The SMART Weather Balloon

A Mechantronics Demonstration Project

by

Lennox Henry
Washington Irving High School
New York, NY 10003

and

Ronald Occhiogrosso
HAFTR High and Middle Schools
Cedarhurst, NY 11516

Abstract

Does a person ever not think of the weather on a daily basis? Arguably not. Weather is followed every second by meteorologists and the National Weather Service, and people then tune in to find out the forecast. And Earth Science students need to become junior meteorologists themselves as part of the curriculum. This SMART Weather Balloon project attempts to improve students' comprehension of basics of weather, most notably the construction of isoline plots for temperature, relative humidity (RH), and barometric pressure. They will also be immersed in the *mechatronics* aspects of the system, thus improving their engineering and technological skills as well. The SMART Balloon accomplishes this by recording temperature and humidity data at different altitudes; this shows the distribution and changes of temperature and humidity. Students will then construct isothermal, isobaric, and isolines of RH plots. The results will help to illustrate how these influence the weather. In addition this project will help students, who usually have difficulty in understanding how to read a graph and what it means, to grasp these concepts by seeing how temperature, RH, and pressure change with altitude and lateral position in the physical world. The project offers the wonderful opportunity to cross-pollinate students' knowledge in Earth Science with chemistry, physics, electronics, and mechanics.

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1. Curriculum Standards Correlation

This project primarily deals with the topic of weather studied in Earth Science, but it also involves several subjects to accomplish its goals. These various subjects are static equilibrium, forces, and circuitry studied in physics, gas laws studied in chemistry, and mechatronics to create a project that would marry all these disciplines.

The SMART Weather Balloon project also supports the following New York State Core Standard content and process skills:

STANDARD 1— Scientific Inquiry

Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.

STANDARD 4—Physical Setting

Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science

STANDARD 6—Interconnectedness: Common Themes

Students will understand the relationships and common themes that connect mathematics, science, and technology and apply the themes to these and other areas of learning.

STANDARD 7—Interdisciplinary Problem Solving

Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

2. Introduction

Weather: A topic of conversation that nearly every person engages in daily. Does a person ever leave their home without considering it? Whether listening to the radio, watching TV, reading a newspaper, the local, regional, and national weather forecasts are constantly reported on and easily available. Try to imagine how you would get along one day without knowing your local forecast, and you will probably agree that your day would be incomplete and too 'unpredictable'.

If you have ever been caught in a rainstorm that was not correctly forecasted, you might have a bad thought or two about the meteorologist who missed the storm!

Predicting the weather is a relatively complex science due to the number of variables involved, including temperature, air pressure, precipitation, wind, percent cloud cover, and others. Weather is defined as, "The state of the atmosphere at a specific time and with respect to its effect on life and human activities. It is the short term variations of the atmosphere, as opposed to the long term, or climatic changes. It is often referred to in terms of brightness, cloudiness, humidity, precipitation, temperature, visibility, and wind." [1]

Meteorology, a science that deals with the atmosphere and its phenomena and especially with weather and weather forecasting, depends on a variety of different equipment including anemometers, barometers, rain gauges, thermometers, lightning detectors, weather radios, and weather balloons. These can be conveniently combined into a single weather station unit, and there are many companies to purchase these from such as Scientific Sales, Inc.[2]

This project will make use of a meteorological weather balloon[3] equipped with electronics including a temperature and relative humidity sensor to create a relatively simple, yet quite unique mobile weather station. Mechatronics[4-6] is a relatively new and exciting field that, "is the synergetic combination of precision mechanical engineering, electronic control and systems thinking in the design of products and processes."[6] The mobile weather station balloon in this study will make use of basic features of mechatronics.

3. Background

3.1 Theory

3.1.A Isolines and Weather

Weather is influenced most notably by variations in *insolation.* Insolation (INcoming SOLar radiATION) is the part of the sun's radiation that is received by the Earth, aka solar energy. These variations cause heat energy to be unevenly distributed in the atmosphere, but nature tends to even out this imbalance towards a state of uniformity. In moving towards this uniformity, the heat energy flow results in the constant changes in the atmosphere that are a major cause of weather.[7-9]

In order to report on local & regional weather conditions several key variables need to be constantly measured: temperature, air pressure, humidity and wind direction. These are especially important to know in the upper levels (high altitudes) of the atmosphere, because they affect the weather experienced at the surface. Most of the weather changes occur in the troposphere, the part of the atmosphere immediately above the Earth's surface located from 0 (sea level) to approximately 13 km (0-7 miles) altitude.[7]

The Earth Science curriculum requires a sound understanding and construction of isolines, lines used on a model of a field, such as a map, which connects points of constant value of a field variable. These include: isobars, lines of constant pressure; isotherms, lines of constant temperature; contour lines, lines of constant elevation and others such as lines of constant pH. Figure 1 shows a map of isotherms taken at some time during the summer

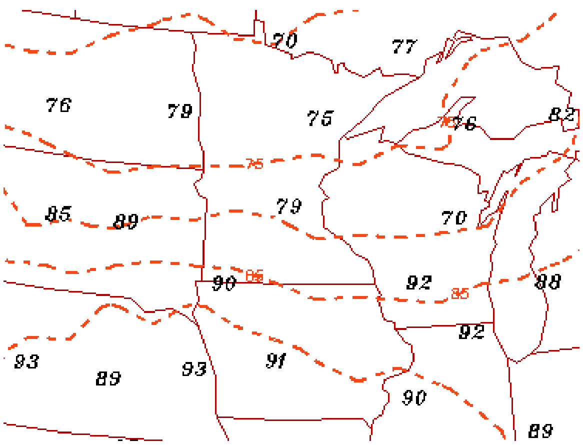


Figure 1. A sample isothermal plot of the upper part of upper midwest U.S. taken at some point during the summer. Temperatures shown are in degrees Fahrenheit.

Besides reporting on the temperature, barometric pressure, wind conditions, precipitation, and air mass movement, weather forecasting will often employ use of isobars, though isotherms, contour lines and isolines of precipitation are often seen on media like The Weather Channel, where complete meteorological reports are provided. A weather report that includes various isolines provides a more thorough weather forecast. Though the average person is not aware of how to read and interpret these isolines, Earth Science students need to be comfortable with each.

3.1.B Weather Balloon Lift

The principle behind how a weather balloon or hot air balloon works involves the concept of buoyancy or lift[3]. If a given volume (mass) of one substance is within another substance, then the former will move upward if its density is lower. Equation 1 shows how to calculate this *lift-force* of balloon which is filled with helium gas, moving upward through air.

$$F_{lift} = (D_{air} - D_{He})\, V\, g \qquad (1)$$

Where D is the density of the gas, V is the volume of the helium in the balloon, and g is the acceleration of gravity. A 36" diameter weather balloon has a volume of about 4.0×10^5 cm^3 (2.44×10^4 in^3), and a lift force F_{lift} *(payload)* of about 275 g. This is more than enough to lift a homework board or board of education microcontroller with 9V battery supply.

3.1.C Barometric Pressure

Altimeters are devices that have been used for many years (e.g, on planes, by mountaineers) to measure height. The altimeter works on the principle that the pressure within a column of air varies in a known way with height. The mathematical relationship that relates height as a function of pressure, temperature, and gas substance is given by:

$$z = (RT/gM) \ln(p_o/p) \qquad (2)$$

where z is the height difference between the starting height (usually sea level) and the measurement height, R is the gas constant, T is the absolute temperature of the air, g is the acceleration due to gravity, M is the molar mass of the gas (in this case air), p_o is the atmospheric pressure at the starting height and p is the atmospheric pressure at the measurement height.[11] If the starting point is sea level, then z will be the 'altitude' where ambient pressure is p.

Since air pressure decreases in a predictable way as altitude (height) increases, equation 2 can be used to calculate the ambient pressure p at a given height z. Equation 3 shows this relationship,

$$P = P_o / \exp(-zgM/RT) \qquad (3)$$

3.1.D Relative Humidity

One of the more important variables in weather reporting is the relative humidity (RH), which is the ratio of the amount of water vapor in the air (i.e., the absolute humidity) to the maximum amount it can hold at the existing conditions. RH is often reported as a percent of saturation, and will vary from 0 to 100%, though values of 0% are rare on the surface of the Earth.[7,8] RH is given by quation #

$$RH = (\text{Amount of water vapor in air})/(\text{Maximum amount of water air can hold})*100\% \qquad (4)$$

Devices exist for measuring the RH, the simplest of which is a *sling psychrometer*. This device is comprised of two thermometers held closely together and swung around in the air. One of the thermometers has a cloth wick affixed around its bulb, which is soaked with water. This thermometer's reading is designated as the *wet-bulb temperature,* and the other's the *dry-bulb temperature.* Figure 2 shows a sling psychrometer.

Figure 2. Sling psychrometer for relative humidity measurement.[12, 13]

While swinging (whirling) the two thermometers in the air, the thermometer with the soaked wick will read a lower temperature, due to the cooling effect of the evaporating water. This cooling effect is controlled by the amount of water vapor (RH) that is in the air: the higher the RH, the less the amount of water that will evaporate, and the lower the cooling effect. When used to measure saturated air – on days when there is precipitation – the two thermometers will read the same temperature.

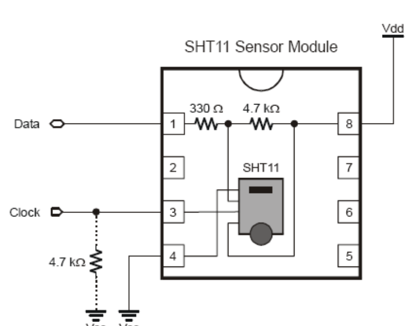
3.2 Components

3.2.A Sensirion SHT11 Sensor Module

The Sensirion SHT11 Sensor Module with the use of a two-wire serial interface, allows to accurately measure temperature and humidity. Parallax simplified the use of the SHT11 chip by mounting it in a user friendly 8-pin module that embeds into the bread board thereby connecting to the Basic Stamp on the HWB. SHT11 features temperature range from –40°C (-40 °F) to +123.8 °C (+254.9 °F), with an accuracy of +/- 0.5 °C @ 25 °C. It has a humidity range of 0 to 100% RH with an accuracy of +/- 3.5% RH.

The Sensirion SHT11 Sensor Module allows precise readings with very low power consumption, typically 30 μW.[14] Figure 3 shows the SHT11 sensor module. For high humidity applications an SHT11 heater can be added (not shown) and switched on briefly to prevent condensation. Another use of the heater is to test the operation of the sensor by reading before enabling the

Figure 3. Sensirion SHT11 module for measuring temperature and humidity.



heater and immediately after the sensor can be verified by noting a higher temperature and lower humidity.

3.2.B Superbright Light Emitting Diodes

A Diode is a one-way check valve allowing current flow in only one direction. An LED, "Light Emitting Diode" is a diode that emits light as current is passed through it. The LED must be connected in correct orientation. The Anode is **c**onnected to the **+** side of

Voltage, and can be identified by the longer lead. The cathode is connected to the **–** side of the voltage, it can be identified by its shorter lead and a flat portion on the lens.

In order to drive LED the an I/O pin must be used from BS2. LED requires 1.4V and approx. 10mA. Using resistors will limit the amount of current flowing through LED thereby protecting it as well as the I/O pin of the BS2.

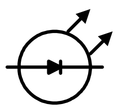


Figure 4. Schematic of LED

Figure 5. Superbright LED

3.2.C Pushbutton

A pushbutton is a component that when pressed it closes a circuit. There are two major categories in Buttons/Switches:

-Momentary switch: its state is altered only during it actuation.

-Permanent switch: its state is altered and maintained after it is actuated. Separate actions are required to open and close the switch.

In this project the pushbutton was used as a momentary switch that when pressed it allows the obtained data to be streamed through portal to computer.

Figure 6. Pushbutton/Switch

3.2.D Resistor

A resistor is an electrical component that is designed to have an internal opposition to current flow.[15] It is designed to be stable and consistent under a wide array of conditions. Resistors are used in this project to divide voltage and limit current. Using Ohm's Law, an appropriate resistance can be determined to produce a desired current flow.

4. Equipment List

4.1 Homework Board with Imbedded Basic Stamp 2 Chip & Components

Though most projects involve use of the Board of Education project board, this project use the HomeWork Board (HWB) complete with Basic Stamp 2 circuit as the microcontroller. The Basic Stamp on the HWB is a special purpose mini computer that contains a mircocontroller chip and a small amount of memory to hold the program code. The HWB provides regulated +5 volts (V_{dd}) and ground (V_{ss}) as well as connections to 16 pins for I/O. There is a small breadboard for circuitry and a DB9 connector for programming the BS2 IC and for serial communications while programs are running. Using a programming language, PBasic, the Stamp can be programmed to perform a variety of operations.

Figure 7. HomeWork Board schematic, complete with imbedded basic stamp 2

4.2 Smart Weather Balloon

The meteorological weather balloon used was purchased from Science Kit and Boreal Laboratories, P/N 69577-01. It was filled with helium gas to a diameter of 36" (0.91m). At this loading of helium, it was capable of lifting nearly 300g of payload. Two rubber-coated clamps were used to quick-seal the outlet.

The electrical components used include:

HomeworkBoard with imbedded Basic Stamp 2 IC, Parallax
Sensirion Temperature/Humidity sensor module, Parallax, P/N 28018
Resistors: 220 ohm (3), 10 kohm (2), (4.7 kohm) (1), Digikey.com
Superbright LEDs (2), Superbrightled.com
Wire, 22 gauge, approx. 2 ft
Push Button Switch
9 V Battery

Section 4.4 shows the integration (circuit design) of these items. They were supported on the top of a piece of 1/8" thick 4"x4.75" Plexiglas, and affixed using 5/8" machine screws and nuts. Two eyelet screws were used to attach a calibrated cord to the underside of the Plexiglas. This cord is used to provide accurate altitude (height) measurements of the SMART Balloon. The balloon is navigated up and down using two (of three) RC thruster engines (with fans) on the gondola from an Interactive Toy Airship America 51" w/3-Channel Radio, Towerhobbies.com, P/N LXWW18. These engines were powered using a 3 V photo battery. The gondola is affixed to the underside of the same piece of Plexiglas using similar machine screws and nuts. The third RC thruster engine was modified to allow for capturing the Sensirion temperature, RH data during flight.

Figure 8 shows the SMART Weather Balloon. The gondola with 3 thruster engines, Plexiglas, and HomeworkBoard are located below the balloon, just below the hand of researcher Ron Occhiogrosso (r). Researcher Lennox Henry is seen working on the calibrated cord used to measure altitude. An electronic Strait-Line laser tape (not shown) was obtained from Home Depot, & is capable of measuring up to 15 m of distance. This device will be used by students in normal operation of the SMART balloon.

As discussed earlier in section 3.1.B, when filled to a size of 36" diameter, the balloon has a limit on its payload (275 g). As such, the weights of all components needed to monitored closely. The items shown in Figure 8a have a weight of about 235 g. Additional mass is therefore capable of being lifted, thus adding future versatility to the balloon.

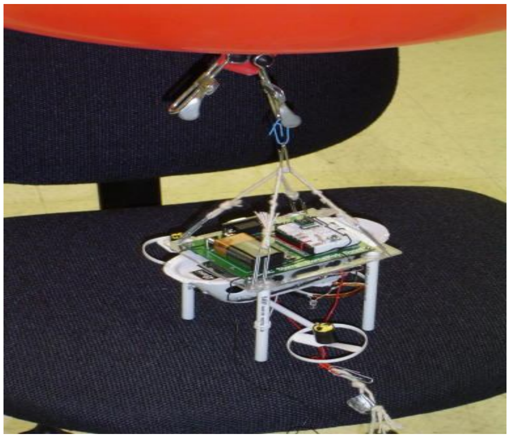


Figure 8.(a)

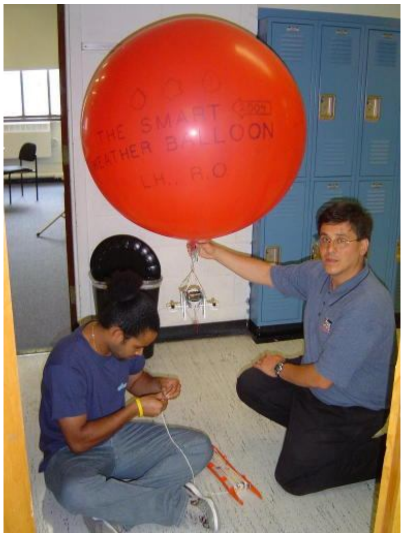


Figure 8.(b)

Figure 8. (a)Gondola with HWB and Thruster engines affixed to the bottom of the balloon and (b) Fully-equipped SMART weather balloon

4.3 SMART Weather Balloon Setup

The SMART Weather Balloon is designed to measure as well as store temperature, relative humidity, and altitude readings in the EEPROM. A toy RC hobby blimp was operated with a 3V battery on the gondola, a 9V battery on the remote control unit, and helium to fill the blimp. The gondola unit was used to control (increase and decrease) the height, and to set up the microcontroller. The original blimp was replaced with a meteorological balloon that could hold a larger volume of helium, which was required due to increased payload caused by newly added equipment. The continuous measurement of temperature and humidity was done by the Sensirion SHT11 microchip, and the storing of data at determined heights was accomplished by the BS2 imbedded in HWB.

b. **HWB was affixed on top of the gondola and two superbright LEDs were wired to the underbelly of the gondola. LEDs were placed in sequence by soldering their leads to each other and a 220Ω resistor. The two superbright LEDs were used to signal capture of data that occurred when the circuit was closed by the movement of copper coated modified thruster engine propeller on the gondola. The SHT11, LEDs, and BS2 were powered by an onboard 9V battery to the HWB. The height was measured by using a STRAIT-LINE laser tape aimed at the base of the gondola, & that data was recorded by the BS2; all data stored in the EEPROM. Once the SMART Weather Balloon is landed, the data is downloaded by portal connection to a computer when a pushbutton that is placed on HWB is depressed. Microsoft Excel's StampDAQ is used to present** various heights and linear distances. Isobar and isolines of RH data will also be constructed.

the data in user-friendly format.

4.4 Circuit Design

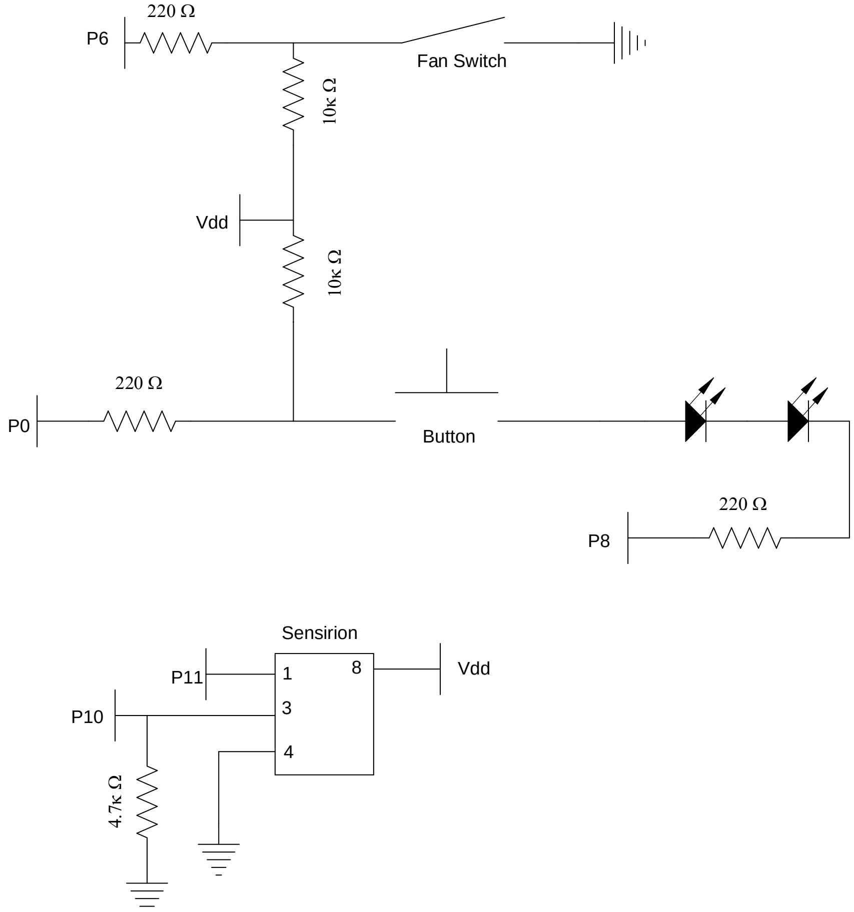


Figure 9. Circuit diagram for BS2 imbedded on the SMART Weather Balloon HWB

5. Experimental Procedure

Goals:

1. a. Experimental determination of altitude (height), temperature, and relative humidity (RH), from ground to a vertical height of 10 m. Dewpoint & barometric pressure data will be regressed from RH and altitude/temperature data, respectively. Graphs of temperature (ordinate) and RH (ordinate) versus height (abscissa) will be constructed.

The same 'vertical' data set will be obtained at several other 'spots' by moving the SMART Weather Balloon to points at 1m, 2m, 3m, etc. away from the original starting point. These additional points must be along a straight line.The sets of data will then be combined to allow for construction of isothermal plots (isolines) at the

Procedure:

1. Prepare the SMART Weather Balloon by filling with helium gas to a size of about 36" diameter. The precise diameter is obtained by adding weights (putty) to the balloon so that it is in a state of static equilibrium, i.e., able to float in midair.
2. Load PBasic program onto BS2 on HWB via the 9-pin portal (serial) connection. Disconnect cable. The first group (of 2-3students) will now begin to collect their data.
3. The first group will now bring the SMART Weather Balloon to the starting position and capture data at ground level. This is accomplished using the RC copper-coated, modified thruster-engine propeller on the gondola. Now, by running the two RC fan thruster engines, move the balloon to a height of 1 m. Use the cord to measure the height, while also measuring it with the STRAIT-LINE Laser Tape. Record both distances.
4. Repeat step 4 for additional heights of 2, 3, 4, . . . 10 m altitude.
5. Lower the balloon to the ground and connect the 9-pin portal connection, and download the data using Microsoft Excel StampDAQ. The second group now takes over.
6. Move the weather balloon to a new spot 1m away, and repeat steps 3-5. When group 2 is done, the third group takes over and so on until all groups of 2-3 students per group are done.

6. Results

The SMART Weather Balloon was used to collect temperature, RH, and altitude data. This data is then used to calculate the existing barometric pressure. The RH and temperature data can also be used to determine dewpoint temperatures that are also needed for weather forecasting.

In order to check on the quality of temperature and humidity data collected from the Sensirion sensor, a simple sling psychrometer was used and the results compared with that from the sensirion. Table 1 shows data collected over several days, and as shown there is a general good agreement between the RH and the DP data from the two sources of data.

Table 2. Temperature and Relative Humidity Data

	Sling Psychrometer Ref: Hubbard Sci. 3106					**Sensirion Sensor Module**		
Date,Time	**Dry Bulb Temp (°C)**	**Wet Bulb Temp (°C)**	**ΔT(°C)**	**RH(%)**	**Dewpoint (DP °C)**	**Dry Bulb Temp (°C)**	**RH(%)**	**DP(°C)**
7/29/04, 9:20am	23	17	6	55	12.8	22.8	57.1	15
12:15 pm	24	18	6	56	14	25.8	46.5	9
7/30/04,10:25am	24	18	6	54	14	24.8	56.6	15.5
12:20 pm	24	18	6	54	14	25.5	56.6	15.5
3:15 pm	24	18	6	54	14	26	52.7	15
8/03/04, 9:30am	23	17	6	55	12.8	24.2	55.1	14
8/04/04, 8:45am	18	14	4	65	11	19.5	66.5	12

11:15 am	23	18	5	61	15	24.9	43.8	11.5

Table 3. shows the data from a trial run of the SMART Weather Balloon.

Table 3. Trial 1 data taken on August 4, 4:30 PM at Atrium to Metrotech 5

Altitude (m)	Temp (Dry Bulb, ^{o}C)	Relative Humidity (%)	Pressure (atm)	Comments
0	25.2	45.8	1.000	This data point was taken in the elevator on the first floor
0	24.5	64.2	1.000	
1	25	69.3	0.988	
2	25.1	69.5	0.977	
3	25.2	68.2	0.966	
4	25.2	68.3	0.955	
5	25.4	67.3	0.944	
6	25.5	66.5	0.933	
7	25.7	65.8	0.922	
8	26.1	64.4	0.912	
9	26.2	64.1	0.901	At this point the SMART Weather Balloon was very close to the ceiling, just about 1/2 m from it

7. Conclusions

NEED TO COMPLETE

8. Suggested Projects/Future Work

1. Replace the meteorological balloon with a blimp that can hold a sufficient volume of helium to sustain the 235g payload. The original blimp provided lacked volume capacity for extra helium needed as payload increased.
2. Add on an additional gondola with three thruster-engine fans to allow for added up/down thrusting, as well as allowing for RC controlled lateral movement that at present is not possible.
2. Addition of transceiver chip to gondola and creation of another BS2 ground setup with a transceiver or receiver to capture real time data.
3. Use SMART balloon in the chemistry curriculum when gas laws are taught.

9. Projects Cost Analysis

1. Balloon/Construction materials:	
a. Meteorological Balloon, 1m diameter	$21.00
b. Strait-Line Laser Tape	$29.00
c. Eyelet & other Screws	$ 5.00
d. Balloon Clamps	$ 4.00
e. Plexiglas	$ 1.00
2. Electrical Components	
a. Sensirion Temperature/Humidity Sensor	$ 25.00
b. Resistors: 220 ohm (3), 10 kohm (2) (4.7 kohm) (1)	$ 4.00
c. Superbright LEDs (2)	$ 3.20
e. Wire (approx. 10 ft)	$ 3.00
g. HomeworkBoard (Parallax) with imbedded Basic Stamp 2 IC	$ 50.00
i. Button Switch	$ 2.00
j. 3 V Photo Battery	$ 11.00
k. 9 V Photo Battery	$ 4.00
TOTAL:	**$162.20**

10. Acknowledgements

We would like to thank the Project Director Professor Vikram Kapila and Project Instructor Sang-Hoon Lee, for their assistance and patience. We would also like to thank Alessandro Betti for his assistance and allowing us to use his workshop.

A special thank you to Anshuman Panda, an undergraduate in the electrical engineering department who was extremely important to the code writing in our project, and with mechanical aspects of our project. We also need to thank graduate student Hong Wong for assisting us with StampDAQ Excel.

Finally, we would like to thank Parallax, Inc. for donating a “Homework Board”, and a “What’s a Microcontroller” text and parts kit to each teacher involved in the project and Polytechnic University and the RET program at the National Science Foundation for making this program possible.

11. Appendix A: PBasic Programs

```
' {$STAMP BS2}
' {$PBASIC 2.5}
‘-----------------------------------------------------------------------------------------------------------
‘I/O Definitions
‘-----------------------------------------------------------------------------------------------------------
ShtData PIN 11                    ‘bi-directional data
Clock   PIN 10
LED     PIN 8
Switch  PIN 0
FanSwitch PIN 6
‘-----------------------------------------------------------------------------------------------------------
‘Constants
‘-----------------------------------------------------------------------------------------------------------
ShtTemp     CON    %00011         ‘read tmperature
ShtHumi     CON    %00101         ‘read humidity
ShtStatW    CON    %00110         ‘status register write
ShtStatR    CON    %00111 ‘status register read
ShtReset    CON    %11110 ‘soft reset
Ack         CON    0
NoAck       CON    1
No          CON    0
Yes         CON    1
DegSym      CON    186            ‘degrees symbol for DEBUG

‘-----------------------------------------------------------------------------------------------------------
‘Variables
‘-----------------------------------------------------------------------------------------------------------
dataCountTemp VAR    Byte
```

```
dataCountRH   VAR     Byte
tC          VAR     Word
rhTrue        VAR     Word
counterT      VAR     Byte
counterRH     VAR     Byte
addr          VAR     Word
result        VAR     Word

ioByte        VAR     Byte              ‘data from/to SHT11
ackBit        VAR     Bit               ‘ack/nak from/to SHT11
toDelay       VAR     Byte              ‘timeout delay timer
timeOut       VAR     Bit               ‘timeout status
soT           VAR     Word              ‘temp counts from SHT11
tC          VAR     Word                ‘temp - Celcius
tF          VAR     Word                ‘temp - Fahrenheit
soRH          VAR     Word              ‘humidity counts
rhLin         VAR     Word              ‘humidity linearized
rhTrue        VAR     Word              ‘humidity compensated
status        VAR     Byte              ‘status byte
counter       VAR     Byte
height        VAR     Byte

height = 0

INPUT FanSwitch
INPUT Switch
‘-----------------------------------------------------------------------------------------------------------------
‘EEPROM Data
‘-----------------------------------------------------------------------------------------------------------------
‘-----------------------------------------------------------------------------------------------------------------
‘ Initialization
‘-----------------------------------------------------------------------------------------------------------------

Initialize:
GOSUB SHT_Connection_Reset                  ‘reset device connection
PAUSE 250                                   ‘let DEBUG window open

'DEBUG CLS,
'"SHT11 Sensor Demo", CR,
'"-----------------", CR
‘-----------------------------------------------------------------------------------------------------------------
‘ Program Code
‘-----------------------------------------------------------------------------------------------------------------

dataCountTemp = 0
dataCountRH   = 50
```

```
DATACOUNT    CON    22                              'DATACOUNT must = the # of
required data points/2

Main:
 IF IN0 = 0 THEN
  GOTO read_data
 ENDIF

 IF IN6 = 0 THEN
   HIGH LED
   GOSUB SHT_Measure_Temp
    DEBUG CRSRXY, 0, 3,
    "soT...... ", DEC soT, CR,
    "tC....... ", DEC (tC / 10), ".", DEC1 tC, DegSym, " ", CR,
    "tF....... ", DEC (tF / 10), ".", DEC1 tF, DegSym, " "

   GOSUB SHT_Measure_Humidity
    DEBUG CRSRXY, 0, 7,
    "soRH..... ", DEC soRH, CR,
    "rhLin.... ", DEC (rhLin / 10), ".", DEC1 rhLin, "% ", CR,
    "rhTrue... ", DEC (rhTrue / 10), ".", DEC1 rhTrue, "% "

   Write_Data:
       WRITE dataCountTemp, tC.LOWBYTE
         dataCountTemp = dataCountTemp + 1
       WRITE dataCountTemp, tC.HIGHBYTE
         dataCountTemp = dataCountTemp + 1

       WRITE dataCountRH, rhTrue.LOWBYTE
         dataCountRH = dataCountRH + 1
       WRITE dataCountRH,  rhTrue.HIGHBYTE
         dataCountRH = dataCountRH +1

   LOW LED

   IF dataCountTemp = DATACOUNT  THEN
     DEBUG CLS

     DO
       'DEBUG HOME, "Press button to display data"
       IF IN0 = 0 THEN
         GOTO PressDetected
       ENDIF
     LOOP

     PressDetected:
```

```
     PAUSE 1000
     'DEBUG CLS

  Read_Data:
      counterT  = 0
      counter   = 0
      counterRH = 50

      PAUSE 1000    'Allow data communications to stabilize
      SEROUT 16,87,[CR]       'Send a lone CR to ensure StampDAQ buffer is ready

      SEROUT 16,84,[CR,"LABEL,TIME, Meter, Temp, DEC Temp, Humidity, DEC
      Humidity",CR]  'Label 5 columns

      SEROUT 16,84,["CLEARDATA",CR]    'Clear all data columns (A-J) in Excel

     FOR  counter = 2 TO DATACOUNT  STEP 2

        READ counterT , result.LOWBYTE
        counterT = counterT + 1
        READ counterT, result.HIGHBYTE
        counterT = counterT + 1

        'DEBUG "Temp = ", DEC (result / 10), ".", DEC1 result , DegSym, " ", CR
          SEROUT 16,84,["DATA,TIME,", DEC height, ",", DEC (result / 10), ",", DEC1
          result, ","]

        height = height + 1
        READ CounterRH , result.LOWBYTE
        CounterRH = CounterRH + 1
        READ CounterRH, result.HIGHBYTE
        counterRH = counterRH + 1

        'DEBUG "Humidity =",  DEC (result / 10), ".", DEC1 result, "% " , CR, CR
        SEROUT 16,84,[DEC (result / 10), ",", DEC1 result, CR]
      NEXT

      PAUSE 5000

  Reintialize:
      DO
        IF IN0 = 0 THEN
        GOTO Initialize
        ENDIF
      LOOP
ENDIF
```

```
    PAUSE 2000
    GOTO main
  ELSE
   LOW LED
   PAUSE 100
   GOTO main
  ENDIF

END

'-----------------------------------------------------------------------------------------------------------------
'Subroutines
'-----------------------------------------------------------------------------------------------------------------
'connection reset : 9 clock cyles with ShtData high, then start sequence
'
SHT_Connection_Reset:
SHIFTOUT ShtData, Clock, LSBFIRST, [$FFF\9]

'generates SHT11 "start" sequence
'
SHT_Start:
INPUT ShtData                              'let pull-up take high
LOW Clock
HIGH Clock
LOW ShtData
LOW Clock
HIGH Clock
INPUT ShtData
LOW Clock
RETURN

'measure temperaure
'
SHT_Measure_Temp:
GOSUB SHT_Start                        ' alert device
ioByte = ShtTemp                       ' temperature command
GOSUB SHT_Write_Byte                   ' send command
GOSUB SHT_Wait                         ' wait for measurement
ackBit = Ack                            another read follows
GOSUB SHT_Read_Byte                        ' get MSB
soT.HIGHBYTE = ioByte
ackBit = NoAck                             ' last read
GOSUB SHT_Read_Byte                        ' get LSB
soT.LOWBYTE = ioByte
```

```
'Note: Conversion factors are multiplied by 10 to return the temperature values in tenths of
degrees
'
tC = soT ** $1999 - 400                        ' convert to tenths C
tF = soT ** $2E14 - 400                        ' convert to tenths F
RETURN

'measure humidity
'
SHT_Measure_Humidity:
GOSUB SHT_Start                            ' alert device
ioByte = ShtHumi                           ' humidity command
GOSUB SHT_Write_Byte                       ' send command
GOSUB SHT_Wait                             ' wait for measurement
ackBit = Ack                               ' another read follows
GOSUB SHT_Read_Byte                            ' get MSB
soRH.HIGHBYTE = ioByte
ackBit = NoAck                                 ' last read
GOSUB SHT_Read_Byte                            ' get LSB
soRH.LOWBYTE = ioByte

'linearize humidity
'Conversion factors are multiplied by 10 to return tenths

rhLin = (soRH ** $67AE) - (soRH ** $83 * soRH ** $5B) - 40

rhTrue = (tC - 250) * (soRH ** $34) + rhLin
RETURN

' sends "status"
'
SHT_Write_Status:
GOSUB SHT_Start                            ' alert device
ioByte = ShtStatW                          ' write to status reg cmd
GOSUB SHT_Write_Byte                       ' send command
ioByte = status
GOSUB SHT_Write_Byte
RETURN

' returns "status"
'
SHT_Read_Status:
GOSUB SHT_Start                            ' alert device
ioByte = ShtStatW                          ' write to status reg cmd
GOSUB SHT_Read_Byte                            ' send command
ackBit = NoAck                                 ' only one byte to read
```

```
GOSUB SHT_Read_Byte
RETURN

SHT_Write_Byte:
SHIFTOUT ShtData, Clock, MSBFIRST, [ioByte]          ' send byte
SHIFTIN ShtData, Clock, LSBPRE, [ackBit\1]           ' get ack bit
RETURN

SHT_Read_Byte:
SHIFTIN ShtData, Clock, MSBPRE, [ioByte]             ' get byte
SHIFTOUT ShtData, Clock, LSBFIRST, [ackBit\1]                ' send ack bit
INPUT ShtData                                        ' release data line
RETURN

SHT_Wait:
INPUT ShtData                                        ' data line is input
timeOut = No                                  ' assume no timeout
FOR toDelay = 1 TO 250                               ' wait ~1/4 second
IF (ShtData = 0) THEN EXIT
PAUSE 1
NEXT
IF (toDelay = 250) THEN timeOut = Yes                ' loop completed = timeout
RETURN
' reset SHT11/15 with soft reset
'
SHT_Soft_Reset:
GOSUB SHT_Connection_Reset ' reset the connection
ioByte = ShtReset                             ' reset command
ackBit = NoAck                                       ' only one byte to send
GOSUB SHT_Write_Byte                                 ' send it
PAUSE 11                                      ' wait at least 11 ms
RETURN

Heater_On:
status = %00000100                            ' heater bit = On
GOSUB SHT_Write_Status
RETURN
Heater_Off:
status = %00000000                            ' heater bit = Off
GOSUB SHT_Write_Status
RETURN
```

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