complete
        goto    ADWait1

        call    BarTable        ;Convert ADRESH to port D coding

        movwf PORTD_CPY ;toggle returned bits into PORTD_CPY


        MOVLF       rdAN0           ;Select ADC's RA0/AN0 input
                                ;for intensity variable
        movlw d'15'
        movwf ADCHARGETIME
waitSet0
        decfsz  ADCHARGETIME,F          ;delay 30 usec for settling
        goto    waitSet0

        bsf     startAD                 ;Start conversion

ADWait0
        btfsc   ADCON0,GO_DONE          ;check GO_DONE bit and continue if clear,
                                ;i.e. conv. complete
        goto    ADWait0
        MOVFF       ADRESH,TEMP2
```

```
        movlw ADCON1  ;using indirect addressing
        movwf FSR ; right justify the AD converter
        bsf     INDF,ADFM

        MOVLF           rdAN3           ;Select ADC's RA3/AN3 input
                                ;for intensity variable
        movlw d'15'
        movwf ADCHARGETIME
waitSet3
        decfsz  ADCHARGETIME,F          ;delay 30 usec for settling
        goto    waitSet3

        bsf     startAD                 ;Start conversion

ADWait3
        btfsc   ADCON0,GO_DONE          ;check GO_DONE bit and continue if clear,
                                ;i.e. conv. complete
        goto    ADWait3

        movf    ADRESH,W   ;put high byte in T1HIGH
        movwf   T1HIGH

        movlw ADRESL ;ADRESL is in bank 1, so must use
        movwf FSR    ;indirect addressing to get it to
        movf    INDF,W ;T1LOW
        movwf T1LOW

        movlw ADCON1  ;using indirect addressing
        movwf FSR ; right justify the AD converter
        bcf     INDF,ADFM ;set back to left justify for other ADs

        bcf     offAD           ;turn AD off, save energy

BarEnd
        return
```

Appendix B

```
;;;;;; InitLCD subroutine ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;
; Initialize the FEMA 16x2 character LCD display.
; (Initialize PIC ports prior to calling this subroutine.)
; This subroutine uses a one-byte RAM variable called LCD_TEMP.

InitLCD
        MOVLF       25,LCD_TEMP         ;Wait 1/4 second
InitLCD_1
        call    LoopTime        ;Call LoopTime 25 times
        decfsz  LCD_TEMP,F
        goto    InitLCD_1
                                ;LCD_TEMP now equals zero
        bcf     PORTE,0                 ;RS=0 for command
InitLCD_2
        call    LCDinit_Table           ;Get next byte, pointed to by LCD_TEMP
        iorlw   H'00'           ;Set Z flag if W=0
        btfsc   STATUS,Z
        goto    InitLCD_done
        movwf TEMP_DISP  ;Save copy of byte
        swapf   TEMP_DISP,F             ;position for xfer part1
        rlf     TEMP_DISP,W             ;position for xfer part2

        movwf PORTB                     ;Send upper nibble
        bsf     PORTE,1                 ;Drive E high
        bcf     PORTE,1                 ;Drive E low so LCD will process input
        call    LoopTime        ;Wait ten milliseconds

        swapf   TEMP_DISP,F
        rlf     TEMP_DISP,W              ;rotate and put into W for Xfer
        movwf PORTB                     ;Send lower nibble
        bsf     PORTE,1                 ;Drive E high
        bcf     PORTE,1                 ;Drive E low so LCD will process input
        call    LoopTime        ;Wait ten milliseconds

        incf    LCD_TEMP,F;Point to next byte
        goto    InitLCD_2       ; and deal with it
InitLCD_done
        return
```

Appendix C

```
;;;;;;;;;;; ScanKeys subroutine;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

ScanKeys

        MOVLF        TRISB,FSR
        movlw B'00011110'
        xorwf  INDF,F;this sequence changes b1,2,3,4 to inputs

        clrf    KEYCODE    ;start by checking the "0" key

ScanKeys_1
        call    ScanKeys_Table        ;get next table entry
;;below xfers appropriate bits to columns
        movwf TEMPKEY; move to TEMPKEY for tests

        btfsc   TEMPKEY,3
        goto    SetCol1
        bcf     Col1
ChkCol2
        btfsc   TEMPKEY,2
        goto    SetCol2
        bcf     Col2
ChkCol3
        btfsc   TEMPKEY,1
        goto    SetCol3
        bcf     Col3
EndCol
        goto    TestRows

SetCol1
        bsf     Col1
        goto    ChkCol2
SetCol2
        bsf     Col2
        goto    ChkCol3

SetCol3
        bsf     Col3
        goto    EndCol
;; TestRows: compare B4,3,2,1 with table entry
;; keypressed->low->match->Z=1
TestRows
        swapf  TEMPKEY,F ;position for xfer part1
```

```
        rlf     TEMPKEY,W;position for xfer part2
;;if a match, get all zeros in w1,2,3,4
        xorwf   PORTB,W
;; AND screens so only compare RB1,2,3,4 inputs
;;Z=1 if a match, so return with value in KEYCODE
        andlw   B'00011110'
        btfsc   STATUS,Z
        goto    ScanKeys_done
        incf    KEYCODE,F ;otherwise try next key
 ;;stop with Z=0 when KEYCODE =xxxx1100
;if both bits 3 and 2 set, will return [ScanKeys_done]
        btfss   KEYCODE,3
        goto    ScanKeys_1

        btfss   KEYCODE,2  ;stop with Z=0 when KEYCODE =xxxx1100
        goto    ScanKeys_1

ScanKeys_done
;;restore B1-4 to outputs

        MOVLF           TRISB,FSR
        bcf     INDF,1;change b1-b4 to output without
        bcf     INDF,2 ;affecting z bit in status register
        bcf     INDF,3 ;use indirect addressing
        bcf     INDF,4

        return
```