Low Cost Embedded Weather Station with Intelligent System

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***Abstract*: This paper presents an embedded design of a low cost weather station. Three weather parameters; wind speed, wind directions and temperature are measured. The measured parameters are used to measure the wind chill temperature and dressing index through calculation and a build-in intelligent system. Only basic types sensors were used (a reflective optical sensor, potentiometer and a temperature sensor) so that the cost of this design is reduced. A small scale neural network was planted into the microcontroller for the post-processing. Taking the three measured data as inputs, the system gave out the dressing index as an output. All of the data were displayed on the LCD and also sent to computer from the serial port.**

Keywords: Weather station; Wind speed sensor; Wind direction sensor; Embedded system; Wind chill temperature; Dressing Index; Intelligent system; Neural network.

I. INTRODUCTION

Normally, a weather forecasting merely tell people the weather conditions within a certain city or district, and within a certain period of time. However, the forecasting sometimes cannot be predicted precisely, especially in some particular cases. For example, strong wind during winter would make the actual feel temperature much lower than what it is. Therefore, this paper represents a design of a small-scale embedded intelligent weather station which can deliver real time weather conditions of surrounding environment. Three basic factors; wind speed; wind direction and temperature and two post-processed elements; real feel temperature and dressing index would be shown on LCD and also could be sent to serial port of a personal computer. The whole system was built using Freescale Dragon12-Plus2 board from HCS12 microcontroller family with MC9S12DG256 inside which uses 5V power supply. The wind speed and wind direction sensors were designed, tested and built in this paper which can get power supply from the board easily. These sensors cost much lower than the products on the market with respect to both the cost and power supply aspects. Most of the existing wind speed and wind direction sensors in the market are medium or large scale with external power supply, obviously not suitable for a small-scale embedded system with limited power supply.

Besides the basic weather parameters, the built-in intelligent system can process these data further. A small-scale neural network was implemented in the system to calculate the dressing index according to the real time temperature, wind speed and wind direction.

The paper is organized as follows: section II presents related work, section III presents the hardware design according to the requirement of the system, section IV describes the code structure of the system, section V introduces the data processing including formulas and the neural network, section Vi and VII presents the testing result, conclusion and future work, respectively.

II. RELATED WORKS

Most of the low-cost embedded weather stations exist in the market like [1], [2], [3] and [4] do not have the function to measure wind speed and wind direction.

Indeed there are many papers that describe the different types of wind speed sensors, such as hot wire anemometers [5], [6], acoustic anemometers [7], however, most of them are large scale sensors. Besides, there are also some complicated and expensive sensors like ultrasonic anemometers [8], [9].

III. HARDWARE IMPLEMENTATION

This section presents the target platform and the sensors of the weather station, and how they are connected with each other.

A. Target Platform

The target platform chosen for this design is the Free scale HCS12 family's Dragon12-Plus2, which is a low-cost, feature-packed training board, and the microcontroller is MC9S12DG256, consisting of a powerful 16-bit CPU, 256K bytes of flash memory, 12K bytes of RAM, 4K bytes of EEPROM and many on-chip peripherals [10].

B. Sensors

There are three sensors that are used in this weather station system; wind speed sensor, wind direction sensor, and temperature sensor. Excrept for the temperature sensor, the other two sensors are designed and built in this paper using

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basic types of sensors with peripheral circuits and structures. All the sensors are low-cost that uses power supply from the target board without external power source.

1) Wind Speed Sensor

The wind speed sensor consists of five parts:

a) CNY70: Reflective optical sensor with transistor output. When it scans black paper, the output is around 4.8V, and when it scans the white paper, the output is around 0.8V.

b) Encoder: Twenty black and white cells as shown in figure 1.

c) Rotor: Romoved from hard disc, this rotor can be easily spined which makes the wind speed sensor able to work at a low wind speed.

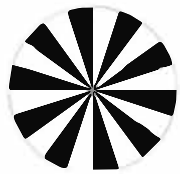


Figure 1. Windspeed sensor encoder

d) Plastic sticks and bowls: They are used for the frame of the fan blades.

e) Steel base: It is a heavy metal base to hold the rotor and keeps the whole wind speed sensor's center of gravity low.

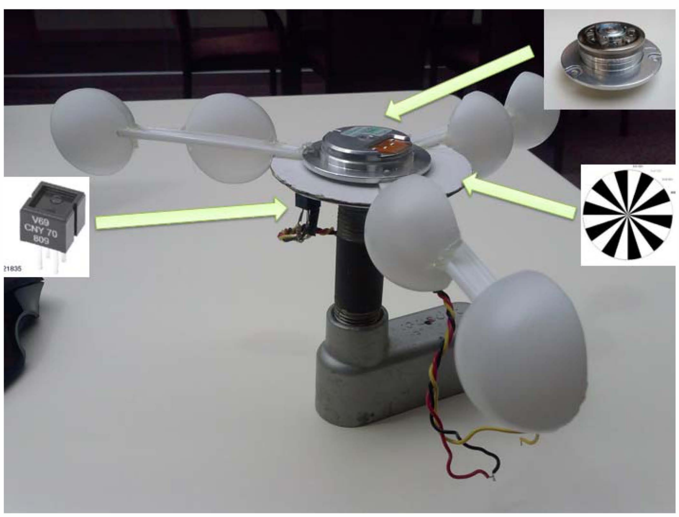


Figure 2. The wind speed sensor

The assembling model of the wind speed sensor is shown in figure 2.

When the wind drives the wind turbine to rotate, the reflective optical sensor will continuously scan the black and white cells of the encoder. When the sensor scans the black cell, the output of the sensor will be about 4.8V, and when it scans the white cell, the output will be about 0.8V. Therefore, if the output wire of the sensor is connected to the I/O port of the target board, the microcontroller will read "1" when black and "0" when white. The system counts the changes between "0" and "1" every 128 milliseconds, and save the number of the changes to a global counter. To transfer the value of the counter to the actual wind speed with the unit of MPH, the the values of the counter were collected at different wind speeds, and then a fitting curve was made as shown in figure 3 for the transformation. The transfer function which is derive is as follows:

$$Wind\ Speed = -0.0002451n^2 + 0.896n,$$

where "n " is the value of the counter.

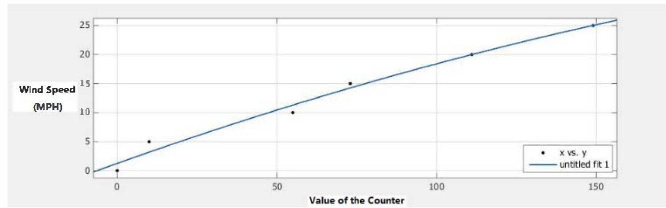


Figure 3. Fitting curve for wind speed

2) Wind Direction Sensor

The wind direction sensor is a 1-turn continuous potentiometer; Bourns 6657S-1-103. A 1-turn continuous potentiometer means the resistance of the potentiometer does not accumulate when the axis turns cycle by cycle. So every position of the axis has a fixed value of resistance. Supplied with 5V power resource, the microcontroller can read the voltage of each direction through analog-to-digital converter (ADC). Figure 4 shows the ADC reading value for the eight directions.

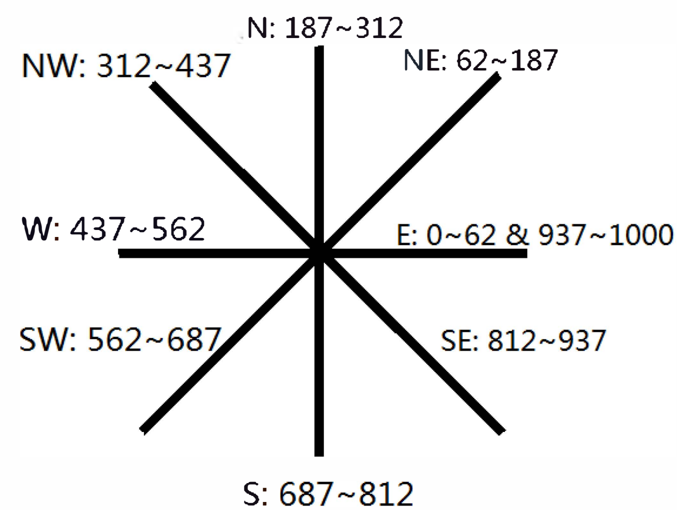


Figure 4. The ADC reading value for the eight directions of the wind direction sensor

The finished wind direction sensor is shown in figure 5.

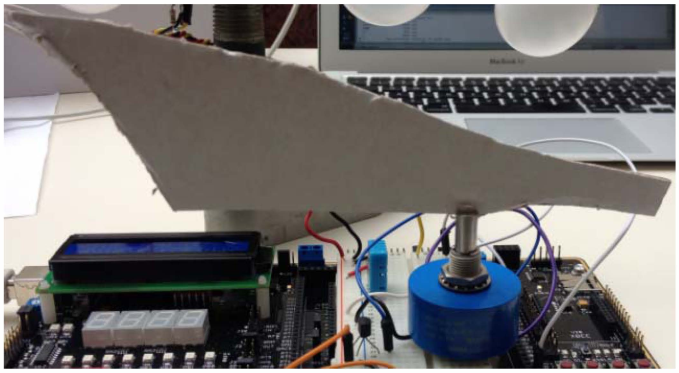


Figure 5. The wind direction sensor

3) Temperature Sensor

The temperature sensor chosen for this design is the Microchip's MCP9700, a low-power linear active thermistor. This tiny analog temperature sensor is optimized for analog-to-digital converters and to drive large capacitive loads with wide temperature measurement ranges from -40°C to +125°C and wide operating voltage ranges from 2.3V to 5.5V.

C. Hardware Structure

Figure 6 shows the hardware structure of the system. The 5V power source supplies the microcontroller, all the three sensors, the serial port and the LCD. Wind speed sensor is connected to the I/O port, and the other two sensors are connected to two different ADCs on board. The outputs of the system are displaced on the LCD and sent to the serial port that can be read by a personal computer.

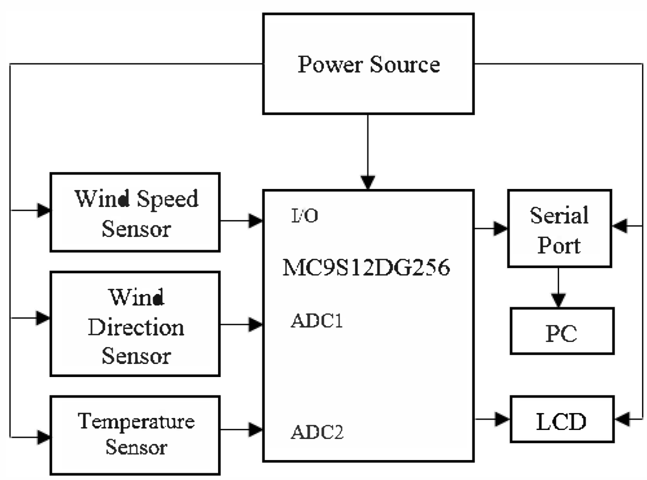


Figure 6. The hardware structure of the system

IV. Software System Structure

The software system design includes two parts, the data input from hardware sensors and the data output to SCI connected to a computer and LCD.

The microcontroller reads the A/D converter data from the wind direction sensor and temperate sensor. It then reads the I/O port data from the wind speed sensor and displays it on the on-board LCD of the Dragon12 development board.

The microcontroller is processing data that it receives from the A/D converter with timer interrupt service routine (ISR) and then it saves it to a global location. The microcontroller then captures the data from global location with timer interrupt.

The weather station will capture the wind direction signal and temperature signal through the A/D converter and speed signal through an I/O port. The weather station will display this data on the LCD and sent data to a computer through SCI. Figure 7 shows the flowchart of how the weather station works.

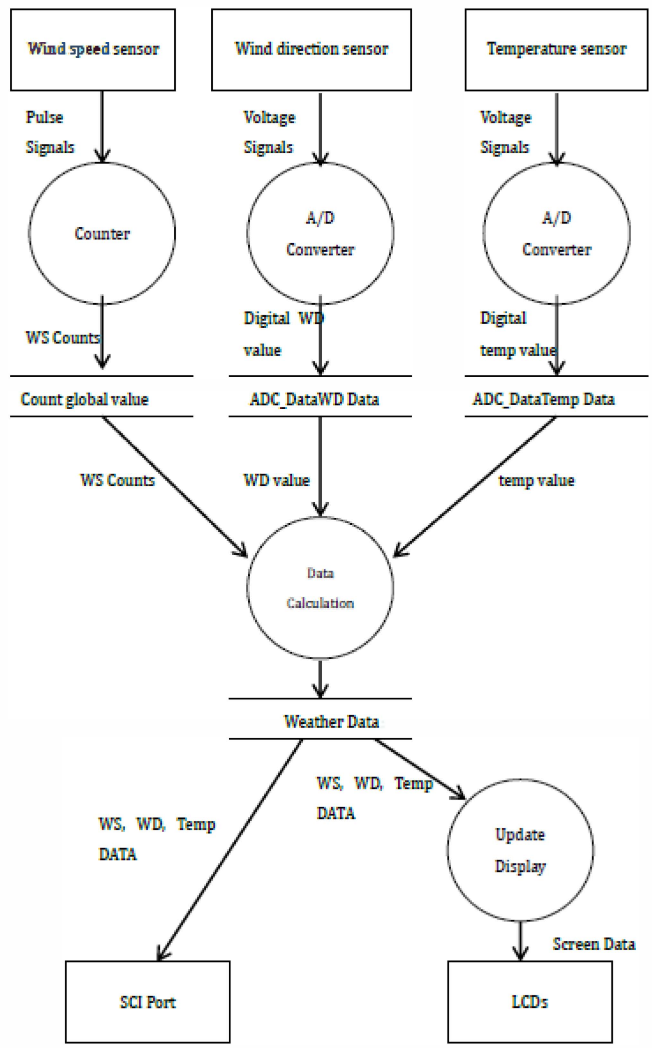


Figure 7. The flowchart for the weather design station.

A. A/D Convertor

There are two 10 bits A/D converter units in the MC9S12DP256 microcontroller, the ADC1 and ADC0. The successive approximation register (SAR) and the sample and hold amplifier (SHA) is the core unit of the microcontroller. For each ADC convertor, the input voltage signal, which will be in the range from 0V to 5V, can be selected from 8 input ports. The SAR will convert a digital value which is based on the input voltage to an analogue voltage. That voltage will be compared with the input voltage from port AN0 to AN7 in the comparator. The register will save the value depending on the result of comparison as can be seen in figure 8.

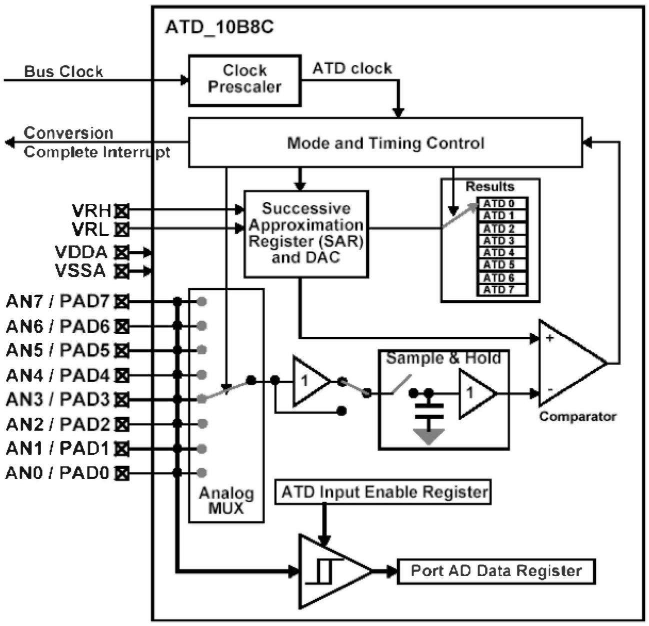


Figure 8. A/D

Data processing in an embedded system always need a timing engine. The timing engine used in ADC is End-of-conversion interrupt which acts inside the A/D converter. What the ADC interrupt does is running the ADC in the background and trigger the interrupt every time the ADC getting a 10 bits value. Applying the ISR to control the ADC will not need any call-up parameters and return values [11]. The interrupt will save the 10 bits value on buffer as a global value. The output will capture the value at the buffer through the use of the timer.

Before running this code, the design need to install the following two ADC starting address in the interrupt vector table:

```
ADCWD_ISR,        /* vector 0x17 (ATD1) */
ADCTemp_ISR,      /* vector 0x16 (ATD0) */
```

The two A/D converters ATD0 and ATD1 are named as ADCWD and ADCTemp by their signal types.

B. Timer Interrupt Output

The timing engine drive the data shown on the LEDs and transmit it to a computer via SCI and under the timer interrupt control. The system extracts data from global values *ADC_DataTemp* for temperature and ADC DataWD for wind direction every 32ms. It also extracts the wind speed counter every 128ms through the use the interrupt handler timer7.

The following is a program segment that shows how to extract the data from global locations and calculate it to numbers that human can understand:

```
PORTB ^= 0x01;                                    //
Toggle output bit (PB0)
   //sprint (temp, "%d", count_global);
   //writeLine (temp, 1);  // bottom line
   if (count_timer == 3) {
    count_global = count;
    count = 0;
    windspeed =  -0.0002451 * count_global * count_global
+ 0.896 * count_global;
    _itoa (windspeed, ws_char, 10);
 }
```

The following program segment shows how to display data on the LCD by calling a series of functions:

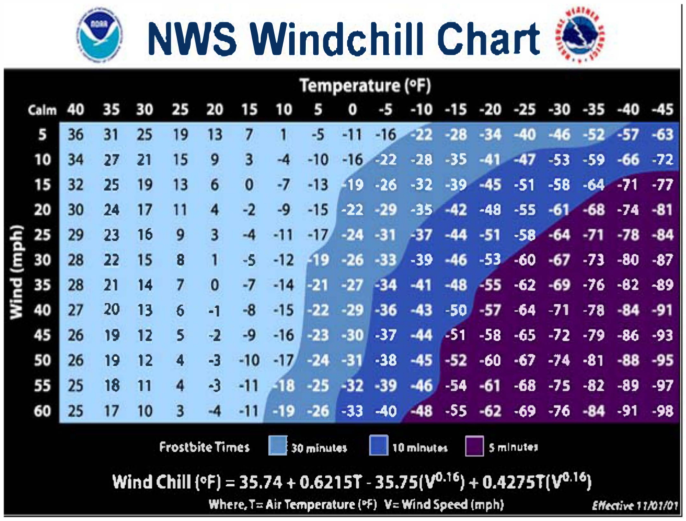
```
LCDClearDisplay;   // clear entire LCD
LCDSetAddr (0x00); // cursor to top line
LCDPutString ("WS:");
LCDSetAddr (0x03);
LCDPutString ("   ");
LCDSetAddr (0x03);
LCDPutString (ws_char);  // write string to top line
LCDSetAddr (0x06);
LCDPutString ("MPH");
```

V. Data Processing

After the acquisition of the basic parameters, these data need to be post-processed to get further information; the wind chill temperature and dressing index.

A. Wind Chill Temperature

In cold winters, usually people feel much colder than the actual temperature due to the chill wind blowing through the skin. Therefore, to get the real feel temperature, the system uses the obtained wind speed and actual temperature to calculate the wind chill temperature by the NWS Windchill Chart shown in figure 9 [12].



NWS Windchill Chart

Temperature (°F)

Wind (mph) \ Calm	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98

Frostbite Times 30 minutes 10 minutes 5 minutes

Wind Chill (°F) = 35.74 + 0.6215T - 35.75($V^{0.16}$) + 0.4275T($V^{0.16}$)

Where, T= Air Temperature (°F) V= Wind Speed (mph)

Effective 11/01/01

Figure 9. Wind-chill chart

NWS also gives the function to calculate the wind chill as follows:

$$\text{Wind Chill (°F)} = 35.74 + 0.6215\text{T} - 35.75(V^{0.16}) + 0.4275\text{T}(V^{0.16}),$$

where T is the air temperature (°F), and V is the wind speed (mph).

Considering that $V^{0.16}$ will increase the work load and may degrade the performance of the system, $V^{0.16}$ is replaced instead by a quadratic function obtained by curve fitting:

$$V^{0.16} = -0.0003195V^2 + 0.02814V + 1.179$$

Once the temperature is extracted, the wind chill temperature will be calculated and sent to LCD and serial port.

B. Dressing Index

Dressing index is an integer equal or greater than zero, which can suggests how many clothes a person should wear according to the real time temperature, wind speed and wind direction. The larger the index is, the more clothes are suggested to dress. Table 1 shows a suggested dress index specification.

Table 1. Dress index specification

Dressing Index	Suggestion
1 - 20	T-shirt/shorts
21 - 40	Shirt/Thin pants
41 - 60	Sweater/pants
61 - 80	Jacket/Warm pants
81-100	Down jacket/Coat
>100	Dress like Eskimo/Stay at home

Considering the tradeoff between the system performance and the information accuracy, a small-scale neural network is implemented. The neural network has one hidden layer and five hidden nodes [13]. The three inputs to the neural network are the real time temperature, the wind speed and the wind direction. The output is the dressing index. The structure of the neural network is shown in figure 10.

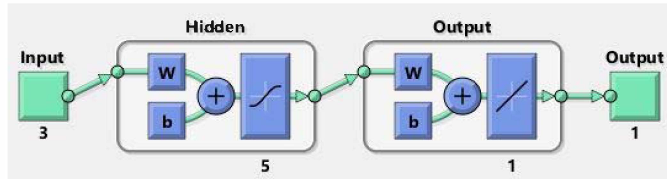


Figure 10. Neural Network Structure for the dressing index

A survey to build the data base for the neural network's training and testing was conducted. First, a 100×3 input matrix was randomly generated (three columns are for the three inputs and one hundred rows are for one hundred sets of inputs). This matrix was then assigned to ten people, five males and five females at different ages, and the participants gave out their dressing index based on their life styles. Finally the results from the ten participants were averaged to get a 100×1 target matrix. 80 sets of data were used for training. Validating and testing each got 10 sets of data. Figure 11 shows the best training, validating and testing results among 20 repeating times generated by MATLAB [14].

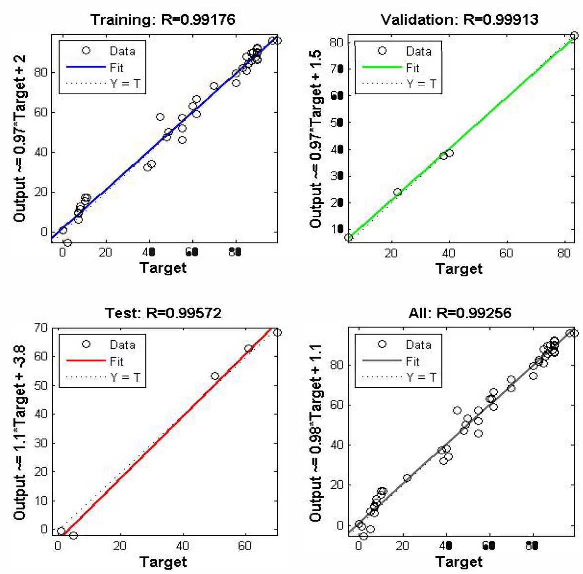


Figure 11. The best training

The weights and biases with the best performance were extracted as follows:

$$w_1 = \begin{bmatrix} 0.7022 & 0.3529 & 0.1848 \\ 2.5251 & 0.1504 & -0.2100 \\ 4.7106 & -0.3120 & 0.8012 \\ 0.9069 & -0.3103 & 0.0249 \\ 4.3782 & 0.5300 & -0.9255 \end{bmatrix} \qquad b_1 = \begin{bmatrix} 4.6241 \\ -1.3566 \\ 2.1266 \\ -0.3044 \\ 2.8092 \end{bmatrix}$$

$$w_2 = [1.3760 \quad -0.2133 \quad -0.0308 \quad -1.1157 \quad -0.1313]$$

$$b_2 = 104.3804$$

Finally, the dressing index was calculated as follows:

$$Dressing\ Index = w_2 \cdot (w_1 \cdot input + b_1) + b_2$$

VI. Testing and Result

The prototype for the system is shown in figure 12.

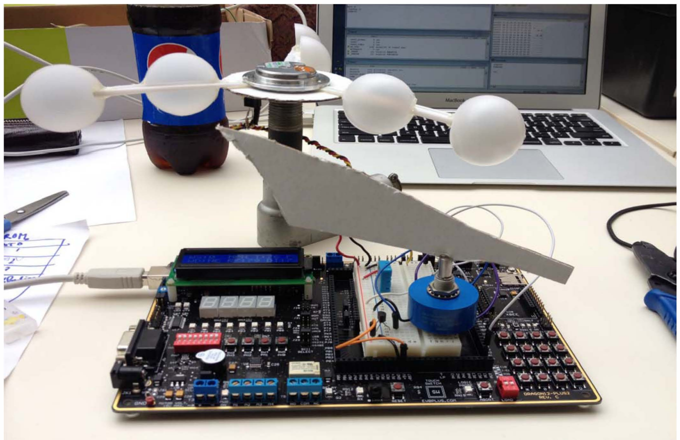


Figure 12. The system prototype.

A series of tests under different conditions were conducted at different temperatures, different wind speeds and different wind directions. The results are shown in table 2.

Table 2. Results

Temperature (F)	Wind Speed (mph)	Wind Direction	Real Feel Temperature (F)	Dressing index
10	3	E	4	100
35	9	N	28	73
61	16	NE	59	45
88	22	W	93	14
93	1	SW	97	0

The LCD has two rows and sixteen columns. The first row will display the following information: “WS: 12 MPH T: 81 F” where “WS” means wind speed and the unit is mph and “T” means temperature with the unit F. The second row will display the following information: “WD: N RF: 82 DI12”, where “WD” means wind direction, “RF” means the real feel temperature (wind chill temperature), and “DI” means the dressing index.

Figure 13 shows a sample LCD display of information.

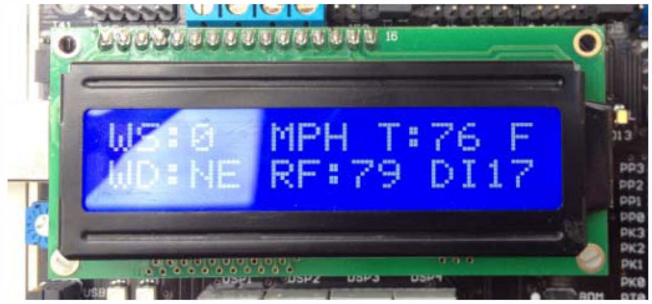


Figure 13. LCD display

The data that is sent through the serial port to a computer is arranged in the following order: temperature, real feel temperature, wind speed, wind direction and dressing index.

VII. Conclusions and Future Work

The paper presented a low-cost embedded intelligent weather station design that can measure the real time wind speed, wind direction, temperature, and gives out information on wind chill temperature (real feel temperature) and dressing index. All the information can be shown on the LCD and also can be sent through the serial port to personal computer.

For the future work, the authors will focus on the data storing and analysis. The data obtained from the intelligent weather station will be stored on a personal computer and according to the history more useful information can be predicted.

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