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ME 5643 MECHATRONICS FINAL PROJECT

DENSITY METER

Shing Lik Wong, Yi Hu, and Jasmin Hume

Group 6

Polytechnic Institute of NYU
6 Metrotech Center, Brooklyn, NY 11201

OUTLINE

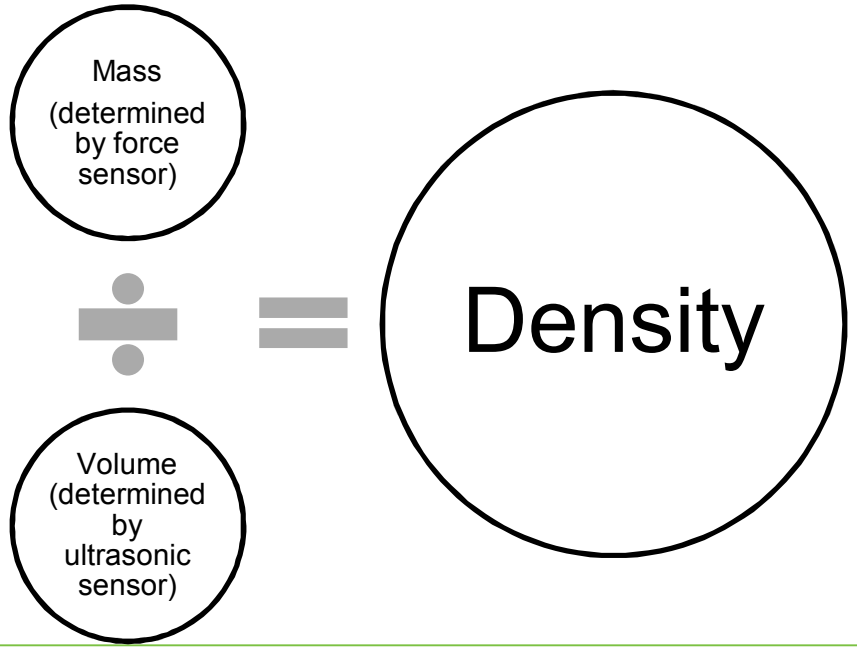
- Introduction
- Materials and methods
  - Sensors and their calibration
  - Circuitry
  - Program
  - Structure
- Results
- Demonstration

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



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
  - → the FlexiForce® therefore acts as a *variable resistor*
  - with no load, the sensor has a resistance of > 5 MΩ
  - A maximum load (25 lbs) decreases the resistance to approximately 5 kΩ
- The FlexiForce® sensor is interfaced to the BS2 through an RC circuit

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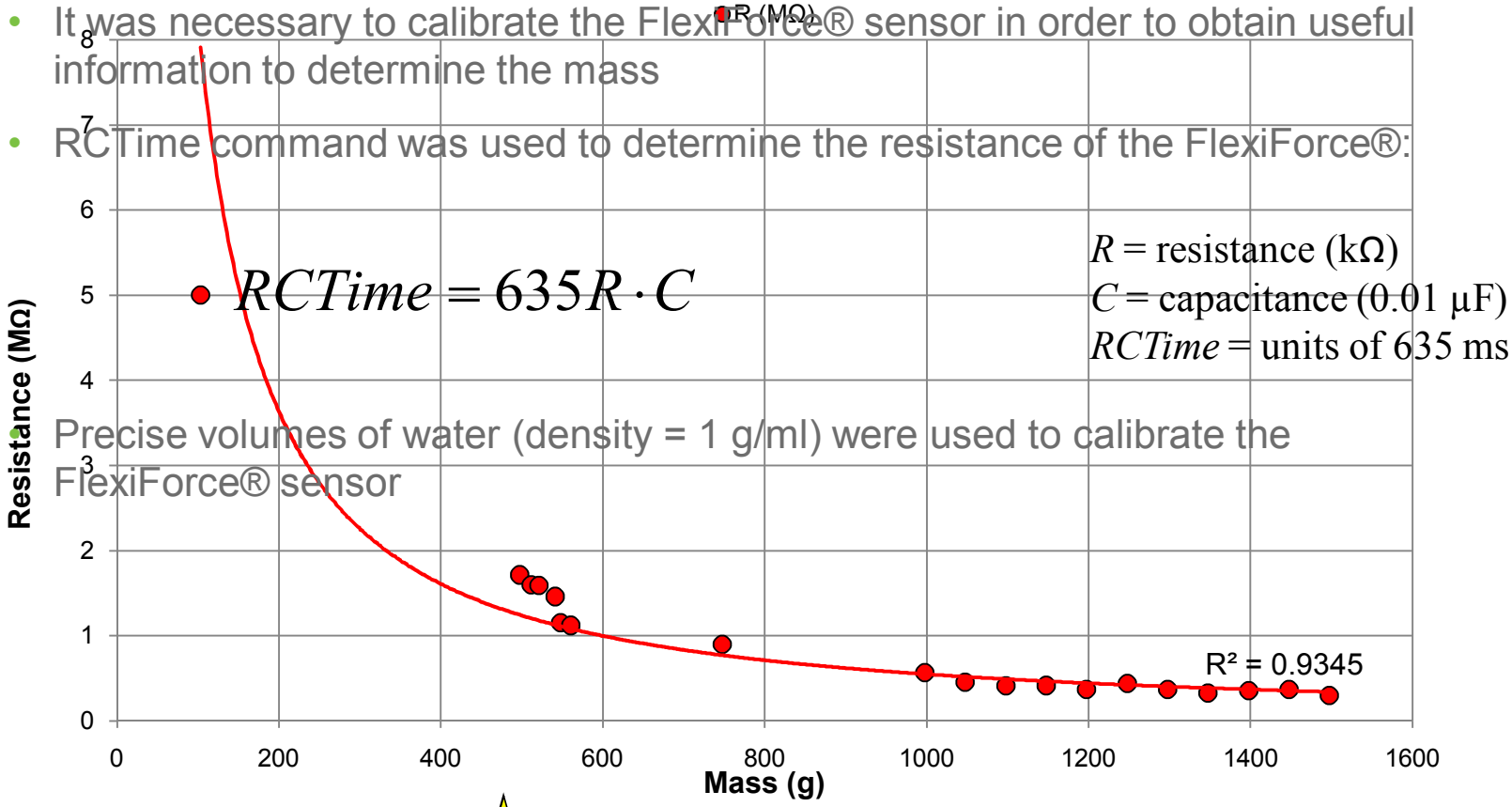
FLEXIFORCE® SENSOR CALIBRATION

- 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®:

$$RCTime = 635R \cdot C$$

R = resistance (kΩ)
C = capacitance (0.01 µF)
$RCTime$ = units of 635 ms

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



★ Resistance is non-linearly related to mass

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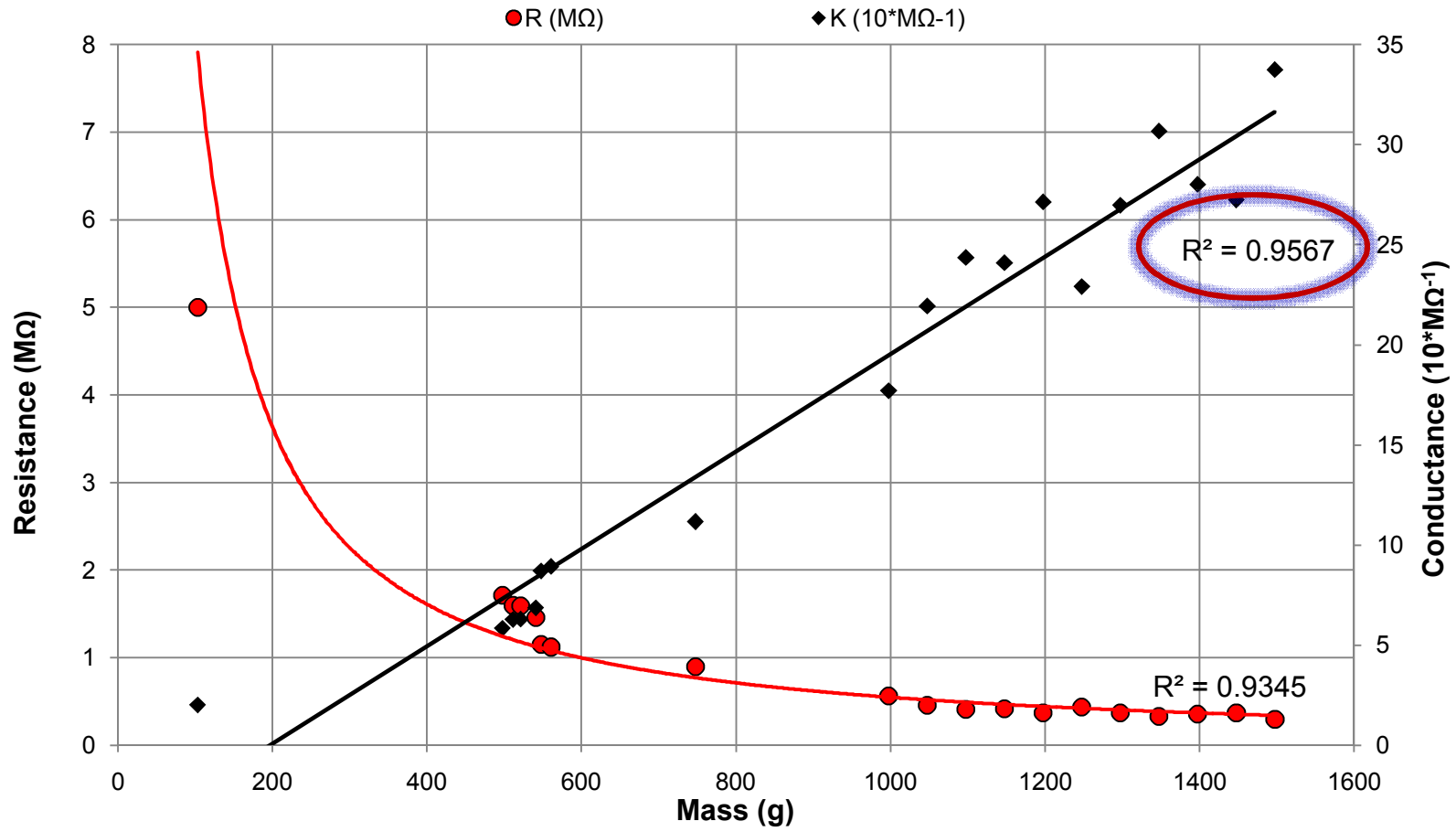
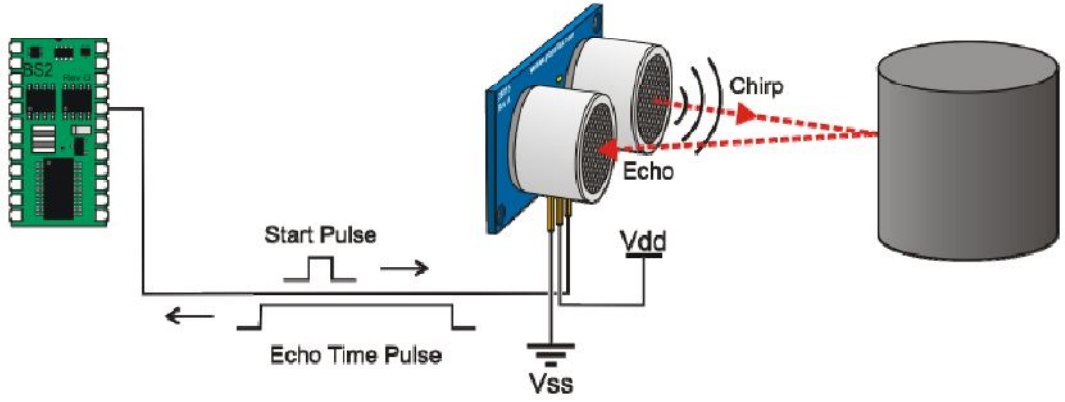
FLEXIFORCE® SENSOR CALIBRATION



SENSORS – ULTRASONIC SENSOR



- A PING)))™ 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:

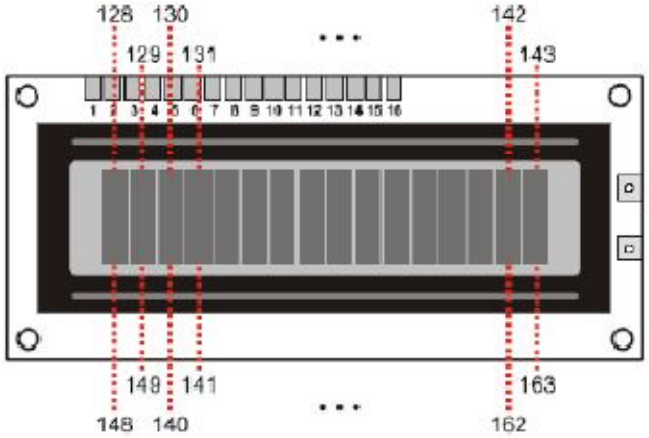
$$D = \frac{c \cdot t}{2}$$

Divided by 2 to account for round trip of signal

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

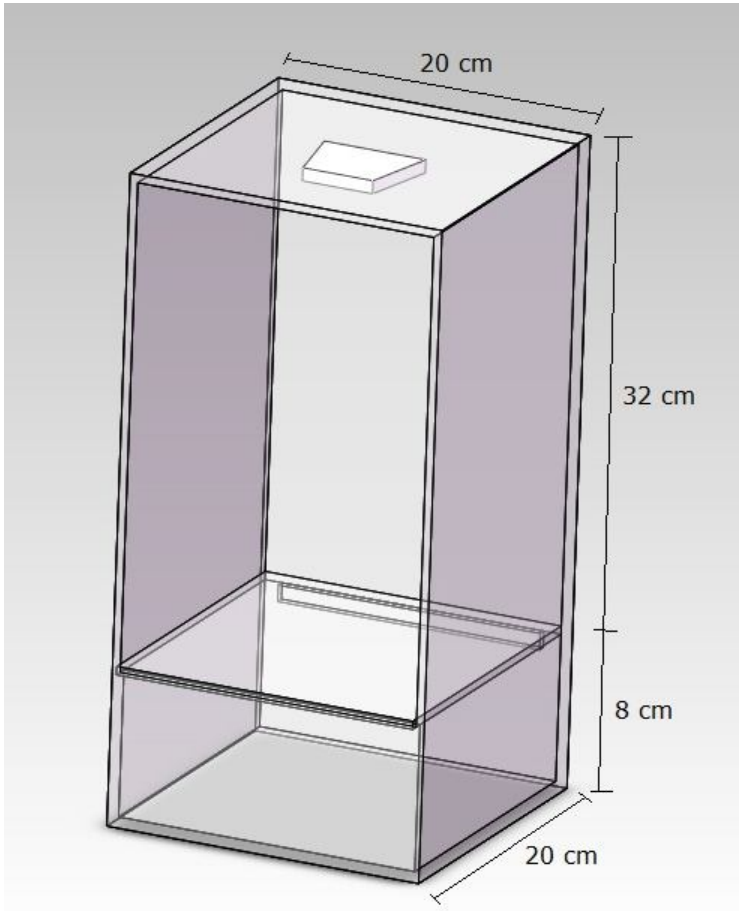
LIQUID CRYSTAL DISPLAY

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



- Displays instructions and measurement results obtained

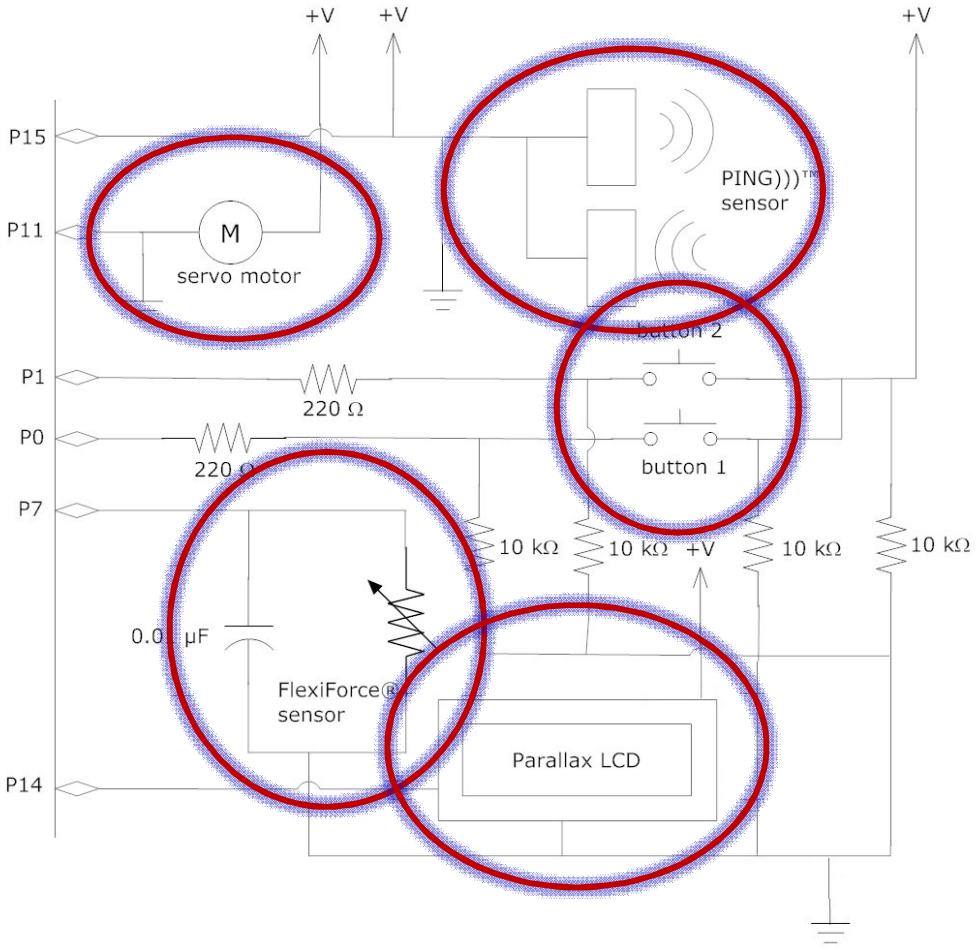
DENSITY METER SPECIFICATIONS



- 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 %

CIRCUITRY



- 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

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PBASIC PROGRAM

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

IF material = 0 THEN                          'If the material is solid, then
PULSOUT USpin, 5                              'measure the initial height
PULSIN USpin, 1, time
h1 = CmConstant ** time                       'height in mm

SEROUT 14, 84, [22,12]                        'Clear LCD screen
SEROUT 14, 84, [128,"Mount specimen"]
SEROUT 14, 84, [148,"then press 1"]
PAUSE 250
 DO
 IF IN0 = 1 THEN                              'Press button 1 to measure the initial mass m1
 GOTO weight
 ENDIF
 LOOP

ELSEIF material = 1 THEN                      'Else if the material is liquid, then
PULSOUT USpin, 5                              'measure the initial height h1
PULSIN USpin, 1, time
h1 = CmConstant ** time

SEROUT 14, 84, [22,12]                        'After m1 is measured, fill the beaker with liquid
SEROUT 14, 84, ["Fill the beaker then press 1"]

DO
IF IN0 = 1 THEN                               'Press button 1 after beaker is filled
filled = 1
GOTO weight                                   'Go measure the final mass m2
ENDIF
LOOP

ENDIF
```

PBASIC PROGRAM

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

IF material = 0 THEN                        'For solid
HIGH FFpin                                  'Measure mass from Flexiforce
PAUSE 2
RCTIME FFpin, 1, rawForce
K = 63500/rawForce                          'Conductance 1/R
K1 = rawForce/100
K2 = (635//K1) * 41/K1                      'K2 = fraction portion of (41 * K)
m2 = 41*K + 197 + K2                        'mass is determined from conductance (linear)

IF dropped = 0 THEN                         'If solid isn't dropped yet, then
m1 = m2                                     'this measurement is initial mass m1
GOTO motor                                  'Use the motor to slowly lower the solid
ELSEIF dropped = 1 THEN                     'Else if the solid is lowered, then
GOTO volume                                 'this measurement is final mass m2
ENDIF

ELSEIF material = 1 THEN                    'For liquid
HIGH FFpin                                  'Measure mass from Flexiforce
PAUSE 2
RCTIME FFpin, 1, rawForce
K = 63500/rawForce
K1 = rawForce/100
K2 = (635//K1) * 41/K1                      'If beaker is filled, then
m2 = 41*K + 197 + K2                        'this measurement is final mass m2

IF filled = 0 THEN                          'If the beaker isn't filled yet, then
m1 = m2                                     'this measurement is initial mass m1
GOTO height                                 'Go measure the initial height h1
ENDIF

GOTO volume

ENDIF
```

PBASIC PROGRAM

```
' -----[ Volume Calculations ]-------------------------------------------------------------------------
volume:

PULSOUT USpin, 5                                    'Run the ultrasonic sensor to measure final height h2
PULSIN USpin, 1, time

IF material = 0 THEN                                'Volume for solid
h2 = CmConstant ** time                             'height in mm, and is converted to cm below
vol = ((25*3*(h1-h2)) + ((h1-h2)*7/2))/10           'volume = (r^2)(3)(h1-h2) + (r^2)(0.14)(h1-h2)

ELSEIF material = 1  THEN                           'Volume for liquid
h2 = CmConstant ** time
vol = ((25*3*(h1-h2)) + ((h1-h2)*7/2))/10

ENDIF

GOTO results
```

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PBASIC PROGRAM

```
' -----[ Display Results ]-----------------------------------------------------------------------
results:

density = (m2 - m1)/vol                         'Calculation for density
K = (m2 - m1) // vol                            'Remainder of density
K1 = K*10 / vol                                 'K1 = first decimal digit of density value
K = K*10 // vol
K2 = K*10/ vol                                  'K2 = second decimal digit of density value

PAUSE 250
SEROUT 14, 84, [22,12]                          'Clear LCD

DO
SEROUT 14, 84, [128, "To see result"]
SEROUT 14, 84, [148, "Press 1"]
LOOP UNTIL (IN0 = 1)

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

DO
SEROUT 14, 84, [128, "Mass: ", DEC5 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: ", DEC5 vol, "ml"]
SEROUT 14, 84, [148, "Press 2 for more"]
LOOP UNTIL (IN1 = 1)

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

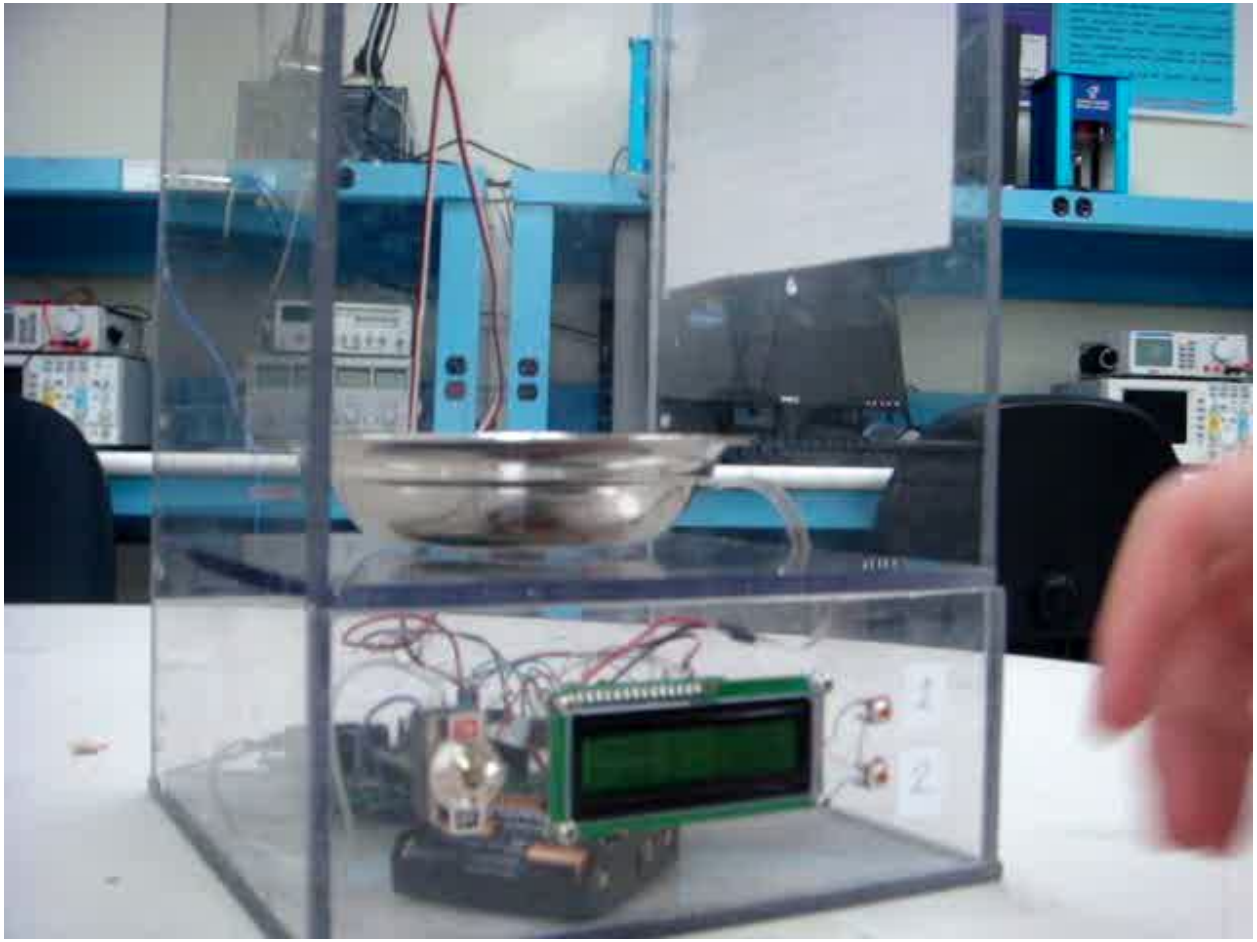
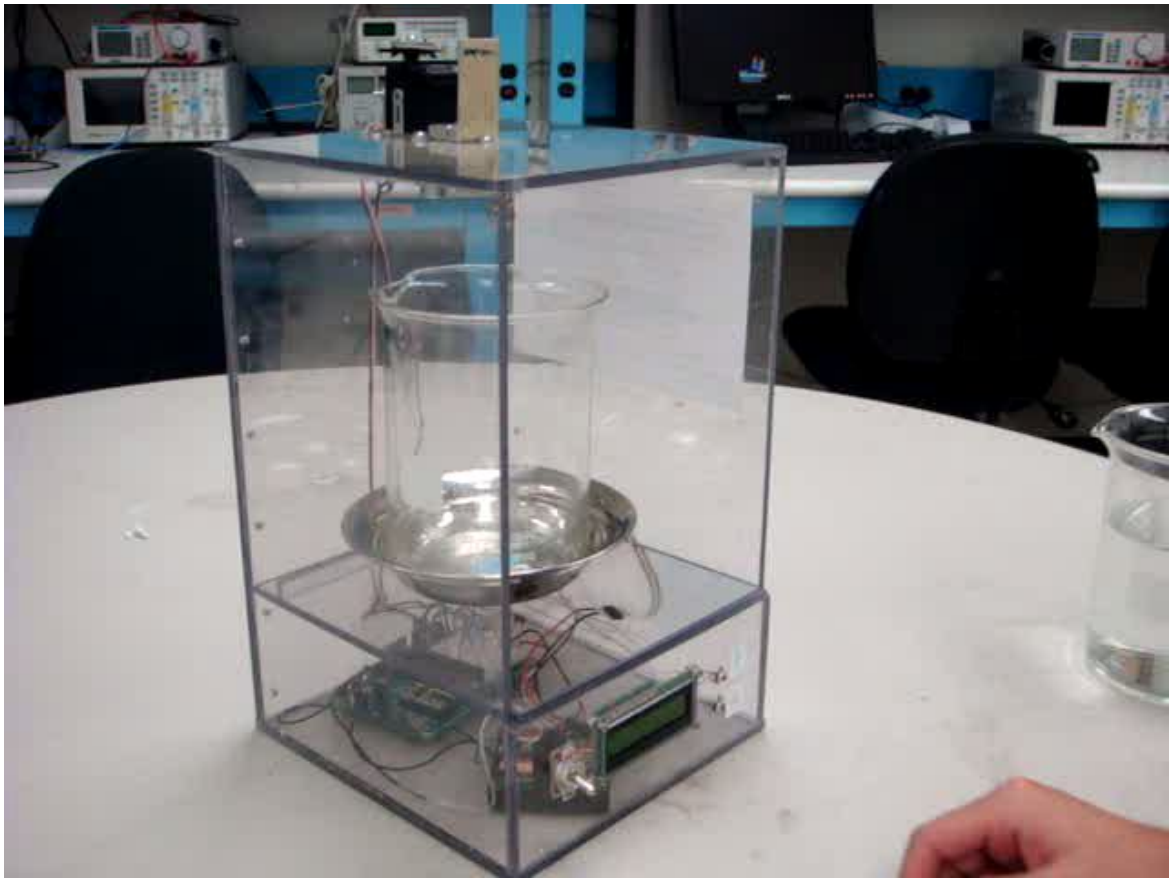
RESULTS

Material	Actual			Experimental			% error
	Mass (g)	Volume (ml)	Density (g/ml)	Mass (g)	Volume (ml)	Density (g/ml)	
Water	750	750	1.0	582	706	0.8	*17.6*
500 g weight	500	110	4.5	482	109	4.4	*2.7*
					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