ME 5643 MECHATRONICS FINAL PROJECT

DENSITY METER

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OUTLINE

• Introduction
• Materials and methods
  • Sensors and their calibration
  • Circuitry
  • Program
  • Structure
• Results
• Demonstration
INTRODUCTION

- Scientific concepts, particularly those related to chemistry and material properties, can be difficult for students to grasp
  - Density is one of the most fundamental material properties to understand
- Hands-on experiments and measurements can make it easier to master difficult scientific concepts and their calculation

- A **density meter** has been designed using the tools of mechatronics to serve as an educational tool to measure:
  - Mass
  - Volume
  - Density
  of both liquids and solids

\[
\text{Density} = \frac{\text{Mass}}{\text{Volume}}
\]
SENSORS – FORCE SENSOR

• A Tekscan FlexiForce® sensor was chosen to measure the force exerted by the mass of an object
  • A201-25 measures between 0 – 25 lbs
• The sensitive area of the FlexiForce® sensor is composed of two adjacent films of conductive polymer
  • When a force is applied they come in contact, reducing the resistance
  • \( \rightarrow \) the FlexiForce® therefore acts as a variable resistor
  • with no load, the sensor has a resistance of > 5 M\( \Omega \)
  • A maximum load (25 lbs) decreases the resistance to approximately 5 k\( \Omega \)

• The FlexiForce® sensor is interfaced to the BS2 through an RC circuit
It was necessary to calibrate the FlexiForce® sensor in order to obtain useful information to determine the mass.

- **RCTime** command was used to determine the resistance of the FlexiForce®:

\[
RCTime = 635R \cdot C
\]

- Precise volumes of water (density = 1 g/ml) were used to calibrate the FlexiForce® sensor.

Resistance is non-linearly related to mass.
Resistance is exponentially related to mass.

Linearization of resistance was performed according to:

\[ R = \frac{M}{K} \]

The force sensor was determined to have an average error of 7.33%.

\[ R^2 = 0.9345 \]

\[ R^2 = 0.9567 \]

\[ K = 10 \times 10^6 \]
A PING\textsuperscript{TM} ultrasonic sensor is used to measure liquid level

- Emits a 40 kHz tone and measures the time it takes to receive an echo from an object
- Range of 2 cm – 3.3 m

Distance is correlated to travel time of the signal:

\[ D = \frac{c \cdot t}{2} \]

\( D \) = distance (cm)
\( c \) = speed of sound in air at 22 °C (34480 cm/s)
\( t \) = time (s)

Divided by 2 to account for round trip of signal
LIQUID CRYSTAL DISPLAY

- A Parallax 2x16 serial liquid crystal display (LCD) component is used as a user interface

- Displays instructions and measurement results obtained
DENSITY METER SPECIFICATIONS

- Plexiglas was used to construct the housing for the density meter
  - Assembled with glue
- Overall measurements are:
  - 20 x 20 x 40 cm
- For measuring solids:
  - volume < 600 ml, dimensions < 10 cm
- For measuring liquids,
  - 200 ml < volume < 1 l
- Voltage: 4 x 1.5 V batteries
- Accuracy of approximately 10 %
- Servo motor connected to $V_{dd}$, $V_{ss}$, and pin 11
- PING)))™ sensor connected to $V_{dd}$, $V_{ss}$, and pin 15
- FlexiForce® sensor connected to $V_{ss}$ and pin 7
- LCD connected to $V_{dd}$, $V_{ss}$, and pin 14
- 2 SPST normally-off buttons connected to pins 0 and 1
- Servo motor, ultrasonic sensor, force sensor, and LCD all interfaced via 3-pin connections
PBASIC PROGRAM

' -----[ Height Measurements ]-----------------------------------------------
height:

IF material = 0 THEN
  PULSOUT USpin, 5
  PULSIN USpin, 1, time
  h1 = CmConstant ** time

  SEROUT 14, 84, [22,12]
  SEROUT 14, 84, [128,"Mount specimen"]
  SEROUT 14, 84, [148,"then press 1"]
  PAUSE 250
  DO
    IF IN0 = 1 THEN
      GOTO weight
    ENDF
  LOOP

ELSEIF material = 1 THEN
  PULSOUT USpin, 5
  PULSIN USpin, 1, time
  h1 = CmConstant ** time

  SEROUT 14, 84, [22,12]
  SEROUT 14, 84, ["Fill the beaker then press 1"]

  DO
    IF IN0 = 1 THEN
      filled = 1
      GOTO weight
    ENDF
  LOOP
  ENDF

'If the material is solid, then
'measure the initial height
'height in mm
'Clear LCD screen

'Press button 1 to measure the initial mass m1

'Else if the material is liquid, then
'measure the initial height h1

'After ml is measured, fill the beaker with liquid

'Press button 1 after beaker is filled

'Go measure the final mass m2
PBASIC PROGRAM

' --- [ Mass Measurements ] -----------------------------------------------------
weight:

IF material = 0 THEN
HIGH FFpin
PAUSE 2
RCTIME FFpin, 1, rawForce
K = 63500/rawForce
K1 = rawForce/100
K2 = (635/K1) * 41/K1
m2 = 41*K + 197 + K2

IF dropped = 0 THEN
m1 = m2
GOTO motor
ELSEIF dropped = 1 THEN
GOTO volume
ENDIF

ELSEIF material = 1 THEN
HIGH FFpin
PAUSE 2
RCTIME FFpin, 1, rawForce
K = 63500/rawForce
K1 = rawForce/100
K2 = (635/K1) * 41/K1
m2 = 41*K + 197 + K2

IF filled = 0 THEN
m1 = m2
GOTO height
ENDIF
GOTO volume
ENDIF

'For solid
'Measure mass from Flexiforce

'Conductance 1/R

'K2 = fraction portion of (41 * K)
mass is determined from conductance (linear)

'If solid isn't dropped yet, then
'this measurement is initial mass m1
'Use the motor to slowly lower the solid
'Else if the solid is lowered, then
'this measurement is final mass m2

'For liquid
'Measure mass from Flexiforce

'If beaker is filled, then
'this measurement is final mass m2

'If the beaker isn't filled yet, then
'this measurement is initial mass m1
'Go measure the initial height h1
PBASIC PROGRAM

' ------[ Volume Calculations ]-------------------------------------------------------------

volume:

PULSOUT USpin, 5
PULSIN USpin, 1, time

IF material = 0 THEN
  h2 = CrConstant ** time
  vol = ((25*3*(h1-h2)) + ((h1-h2)*7/2))/10
ENDIF

ELSEIF material = 1 THEN
  h2 = CrConstant ** time
  vol = ((25*3*(h1-h2)) + ((h1-h2)*7/2))/10
ENDIF

GOTG results

'Run the ultrasonic sensor to measure final height h2

'Volume for solid
'height in mm, and is converted to cm below
'volume = (r^2)(3)(h1-h2) + (r^2)(0.14)(h1-h2)

'Volume for liquid
PBASIC PROGRAM

' ------[ Display Results ]-----------------------------------------------
results:
density = (m2 - m1)/vol
K = (m2 - m1) // vol
K1 = K*10 / vol
K = K*10 // vol
K2 = K*10// vol

PAUSE 250
SEROUT 14, 84, [22,12]

DO
SEROUT 14, 84, [128, "To see result"]
SEROUT 14, 84, [148, "Press 1"]
LOOP UNTIL (IN1 = 1)
PAUSE 250
SEROUT 14, 84, [22,12]

DO
SEROUT 14, 84, [128, "Mass: ", DEC8 m2-m1, "g"]
SEROUT 14, 84, [148, "Press 2 for more"]
LOOP UNTIL (IN1 = 1)
PAUSE 250
SEROUT 14, 84, [22,12]

DO
SEROUT 14, 84, [128, "Volume: ", DEC8 vol, "ml"]
SEROUT 14, 84, [148, "Press 2 for more"]
LOOP UNTIL (IN1 = 1)
PAUSE 250
SEROUT 14, 84, [22,12]
## RESULTS

<table>
<thead>
<tr>
<th>Material</th>
<th>Actual</th>
<th>Experimental</th>
<th>% error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mass (g)</td>
<td>Volume (ml)</td>
<td>Density (g/ml)</td>
</tr>
<tr>
<td>Water</td>
<td>750</td>
<td>750</td>
<td>1.0</td>
</tr>
<tr>
<td>500 g weight</td>
<td>500</td>
<td>110</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Average % error = 10.1

- Water, methanol, and several solid samples were measured
- Water had an error of 17.6 %, while a standard weight of 500 g had an error of 2.7 %
  - Average error of approximately 10 % was obtained
- Factors contributing to error include:
  1. Error from FlexiForce® and PING)))™ sensors
  2. Limitations of PBASIC program in calculations
THANK YOU FOR YOUR ATTENTION!
DENSITY METER OPERATION - SOLID
Density meter operation - Liquid