

Final Project Report: Shipment Health Monitoring System



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Executive Summary

Shipping fragile packages with ease of mind is a priority to all postal service users. In years past, the only ways to protect delicate materials have been packaging them sufficiently with insulation or padding and hoping that they arrive in the same condition with which they were sent. To better ensure the integrity of a sensitive device or vulnerable product is maintained during shipping, a health monitoring device has been developed.

This package monitoring device makes certain a package has been kept in an appropriate environment. It utilizes a thermistor as a temperature sensor and an accelerometer as a damage tracker. The thermistor keeps track of the temperature within the package during shipping, and continuously displays an average temperature on a 2-digit LED display. The accelerometer senses sharp changes in acceleration due to package mistreatment. If the sudden change is too high, output is sent to a single-digit LED display, acting as a hit counter for the package.

Upon receiving their package, the user can easily evaluate the quality with which their package was handled and take appropriate action as a result.

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Introduction

In the United States, post mail and package transport is a trillion dollar industry. In many cases, items being shipped are fragile and vulnerable to weather conditions and mistreatment.

Although there are no concrete statistics on the frequency with which fragile packages survive their trip, everyone has surely had at least one disappointing experience when shipping a package. Every day, the United States Postal Service delivers about 660 million pieces of mail [\[1\]](#), while UPS delivers approximately 15 million packages per day [\[2\]](#). Assuming packages only comprise 1% of the postal service's volume, this equates to about 21 million packages total between both companies. Also assuming that the USPS and UPS both successfully deliver 99.99% of their daily package volume without damages, this leaves 2100 packages unsuccessfully delivered each day. With customer satisfaction a priority for these companies, a device to help alleviate this issue has been conceived.

Objective

By implementing a small device used to keep track of damaging blows to a package and temperature within a package, the end receiver can judge the quality with which it was treated en route. Upon shipping, the sender can insert the device inside the package itself. Upon receipt, the user can remove the device and read the displayed data. If they feel that their fragile package was mistreated, the carrier can be notified. Using a prevention method like this within the companies can also alert them to the quality with which they treat fragile packages, hopefully leading to improved services and customer confidence.

Existing Products

Gulf Coast Data Concepts, LLC produces a Freight Monitoring Accelerometer which performs a similar task [3]. It continually logs data from an accelerometer over a maximum of 60 days and if the package experiences excessive g-forces from an external impact during shipping, the user can observe the irregularities in the data log. *Gulf Coast Data Concepts* also produces an Impact Sensor with a USB interface for easy access to its data log [4]. In addition, a product produced by *Instrumented Sensor Technology* logs acceleration data continuously and can report any impact sensed over a period of time, but it does not offer temperature measurement capabilities [5]. Both of these products are very expensive, \$165 and \$199 respectively, whereas our product would be a cheap and comparable alternative for the home or small business markets.

Engineering Specifications

- Able to run on a battery supply voltage for up to 30 days
- Compact, preferably no bigger than 4" x 6" X 2"
- As lightweight as possible
- Able to be attached to the inside of the box and remain in place
- No risk of damaging package
- Reliable and accurate readings
- Not vulnerable to noise
- Robust and able to withstand high impacts without erroneous readings

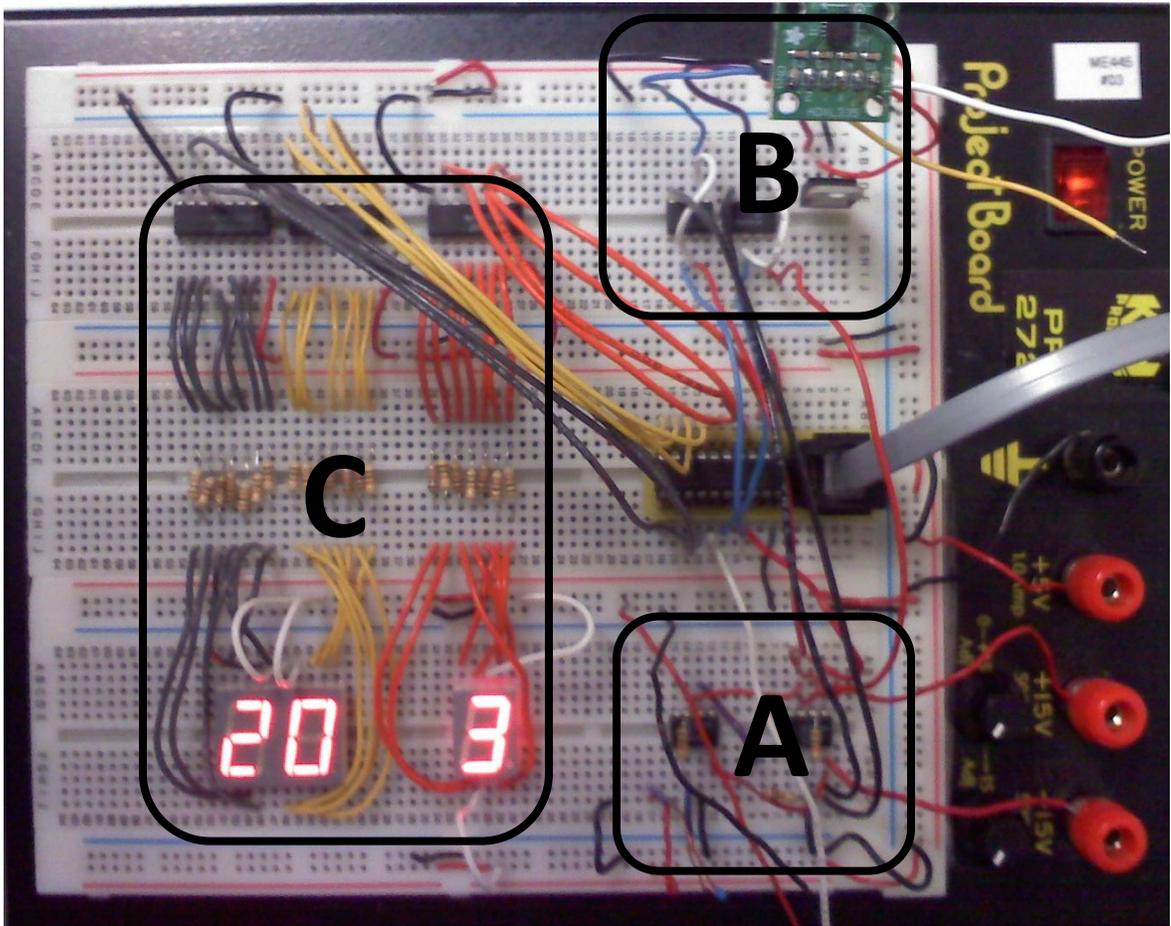
Technical Detail

The shipment health monitoring system is comprised of three distinct sections:

- A) Temperature Measurement
- B) Impact Measurement
- C) Data Display

As a whole, the system is arranged as shown below, with Section A in the lower right, Section B in the upper right, and Section C on the left. The PIC can also be seen in the middle right of the protoboard (Figure 1).

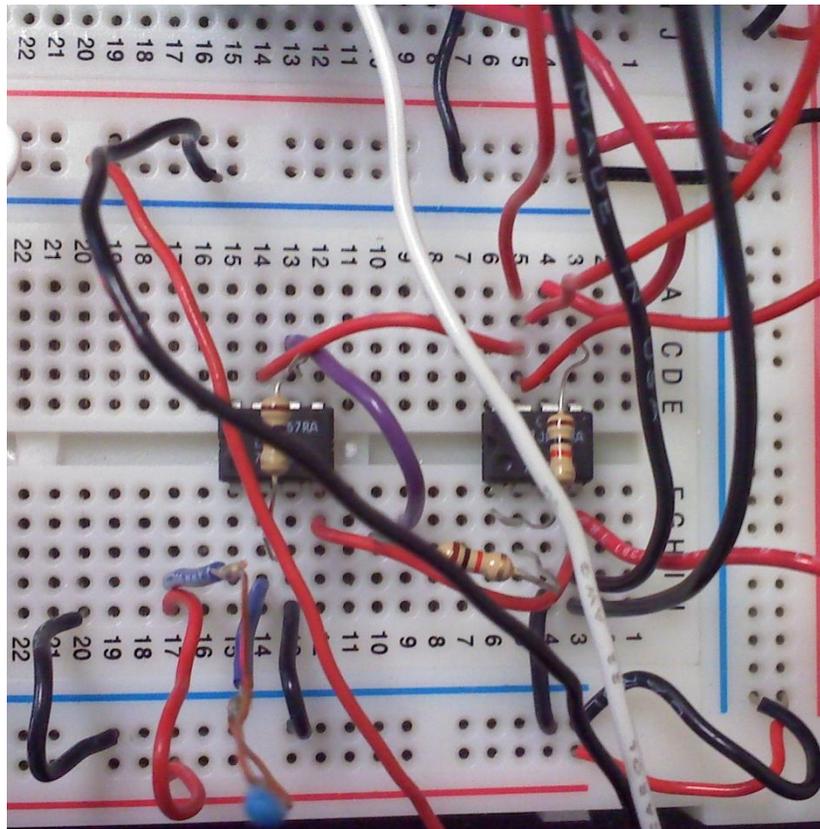
Figure 1 – Overall Project Layout



A) Temperature Measurement

The purpose of this circuit is to continuously monitor the temperature within the package, ensuring it does not exceed acceptable levels. This task is accomplished by using a modified thermistor in combination with two inverting LM741CN operational amplifiers (Figure 2). The voltage output of this circuit is measured by the PIC, and through simple algebra the thermistor resistance is determined (Equation 1). By using this resistance in a linear equation valid for the 0° C to 40° C range, we are then finally able to determine the ambient temperature (Equation 2).

Figure 2 – Thermistor and Two Inverting Operational Amplifiers



Equation 1 – Inverting Operational Amplifier Calculation

$$V_o = -\left(\frac{R_{in}}{R_f}\right)V_{in} \text{ where } R_{in} = R_T$$

So,

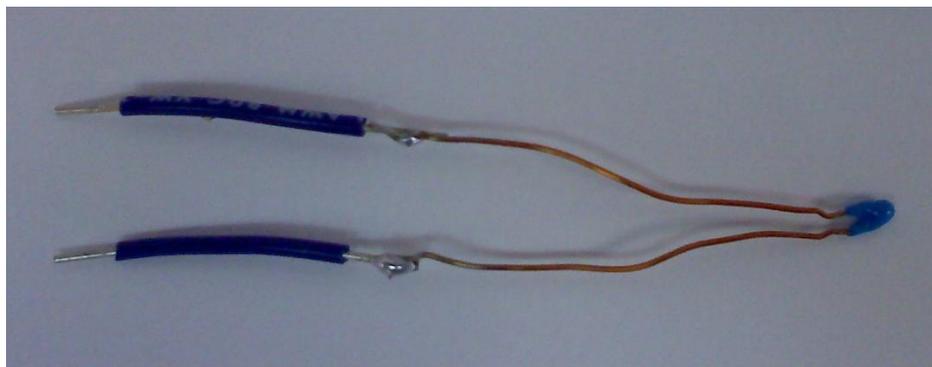
$$R_T = -\left(\frac{V_o}{V_{in}}\right) * R_f$$

Equation 2 – Termistor Temperature Calculation

$$T = .0715 * R^2 - 4.13 * R + 60.211$$

The modifications to our thermistor were dictated by a problem that became apparent when we were first testing the circuit. It seemed that the voltage it was producing would bounce between zero and predicted value for room temperature. Eventually, it was determined that this was due to the leads of the thermistor not making full contact with the protoboard, likely due to its thin wire gauge. Therefore, we soldered short lengths of wire onto the leads, which eliminated this problem (Figure 3).

Figure 3 – Modified Thermistor



As previously mentioned, two inverting operational amplifiers were integral parts of the circuit design (Figure 4). The first was necessary in order to allow for resistance measurement and the second in order to convert the negative voltages produced into positive values that the PIC can actually recognize. A multisim circuit representing this arrangement and the hardware used can be found below (Figure 5).

Figure 4 – Inverting Operational Amplifier Schematic

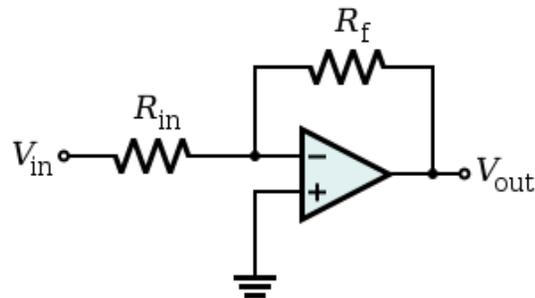
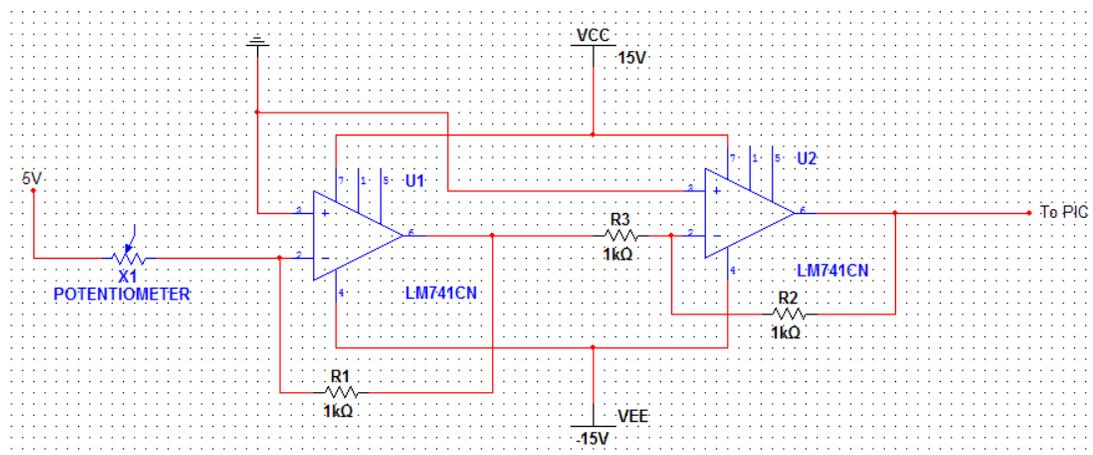


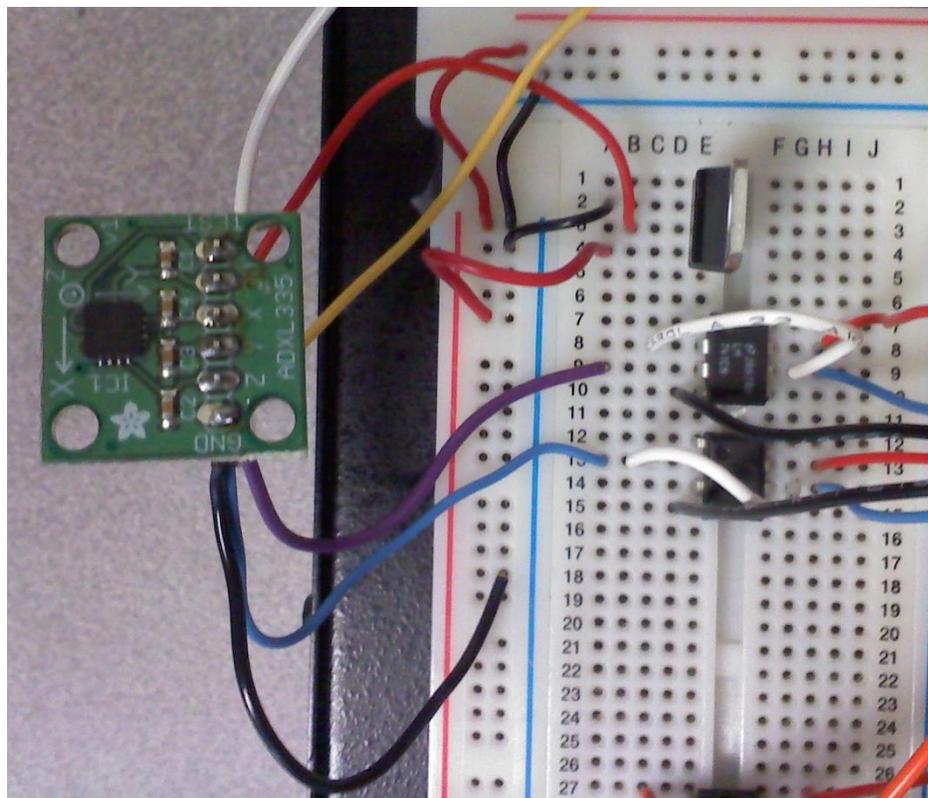
Figure 5 – Temperature Measurement Circuit



B) Impact Measurement

A critical feature of our system is the ability for it to sense severe, and potentially damaging, impacts that a package is exposed to. In order to accomplish this task, a circuit containing an ADXL335 accelerometer, two LM741CN operational amplifiers, and a voltage convertor was constructed, as seen below (Figure 6).

Figure 6 – Accelerometer, Two Operational Amplifiers, and a Voltage Convertor



By combining the ADXL335 accelerometer, which outputs a voltage proportional to acceleration, with the PIC's analog to digital convertor this monitoring feature can be implemented. The equation governing the voltage to acceleration conversion that the PIC will perform is prescribed in the manufacturer's data sheet, and can be seen below (Equation 3).

Equation 3 – Accelerometer Calculation

$$A_G = \frac{V_o}{.3 V/G}$$

There were two other factors that we had to consider when constructing this circuit, which dictated its structure as seen previously. First, the accelerometer requires approximately three volts of input in order to perform as expected. It is important to maintain this requirement in order to produce an acceleration response and sensitivity that is stable enough to be relied on for accurate calculations. In order to achieve this, a 3.3 volt convertor was used, which can transform the 5 volts that is typically available into something that will be useful for this application. Second, two LM741CN operational amplifiers were implemented between the accelerometer output and PIC in order to perform as unity gain buffers (Figure 7). This is necessary due to the fact that the input impedance of the accelerometer is very high, on the order of 35 k Ω , whereas the PIC prefers values of 10k Ω or lower. A multisim representation of this entire circuit can be found below (Figure 8).

Figure 7 – Unity Gain Buffer Schematic

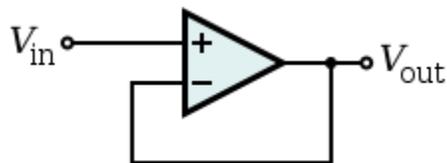
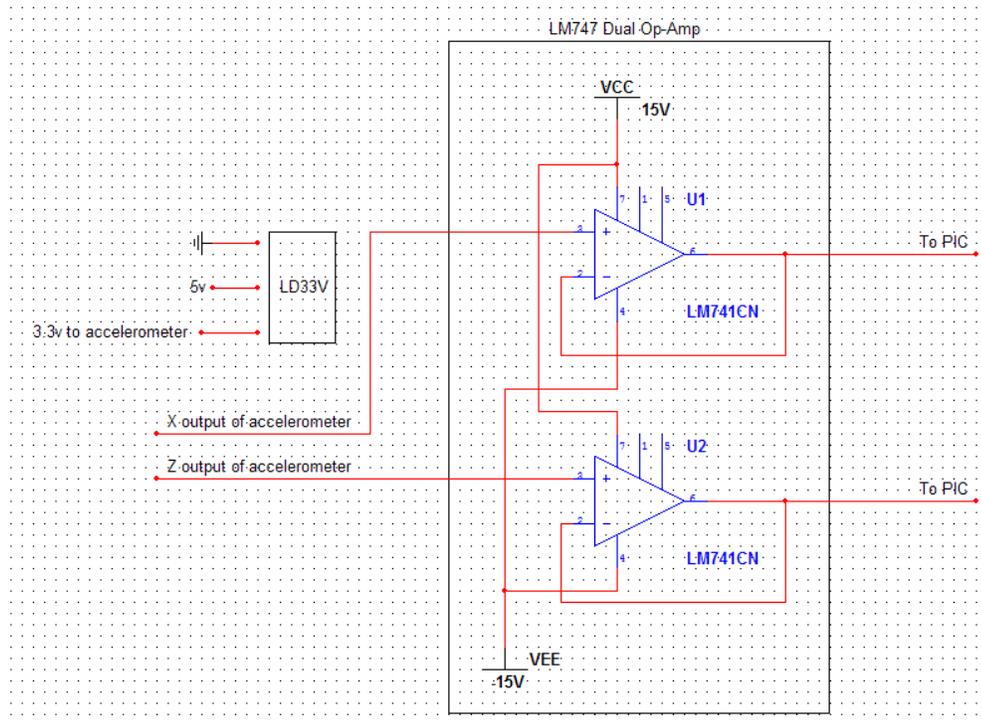


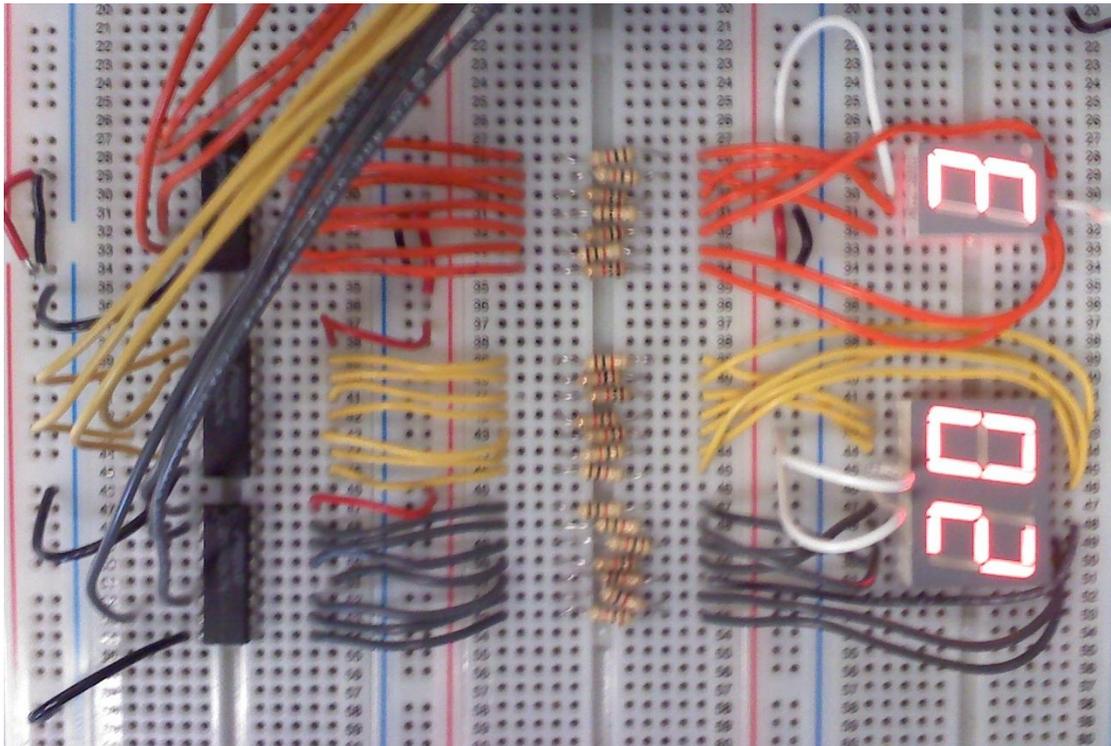
Figure 8 – Impact Measurement Circuit



C) Data Display

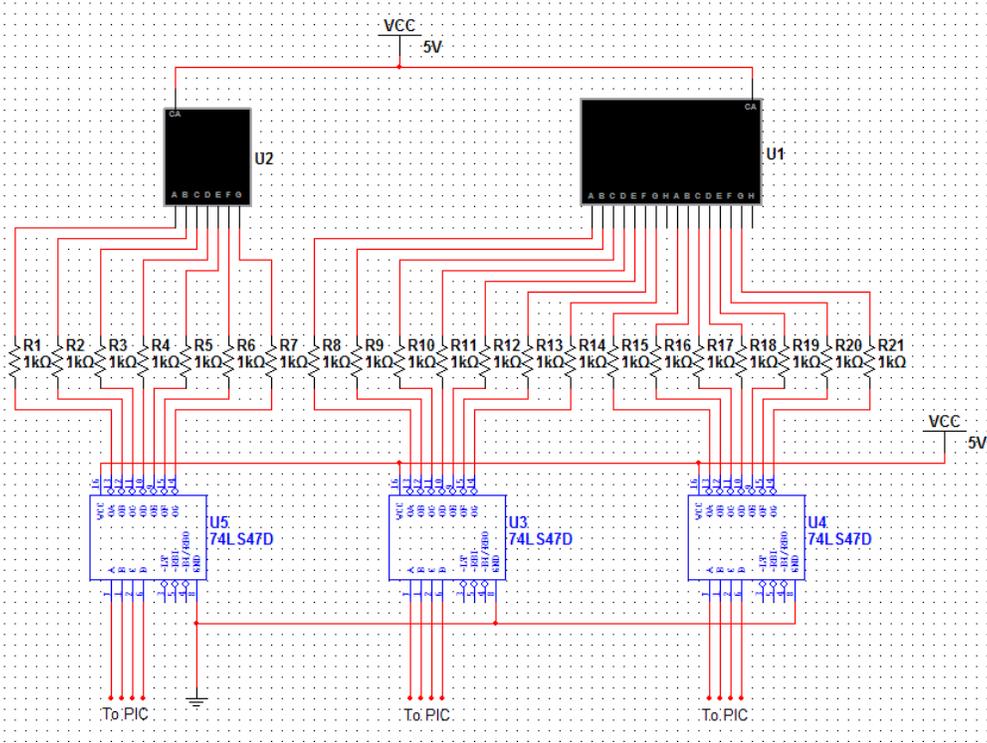
All the data gathered by the PIC from both the thermistor and accelerometer is of no use unless it can be displayed when the package arrives at its destination. This has been accomplished through the use of a LSD5061-11 single seven segment LED for the accelerometer, as well as a HDSP5216 dual seven segment LED for the temperature. In addition, each seven segment LED requires a 74LS47N decoder/driver in order to operate, and as a result our circuit contains three of these chips. This entire arrangement can be seen below, with yellow and grey wires corresponding to the temperature LED, and orange to the accelerometer LED (Figure 9).

Figure 9 – Three 7447 decoders, Seven Segment LED Displays, and Resistors



As always, LEDs must be protected from excess current, and to that end 1 k Ω resistors were placed between our decoder/driver chips and the displays. This will ensure a long life for the LEDs and prevent them from burning out while the package is in transit. A multisim diagram of this setup is shown below (Figure 10).

Figure 10 – Data Display Circuit



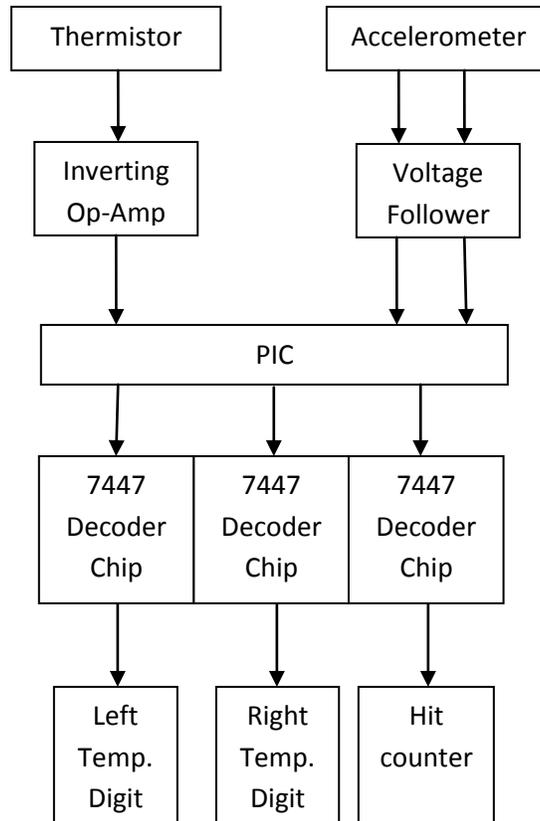
Conclusions and Recommendations

In conclusion, our team learned about new hardware devices such as the thermistor and accelerometer, and how to successfully interface them with the PIC microcontroller. Being able to understand what these components output and how to manipulate it makes coding with the PIC much easier. We also became more familiar with displaying data on the 7-segment LEDs and illustrated that if integers are to be displayed as data, the 7-segment LED is a good and easy choice. Furthermore, we solidified our circuit 'housekeeping' skills, which included color coding wires and breaking up large circuits into modules helps to systematically debug problems within the circuit without wasting time.

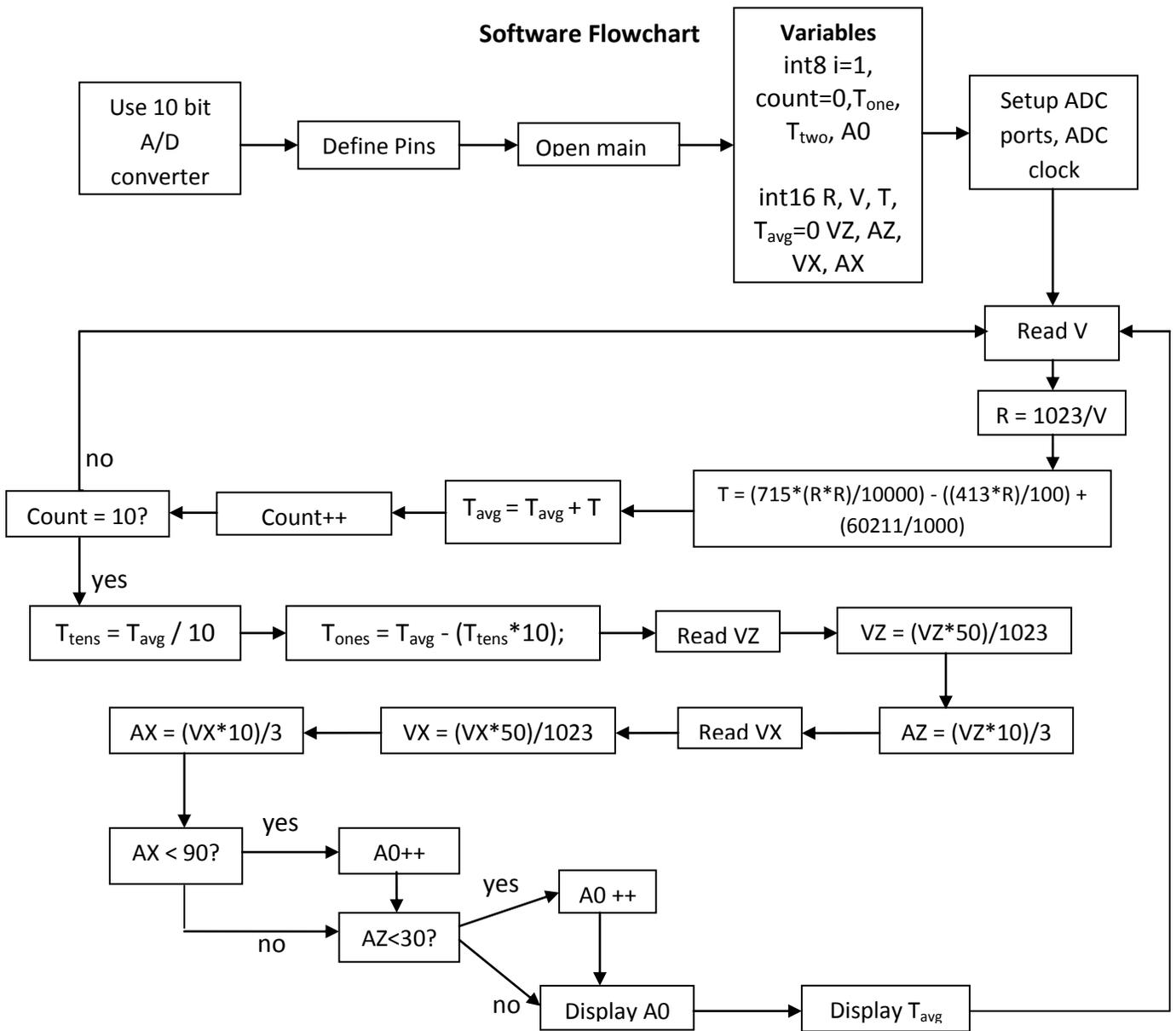
For the future, we believe that this project is very viable to be packaged and marketed as a commercial product. With the accelerometer being the costliest component at around \$25-\$30, the packaged product would have the potential to be much cheaper than current models on the market. Also, its fewer components would keep it simple to produce, as well as lightweight and compact. A product of this sort, once on the market, would provide our customer with the ability to accurately gauge the treatment of their shipped item and therefore make a judgment on its condition. By doing so, the ambiguity that often is associated with a broken product can be mitigated, and the shipment company will be held accountable for its treatment of customer goods.

Appendix A: Hardware and Software Flowcharts

Hardware Flowchart



Software Flowchart



Appendix C: Final Project Code

```

////////////////////////////////////
//Final Project - Spring 2010, Shipping health monitor, Erick Froede, Dave Stout

#include <16f690.H>
#define ADC = 10          //use 10-bit ADC
//
//      Vdd 1 o| |o 20 GND
//      RA5 2 o| |o 19 RA0/AN0/ICSPDAT
//      RA4/AN3 3 o| |o 18 RA1/AN1/ICSPCLK
// RA3/_MCLR/Vpp 4 o| |o 17 RA2/AN2
//      RC5/CCP1 5 o| |o 16 RC0/AN4
//      RC4 6 o| |o 15 RC1/AN5
//      RC3/AN7 7 o| |o 14 RC2/AN6
//      RC6/AN8 8 o| |o 13 RB4/AN10
//      RC7/AN9 9 o| |o 12 RB5/AN11/RX
//      RB7/TX 10 o| |o 11 RB6
//
//      -----
// RA3 is input only if not using _MCLR
//
// ICSP programming - must supply Vdd to ICSP programmer
// pin 4 = Vpp - no user connection for ICSP
// pin 1 = Vdd
// pin 20 = GND
// pin 19 = PGD - no user connection for ICSP
// pin 18 = PGC - no user connection for ICSP

#fuses intrc_io, nomclr, nowdt, noprotect
#use delay( clock=8MHZ )          // 8 MHz internal clock

#define O1 PIN_A5 // pin 2
#define O2 PIN_A4 // pin 3
#define O3 PIN_C5 // pin 5
#define O4 PIN_C4 // pin 6
#define Y1 PIN_C3 // pin 7
#define Y2 PIN_C6 // pin 8
#define Y3 PIN_C7 // pin 9
#define Y4 PIN_B7 // pin 10
#define G1 PIN_C2 // pin 14
#define G2 PIN_B4 // pin 13
#define G3 PIN_B5 // pin 12
#define G4 PIN_B6 // pin 11

```

```

////////////////////////////////////
// main loop
void main()
{
// variables
int8 count;
int16 R;      //Thermistor resistance, in Kohms
int16 V;      //Thermistor voltage
int16 T;      //Thermistor temperature
int16 Tavg = 0; //Temperature average
int8 Tones, Ttens; //Tens and ones temperature digits
int8 A0 = 0;   //Hit counter value
int16 V1, V2; //Accelerometer voltage values
int8 A1, A2;  //Acceleration values

//setup A/D converter pins
setup_adc_ports( sAN2 ); //A/D port for thermistor voltage
setup_adc_ports( sAN5 ); //A/D port for Z acceleration
setup_adc_ports( sAN4 ); //A/D port for X acceleration
setup_adc( ADC_CLOCK_INTERNAL );

// top of infinite loop
do
{
Tavg = 0; //Temperature initially zero
for(count=0; count<=10; count++) //For loop, counts 10 temperatures
{
set_adc_channel( 2 );
V = read_adc(); //Read thermistor voltage input
R = (1023/V); //Convert to resistance
T = (715*(R*R)/10000)-((413*R)/100)+(60211/1000); //Calculate temp
Tavg = (Tavg + T); //Temperature summation
} //End for loop
Tavg = Tavg/10; //Temperature average

Ttens = Tavg/10; //Pull tens temperature digit from average
Tones = Tavg - (Ttens*10); //Pull ones temperature digit from average

//Accelerometer
//measure Z
set_adc_channel(5);
V1 = read_adc(); //Read accelerometer Z voltage - digital value
V1 = (V1*50)/1023; //Convert to analog value

```


Appendix D: Works Cited and Datasheets

Works Cited

1. "F6E Freight Monitoring Accelerometer." *Data Acquisition Hardware*. Gulf Coast Data Concepts. Web. 30 Apr. 2010.
<<http://yhst-21371435622982.stores.yahoo.net/freight-monitoring-accelerometer.html>>.
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<<http://www.isthq.com/Products/SnapShockPlus/tabid/602/Default.aspx>>.
3. United States of America. United States Postal Service. *USPS - Postal Facts*. Web. 30 Apr. 2010.
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4. "UPS Fact Sheet." *UPS Pressroom*. UPS. Web. 30 Apr. 2010.
<<http://www.pressroom.ups.com/Fact+Sheets/UPS+Fact+Sheet>>.
5. "X250-2 Impact Sensor." *Data Acquisition Hardware*. Gulf Cost Data Concepts. Web. 30 Apr. 2010. <<http://yhst-21371435622982.stores.yahoo.net/x2502-impact-se2502.html>>.

Datasheet References

1. ADXL335 Accelerometer:
http://www.analog.com/static/imported-files/data_sheets/ADXL335.pdf
2. LM741CN Operational Amplifier:
<http://www.national.com/ds/LM/LM741.pdf>
3. DM74LS47N Decoder:
<http://pdf1.alldatasheet.com/datasheet-pdf/view/51079/FAIRCHILD/DM74LS47N.html>
4. LD33V Voltage Regulator:
<http://www.sparkfun.com/datasheets/Components/LD1117V33.pdf>
5. HDSP-H151 7-Segment LED Display:
<http://www.datasheetcatalog.org/datasheet/hp/HDSP-5507.pdf>
6. LDDA516RI Dual 7-Segment LED Display:
<http://datasheet.octopart.com/LDD-A516RI-Lumex-datasheet-163685.pdf>