Weighing Scale

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Agenda

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- Prior Work/Design
- Safety Hazards (OSHA) & (FCC)
- Objective Tree
- Design Alternative
Agenda

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- Parts List
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- Circuit Schematics
- Hardware Problems
Agenda

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- Implementation into the code
- The Code
- Registers
- Calculation of Weight
- Software Design Problems
- Closing
Overview of the Project

- Weigh several items
- Display on the LCD
- Weigh up to 17 lbs + the Tray
- A/D Converter
- Used a Flexi-Force Pressure Sensor
  - Acts a variable resistor
  - Can be implemented in an Inverting Circuit
Prior Work/Design

Apparatus for automatically changing the integration time and resolution of an electrical scale under predetermined operating conditions

Patent Number: 4,156,472
Date: May 29, 1979

Aspects of the patent that concerns our project: This patent applies to the iterative method employed in calculating weight from the digitized input signal of the scale.
Prior Work/Design

Electronic scale with CRT display

Patent Number: 4,597,457
Date: July 1, 1986

Aspects of the patent that concerns our project: This patent is the earliest patent in which the output of the scale is displayed in a digital fashion on a CRT display. It also mentions the addition of timepiece functionality. The main purpose of this invention, however, is its application in a sales environment where units are sold by weight.
Prior Work/Design

Mechanical scale conversion system

Patent Number: 5,207,284
Date: May 4, 1993

Aspects of the patent that concerns our project: This patent is for the conversion of a mechanical scale system to an electrical system by the use of a pressure-sensitive transducer.
Prior Work/Design

Electronic scale

Patent Number: 6,373,237
Date: April 16, 2002

Aspects of the patent that concerns our project: This patent is for an electric weight scale that integrates the functionality of a scale with that of a real time clock. The output is determined using a process, which converts an analog signal to a digital one and presented on a liquid-crystal display. The patent holder, however, uses a capacitor whose plates overlap variably depending on the weight placed on the scale.
Safety Hazards

OSHA

FCC
OSHA

Section 1910.304:

WIRING DESIGN AND PROTECTION

Use and identification of grounded and grounding conductors

Identification of conductors. A conductor used as a grounded conductor shall be identifiable and distinguishable from all other conductors. A conductor used as an equipment grounding conductor shall be identifiable and distinguishable from all other conductors.
OSHA

- Polarity of connections. No grounded conductor may be attached to any terminal or lead so as to reverse designated polarity.

- Use of grounding terminals and devices. A grounding terminal or grounding-type device on a receptacle, cord connector, or attachment plug may not be used for purposes other than grounding.
OSHA

Section 1910.305: 
WIRING METHODS, COMPONENTS, AND EQUIPMENT FOR GENERAL USE

- Use and identification of grounded and grounding conductors
  - Polarity of connections. No grounded conductor may be attached to any terminal or lead so as to reverse designated polarity
OSHA

- Identification of conductors. A conductor used as a grounded conductor shall be identifiable and distinguishable from all other conductors. A conductor used as an equipment grounding conductor shall be identifiable and distinguishable from all other conductors.

- Use of grounding terminals and devices. A grounding terminal or grounding-type device on a receptacle, cord connector, or attachment plug may not be used for purposes other than grounding.
Section 1910.303: GENERAL REQUIREMENTS

Marking

Electrical equipment may not be used unless the manufacturer's name, trademark, or other descriptive marking by which the organization responsible for the product may be identified is placed on the equipment. Other markings shall be provided giving voltage, current, wattage, or other ratings as necessary. The marking shall be of sufficient durability to withstand the environment involved.
FCC

This project is a non-communicative device which requires the use of no wireless components, therefore no FCC regulations govern its design, implementation, or distribution.
Objective Tree

Objective Tree for the Design and Production of a Weight Scale

Building and Designing a Weight Scale

Product Qualities

Inexpensive

Easy to Handle

Professional Looking Product

Percieved as Safe

Durable

Portable

Accurate Measurement

Weigh up to Maximum Capacity

Stable Measurement

Quantitatively Accurate

Digital Display Easy to Read

Weigh up to Maximum Capacity

Stable Measurement

Quantitatively Accurate

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Digital Display Easy to Read

Weigh up to Maximum Capacity

Stable Measurement

Quantitatively Accurate

Digital Display Easy to Read

Weigh up to Maximum Capacity

Stable Measurement

Quantitatively Accurate

Digital Display Easy to Read
Design Alternative

- Four columns of base pipes connected on the bottom by connecting tubes
- Scale pipes would then be placed in the base pipes and they would be connected on top by a weighing platform
- Although short, would be too bulky and wouldn't measure with the greatest accuracy
Detailed Theory of Design

Design Factors

Design Structure
- Base made from Plexiglas
- Platform composed of wood
- Metal rod and engine valve
- Metal plate
Design Assembly

- Physical Properties of Weight Scale
- Assembled Picture of Weight Scale
Parts List

Motorola HC11 Micro-Computer Evaluation Board
- 120 Volt AC to 5 Volt DC converter
- Male to Female Serial Cable
- Buffalo Assembler
- Monitor Program
- LCD Display

Logic ICs
- 2 NTE 941 Operational Amplifiers
Parts List

Miscellaneous Parts

- Switch
- Flexi-force Pressure Sensor
- 1 - 10 K Ω Resistors
- 2 - 20 K Ω Resistor
- 2 – 9 V Batteries
- 2 – Power Plugs
- Wires
- Plexiglas
- 2 – 2”x4” wood
- Engine Valve
- Metal Plate
- 5 Screws
- Metal Pipe
## Cost Analysis

<table>
<thead>
<tr>
<th>Product</th>
<th>Cost</th>
<th>Quantity</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>NTE 941 Operational Amplifiers</td>
<td>$1.50</td>
<td>2</td>
<td>$3.00</td>
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<tr>
<td>Flexi-force Pressure Sensor</td>
<td>$24.99</td>
<td>1</td>
<td>$24.99</td>
</tr>
<tr>
<td>LCD Display</td>
<td>$23.99</td>
<td>1</td>
<td>$23.99</td>
</tr>
<tr>
<td>10 K Ω Resistors</td>
<td>$0.15</td>
<td>1</td>
<td>$0.15</td>
</tr>
<tr>
<td>20 K Ω Resistor</td>
<td>$0.15</td>
<td>2</td>
<td>$0.30</td>
</tr>
<tr>
<td>9 V Batteries</td>
<td>$7.50</td>
<td>2</td>
<td>$15.0</td>
</tr>
<tr>
<td>Power Plugs</td>
<td>$0.50</td>
<td>2</td>
<td>$1.00</td>
</tr>
<tr>
<td>Wires (Different Sizes)</td>
<td>$0.05</td>
<td>14</td>
<td>$0.70</td>
</tr>
<tr>
<td>2”x4” wood</td>
<td>$1.00</td>
<td>2</td>
<td>$2.00</td>
</tr>
<tr>
<td>Engine valve</td>
<td>$2.50</td>
<td>1</td>
<td>$2.50</td>
</tr>
<tr>
<td>Metal Plate</td>
<td>$0.50</td>
<td>1</td>
<td>$0.50</td>
</tr>
<tr>
<td>Screws</td>
<td>$0.10</td>
<td>5</td>
<td>$0.50</td>
</tr>
<tr>
<td>Metal Pipe</td>
<td>$0.63</td>
<td>1</td>
<td>$0.63</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$175.25</strong></td>
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</table>

**Conclusion: Money is Honey!**
Flexiforce Pressure Sensor

Flexiforce pressure sensors can measure force between almost any two surfaces and is durable enough to stand up to most environments. Flexiforce has better sensor properties, linearity, drift and temperature sensitivity than any other thin film force sensor.
Flexiforce Pressure Sensor

Typical Sensor Response

- Acts as a Resistor in an electrical circuit
- Sensor unloaded, resistance is high
- Sensor loaded, resistance is lowered

Applications

- Force to Voltage Circuit
- Calibration
Flexiforce Pressure Sensor

Characteristics/Physical Properties
- Thickness: 0.005" (0.127 mm)
- Length: 8.000" (203 mm) - End of connector to tip of sensor
- Width: 0.55" (14 mm)
- Active Sensing Area: 0.375" (10 mm) diameter
- Connector: 3 pin Berg Clincher
Test Circuit for Sensor

Initial Circuit Set-Up

\[ V_{out} = V_r \times \left( \frac{R_f}{R_s} \right) \]

- **Rs** = Pressure Sensor
- **Rf** = feedback resistor range (1K to 100K ohms)
Operational Amplifier

NTE941 Op-Amp
- Pin 1: Offset Null
- Pin 2: Inverting Input
- Pin 3: Non-Inverting Input
- Pin 4: V-
- Pin 5: Offset Null
- Pin 6: Output
- Pin 7: V+
- Pin 8: NC
Mechanical/Hardware Design Problems

- Keeping a consistent mating surface between the sensor and the stand
- Friction
- Following error
- Maximizing the resolution of the analog-to-digital conversion
Mechanics/Hardware Design Problems

Keeping a consistent mating surface between the sensor and the stand

Problem: There was too much clearance between the hole drilled into the block of wood and the shaft of the stand.

Solution: Copper tape was used to increase the diameter of the shaft to keep the weight stand stable and the interface between it and the sensor consistent.
Friction

Problem: With the copper tape in place, there was too much friction between the wood and the shaft of the weight stand.

Solution: The wood was bored out to a greater diameter and a piece of pipe was inserted. This greatly decreased the friction.
Following error

Problem: The values of the voltages measured during the calibration process fluctuated too much.

Solution: By increasing the values of all of the resistors used in our inverting amplifiers, we were able to stabilize the analog representation of the weight.
Mechanics/Hardware Design Problems

Maximizing the resolution of the analog-to-digital conversion

**Problem:** Because the value of the voltage corresponding to the maximum allowable weight was so low, we were not using more than half of the digital values available.

**Solution:** We doubled the gain of one of our inverting amplifiers so that our maximum signal was closer to 5 volts.
Calibration Process

- Importance
- Process
- Implementation in the code
- Testing
Importance of Calibrating the Scale

- Dr. Mahmud won’t give an account for an uncalibrated scale

- No one wants to buy or use a scale that isn’t accurate
The Calibration Process

- Gathering data
  - Using known weights and a digital multimeter, the analog values of voltages corresponding to specific weights were obtained.
  - The values were graphed to check for linearity.
  - The values were converted into 8-bit digital numbers.
Implementation into the Code

Consideration of two methods
- Tabular, or Look-Up Method
- Integrative Method
Implementation into the Code

The **tabular method** consists of a subroutine that progressively checks the value of ADR2 against the known digital values until a match is found.
Implementation into the Code

The **iterative method** takes advantage of the linearity of the system and uses a loop to subtract the digital equivalent of a one pound load from the contents of ADR2 until it reaches a value corresponding to less than one pound. A counter keeps track of the weight of the object in question.
Implementation into the Code

We have chosen a combination of the two:

- For the whole part of the weight, the tabular method was used
  - The system is practically linear. However, there is a small degree of error that introduces too much deviation in the final weight
  - Comparing the digital value to known values for specific weights is more accurate
Implementation into the Code

- For the fractional part of the weight, the iterative method was used
  - The degree of difficulty and inaccuracy in finding corresponding values of small amounts of weight is too high
  - The amount of error introduced in the linearization of the fractional weight is small
The Code

Setting up the appropriate registers
- A/D Control/Status Register (ADCTL)
- Option Register

Calculation of the weight
- Obtaining the digitized input
- Manipulating the digital number

Displaying the weight
The Registers

ADCTL Register

<table>
<thead>
<tr>
<th>ADCTL</th>
<th>CCF</th>
<th>-</th>
<th>SCAN</th>
<th>MULT</th>
<th>CD</th>
<th>CC</th>
<th>CB</th>
<th>CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>X</td>
<td>X</td>
<td></td>
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</tbody>
</table>

Option Register

<table>
<thead>
<tr>
<th>OPTION</th>
<th>ADPU</th>
<th>CSEL</th>
<th>IRQE</th>
<th>DLY</th>
<th>CME</th>
<th>-</th>
<th>CR1</th>
<th>CR0</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>X</td>
<td>0</td>
<td>X</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Registers

Using the ADCTL Register:
- A Multi-Channel, non-Continuous Scan set-up that converts an analog signal from PE5 and converts it into a digital value to be stored in the ADR2 register

Using the Option Register:
- Turn on the A/D charge pump and set the E-clock to 2 MHz
Calculating the Weight

The calculation of the weight is divided into two parts:

- Calculation of the whole part
- Calculation of the fractional part
The Whole Part

\[ \text{A/D} \rightarrow \text{ADR2} \rightarrow \text{ACC A} \]

- If \( > D_{17} \), then \( \text{ACC A} = \text{ACC A} - D_{17} \)
- If \( > D_{16} \), then \( \text{ACC A} = \text{ACC A} - D_{16} \)
- If \( > D_{1} \), then \( \text{ACC A} = \text{ACC A} - D_{1} \)

To Fraction Part
The Fractional Part

ACC A
(whole rtn)

INC
Whole

SUB 100
From Fract

PRINT

<0

INC
Fract

SUB A

>100

PRINT
Any good design includes the testing the resulting prototype

Various items of known weight were used to ensure the proper calibration and implementation of the scale
Software Design Problems

- Inclusion of the weight display routine
- Inaccuracy of our clock
- Jumping cursor
Software Design Problems

Inclusion of the weight display routine

- **Problem:** Inserting the code to print the weight into the infinite loop succeeding the CLI command sent the clock out of control

- **Solution:** A quarter second routine was added to the original clock code for the purpose of calculating and displaying the weight
The Time-flies Problem

LDX #REGBAS
LDAA #$F0
STAA DDRD,X
LDD TCNT,X
ADDD #TFIVE_MS
STD TOC2,X
BSET TMSK1,X $40
BCLR TFLG1,X $BF
CLI
BRA *

STD TOC2,X
BSET TMSK1,X $40
BCLR TFLG1,X $BF
CLI
BRA LOOP
Software Design Problems

Inaccuracy of our clock

Problem: Including at lengthy quarter second routine resulted in missed OC2 interrupts

Solution: The time between OC2 interrupts was lengthened to accommodate the scale code and still ensure the accuracy of our clock
Software Design Problems

- **Problem:** Because our time is displayed on line 2 of the LCD and the weight is displayed on line 4, the cursor on the LCD continuously jumped around in an annoying fashion.

- **Solution:** The code setting up the LCD was altered to remove the flashing cursor.
Closing

- A brief demonstration
- Questions

Thank You