Design and Implementation of a Cost Effective, Portable and Scalable Electronic Weather Station

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Abstract: The purpose of this project is to design and implement a cost effective weather data measurement system that can measure and display different weather data to certain accuracy while being less costly and small in size at the same time. Present weather stations are large in size and incur a huge cost of installment, which is a limiting factor for developing countries. Some low cost table top systems are also available which has very less accuracy. The principle concerns of our design are to ensure low cost, flexibility, portability, scalability and user friendly operations. In this design sensors and equipments with good accuracy and low cost are used for measuring temperature, humidity, atmospheric pressure. For measuring wind speed and precipitation, a cost effective mechanical structure is designed which can be made from locally available products. The full system is designed considering the requirement of weather in Bangladesh.

Key-Words: - Weather station, Microcontroller, Anemometer, Hall Effect sensor, LM35, MPL115A1.

1 Introduction

Weather has always been the force of nature that influenced mankind in a very commanding manner. According to the National Center for Atmospheric Research, Americans check the weather 3.8 times a day. We are compelled by this force of nature because it is one of the few things that humans left untouched and out of their grasp of control. Trying to understand the weather and trying to forecast it correctly has been going on over the centuries and a lot of knowledge and data has been gathered which helped the researchers extrapolating methods of measuring weather phenomena and even forecasting the hazardous incidents of weather. “Meteorology” is a part of science which is solely devoted to this field. In this modern era many new technologies and methods have been developed for accurate monitoring of weather.

The first weather measuring instrument invented was hygrometer. It was invented by Nicholas Cusa in the mid-fifteenth century. Then in 1592 thermometer was invented by Galileo Galilei and about 50 years after that in 1643 Evangelista Torricelli invented the barometer for measuring atmospheric pressure.

During seventeenth through nineteenth centuries, these meteorological instruments were being refined and new instruments were being invented. All the observational, theoretical and technological development through centuries contributed to our knowledge of the atmosphere and individuals at scattered location began to make and record atmospheric measurements. [1]

A weather monitoring station which gives digital data usually consists of several weather phenomena sensing sensors and a processor unit which integrates all of the monitoring systems altogether. This paper will discuss on the self sustainable weather station which have the option to recharge the power source to prolong operation time. Also the design is a standalone wireless weather station module so no external power source will be needed and data will be extracted by wireless means.

Digital weather stations can be categorized into personal stations and professional stations. The personal weather stations are characterized to have relatively low cost with limited capabilities. The equipped sensors are less sensitive and usually they don't have the capabilities of logging data or transmitting them. On the other hand professional stations are more costly. They usually are wireless and standalone stations with capability of logging data autonomously and transmit them by wireless means to a nearly situated base station/computer. Personal weather stations lack self sustainability, precision and reliability. On the other hand, professional weather stations are too expensive for public use [2]. The aim of this research is to develop a less costly, user friendly portable weather measuring device. Figure 1 shows a picture of the full implemented system.

2 Relevant Works

Several low cost portable weather station projects have been proposed and Implemented in many countries over the past years. In the

Fig.1 Implementation of portable weather station

economical weather monitoring system proposal, the author Kulkarni et al [3] developed a similar system like ours but did not measure pressure and precipitation. Similar issues have arisen in the system mentioned by Sutar [4] and precipitation was not recorded in the system proposed by Popa et al [5]. Surussavadee et al [6] presented a method for evaluating weather forecasts via weather satellite. Weather satellites are being used for a long time in different countries and have contributed to improved weather analysis and weather predictions. But this concept is quite impractical to be implemented in a country like Bangladesh. Bangladesh does not have a satellite of its own and setting up satellites is not feasible considering the economic condition of the country. Besides satellites have trouble measuring some ground phenomenon such as precipitation whereas ground stations offer higher accuracy. Satellites do allow greater coverage of various

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parameters over a landscape but the precipitation ground measurements are more precise. Satellites undoubtedly provide more promising measures of weather variables however ground stations are more preferable in the rural area especially for precipitation measurement and cost-effectiveness. The embedded system proposed by Sankar et al [7] uses a hydrogen balloon for monitoring weather conditions, which is not suitable for implementation in Bangladesh. Krejcar [8] has also used temperature sensors in his proposed model that comes with a remote control but the construction of the entire setup is comparatively complex. Precipitation measurement has been proposed by Conti et al [9]; the system uses X-band weather radar. The radar monitors precipitation fields with high resolution in space and time and is supported by a rain gauges network of 18 tipping bucket gauges spread over the observed area, a weight rain gauge, an optical disdrometer, and a weather station. The setup is considerably complex and costly. Our proposed model allows measurement of various parameters in a cost effective and easily deployable structure.

3 System Design and Implementation

3.1 Temperature Measurement System

Temperature is a comparative measure of thermal state. Several scales and units exist for measuring temperature, the most common being Celsius (denoted by ºC), Fahrenheit (denoted by ºF) and Kelvin (denoted by K). Temperature is a very critical and widely measured variable. Measurement of this variable encompasses a wide variety of needs and applications. To fulfill this wide array of needs, a large number of sensors and devices have been developed. Temperature measurement can be done through many methods. In this proposed project, temperature has been monitored and controlled by the use of microcontroller based precision-integrated circuit temperature sensor. The sensor is of low cost, smaller in size, and is not subjected to oxidation. The sensor's low output impedance, low self heating, linear output, and precise inherent calibration make interfacing to readout or control circuitry convenient. The use of these sensors ensures accuracy and wide range measurement. Moreover, this controller based system can send data to the web server without the requirement of any user input. All these reasons stated makes the choice of this particular method of measurement more preferable if compared to other available methods.

Components Used:

1. Microcontroller (ATMEGA328)
2. Temperature sensor(LM35)
3. Circuit elements

Data Acquisition Process:

In this project to measure temperature, electronic sensor has been used. The sensor IC LM35 gives linear output voltage proportional to ambient temperature ranging from -55ºC to 150 ºC. For weather data this range is quite enough as temperature usually does not exceed this range. The output voltage is processed using ATMEGA328 microcontroller IC in such a way that the system displays temperature output in degree Celsius unit.

3.2 Humidity Measurement

The amount of water vapour which exists in the atmosphere at a certain time is known as humidity. Absolute humidity refers to the actual amount of water vapour present in a specified volume of air. Relative humidity is defined by the ratio of partial pressure of water vapour to the equilibrium vapour pressure at a given temperature. Relative humidity is expressed in percentage. The device which is used to measure relative humidity is highly dependent on temperature and pressure known as hygrometer. Hygrometers are of various types which uses change in different properties such as temperature, dimension, impedance, thermal conductivity, colour, acoustic transmission and so on. Measurement of relative humidity can be done both in digital and analog system. In this system HSM-20G sensor is used. This sensor converts relative humidity and provides voltage output that varies with relative humidity. The main reason for using this sensor is it enables high accuracy and range of measurement at very low cost. Moreover, this sensor allows continuous and convenient operation. The sensor is interfaced with the system microcontroller which measures the output voltage provided by the sensor and compute the corresponding relative humidity. The measurement is displayed via an LCD display connected with the system microcontroller.

Components Used:

1. HSM-20G Sensor
2. Microcontroller (ATMEGA328)..
3. Circuit elements

Data Acquisition Process:

HSM-20G is the main component in the humidity sensing unit. The operating voltage input for this sensor is 5.0±0.2V.. The maximum operating current rating of the sensor is rated at 2mA which ensures very low power consumption. Depending on the relative humidity of the surrounding atmosphere, the sensor output voltage range is 1.0-3.0VThe variation in output voltage corresponding to change in relative humidity is given by the following table supplied by the manufacturer of the sensor:

%RH	10	20	30	40	50	60	70	80	90
Output Voltage	0.74	0.95	1.31	1.68	2.02	2.37	2.69	2.99	3.19

The above data was used to generate a 4th order equation. The equation is

$$\%RH = P_1 * V^4 + P_2 * V^3 + P_3 * V^2 + P_4 * V + P_5$$

Coefficients:

P_1 = 3.176e-08
P_2 = -9.8284e-06
P_3 = 0.0009064
P_4 = 0.0035786
P_5 = 0.61444

This equation converts the analog voltage measured by the microcontroller to accurate humidity data.

3.3 Pressure Measurement

Atmospheric pressure can be measured in several techniques. Some of the older technique includes using liquid column and using bourdon tubes, which are bulky way to implement measurement of pressure. Due to the advancement of microelectronics, so many small size sensors can be made which measures the pressure effectively without that bulk. One of the common microelectronic pressure measurement techniques is using the Piezoresistive effect of semiconductor materials. For a semiconductor material, when mechanical stress is applied, resistivity of the material varies. When atmospheric pressure increases, the stress on semiconductor material also increases. Electronic circuit can be used to measure the resistivity of material and hence the pressure

Components Used:

- MPL115A1
- Microcontroller
- LCD Display
- Circuit elements

Data Acquisition Procedure:

MPL115A1 is a digitized pressure sensor which converts the data measured by its Piezoresistive portion into digital data. As MPL115A1 is factory calibrated, there is no need to calibrate the sensor during use. The pressure sensor MPL115A1 provides pressure data in digital SPI interface. When requested by microcontroller, MPL115A1 sends proper bits of data which is then converted to pressure data by the equation provided by the manufacturer.
According to manufacturer the pressure measurements are accurate to 1kPa and can measure pressure from 50kPa to 115kPa absolute pressure.

3.4 Wind Measurement

There are two different component of wind, wind speed and wind direction. As the main target of this research is to implement a system that is cost effective, wind direction measurement was skipped. Wind speed can be measured in several different methods. Some of the popular methods include using momentum transfer sensor, heat transfer sensors, and Doppler Effect sensors. The instrument used to measure wind speed is called anemometer. By mechanical design most popular anemometer used are cup anemometer, propeller anemometer and sonic anemometer.

In this project cup anemometer was used, mainly because it is easier to build, it has a linear response to wind and direct measurement of wind speed can be possible. Cup anemometers provide instantaneous speed of wind.

A cup anemometer has three or four cups mounted symmetrically around a freewheeling vertical axis. The difference in the wind pressure between the concave side and the convex side of the cup causes it to turn in the direction from the convex side to the concave side of next cup. The revolution speed is proportional to the wind speed irrespective of wind direction. In our design a three cup anemometer was designed and was build with brass stator base and stainless steel cups with stainless steel rotating base, as shown in figure 3. A magnet was added in base. A Hall Effect sensor was used to generate the rotation signal for use of microcontroller for further processing. The full working procedure is depicted in figure 2 below.

Components Used:

- Mechanical body
- Hall effect sensor A6851
- Microcontroller
- LCD Display
- Circuit elements

Working Principle Block Diagram:

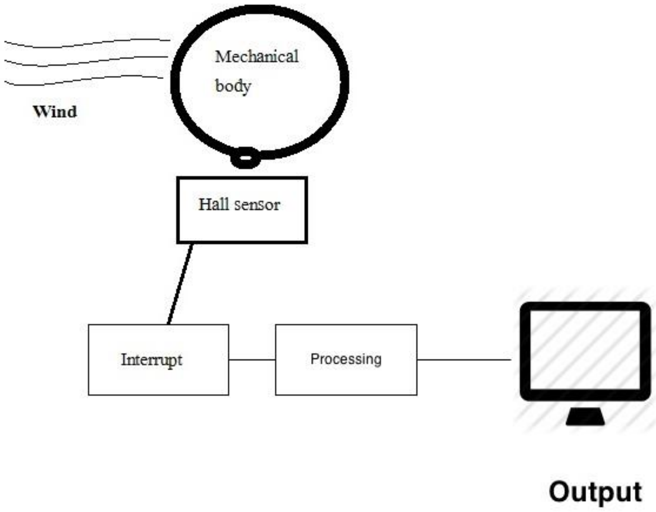

Fig. 2 Block diagram of anemometer

Fig.3 Anemometer

Data Acquisition Procedure:

When the anemometer base moves due to wind, for every rotation the magnet crosses the Hall Effect sensor. The hall effect sensor creates a voltage level transition. Microcontroller interrupt is used to detect this change. A counter in microcontroller is used to count the number of rotation per 4 second. This rotation per four second data can be used to measure rotation per minute. This in turn gives the speed of wind.

3.5 Precipitation

A rain gauge is a type of instrument which is used to gather and measure the amount of rainfall for a period of time. The unit of measurement for precipitation measurement varies from system to system. Some design

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measure the precipitation in millimeters which is equivalent to liters per square meter. Sometimes the level is measured in inches or centimeters. Rainfall can be measured automatically or manually. There are many methods of measuring rainfall but all the methods do not merge with automatic weather station because for automation the system has to measure the rainfall automatically. For this reason tipping bucket concept is used. This concept is convenient and offers high accuracy.

The tipping bucket system consists of a funnel which collects the water; the channel guiding the water in a seesaw-like container. After a preset amount of water is stored in the container, lever tips, dumping the collected water and an electrical signal is transmitted to the controlling unit.

Equipment:

Components Used:

1. Microcontroller
2. Funnel
3. Bucket
4. Jar
5. Hall effect sensor
6. Circuitry Elements
7. Magnet

Hall Effect Sensor :

In this system A6851 hall effect sensor is used. It is an integrated Hall latched sensor which has a output pull high resistor driver for electrical communication with brushless DC motor application and contactless switch. It has an on-chip voltage generator for magnetic sensing and it has a comparator which amplifies the Hall voltage. It has 3 pins one two pins for vcc and ground and the other one is for hall sensing output. When magnet passes the sensor this pin turned high. This sensor's rated temperature range is -20^{0}C to 100^{0}C and it has a voltage range of 3.5V to 28V. It works for unlimited magnetic flux density. Power dissipation is only 20mW and maximum junction temperature is 175^{0}C.A funnel was used to collect water from rainfall. A bucket was added in a way that every turn is equivalent to 1mm rainfall.

Data Acquisition Procedure:

A plastic jar was used to seal the bucket so that there is no external effect and to direct the water from funnel to bucket directly. The bucket used is portrayed on figure 4.

Fig. 4 Rain measurement System

In this system a funnel is designed to collect water and measure the area of the funnel. A channel guides the water in a bucket. According to the area of funnel the bucket is made which will trip when 1mm precipitation is measured. The tips of the bucket are measured using a magnet and a Hall Effect sensor. The magnet is attached to the center of the bucket and the hall effect sensor is attached to the base of the bucket in a way that the bucket trips whenever the magnet passes the sensor. As a result, for every tip the Hall Effect sensor will send a 5V signal to the main circuit. Measuring each signal the system will display the total mm of rain within a certain time.

System Block Diagram:

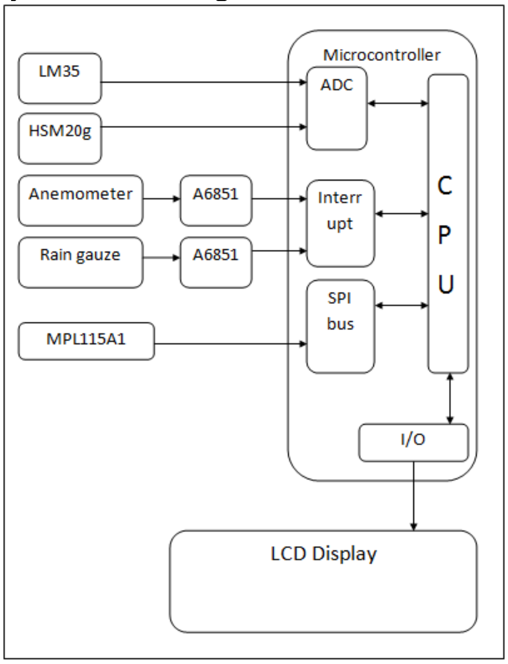

Fig.5 System block diagram

4 Research Contributions

The project was designed considering the environmental factors and weather condition in Bangladesh. Our implemented device is supposed to be used in outdoor and can withstand certain level of abuse from weather and human interference. The circuit is fully enclosed inside water tight box, so that the system can stand outside during rain or storm. Power can be provided from the main grid or using battery for power outages. The weather data included in the system includes temperature, humidity, pressure, wind speed and rainfall. These five weather data are mostly needed considering weather condition and need in Bangladesh. The system is designed to be scalable. If for certain purpose anyone needs any weather data to be excluded or included, that custom preferred system can be easily set without much change to the system hardware and software. The completed system is very much portable. There is four screws in the feet of the stand. To move from one place to another the system can be unscrewed from one place and screwed in new place. The system is lightweight for easy handling but not very light so that it cannot withstand rugged weather. Operation of this system is very simple. As there is no need of calibration, switching on the power will start the system measurement procedure and in some time start to show the current weather data. The system can also hold some previous data which when a preview button is pressed can show the data. Approximate cost of the total system is taka 1400 ($180 / € 165)

5 Conclusion

Our main concern for this project was to implement a cost effective mini weather station which can measure weather data like temperature, humidity, pressure, wind speed and precipitation, which will be small in size to be installed in building top or harvesting field but can withstand certain abuse from weather. This can be very useful to farmers and people who want to keep a close eye on the current weather conditions. The system is also easy to operate for any person as it does not require calibration or configuration after installation. Simply powering on the system will show and store the weather data.

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Appendix

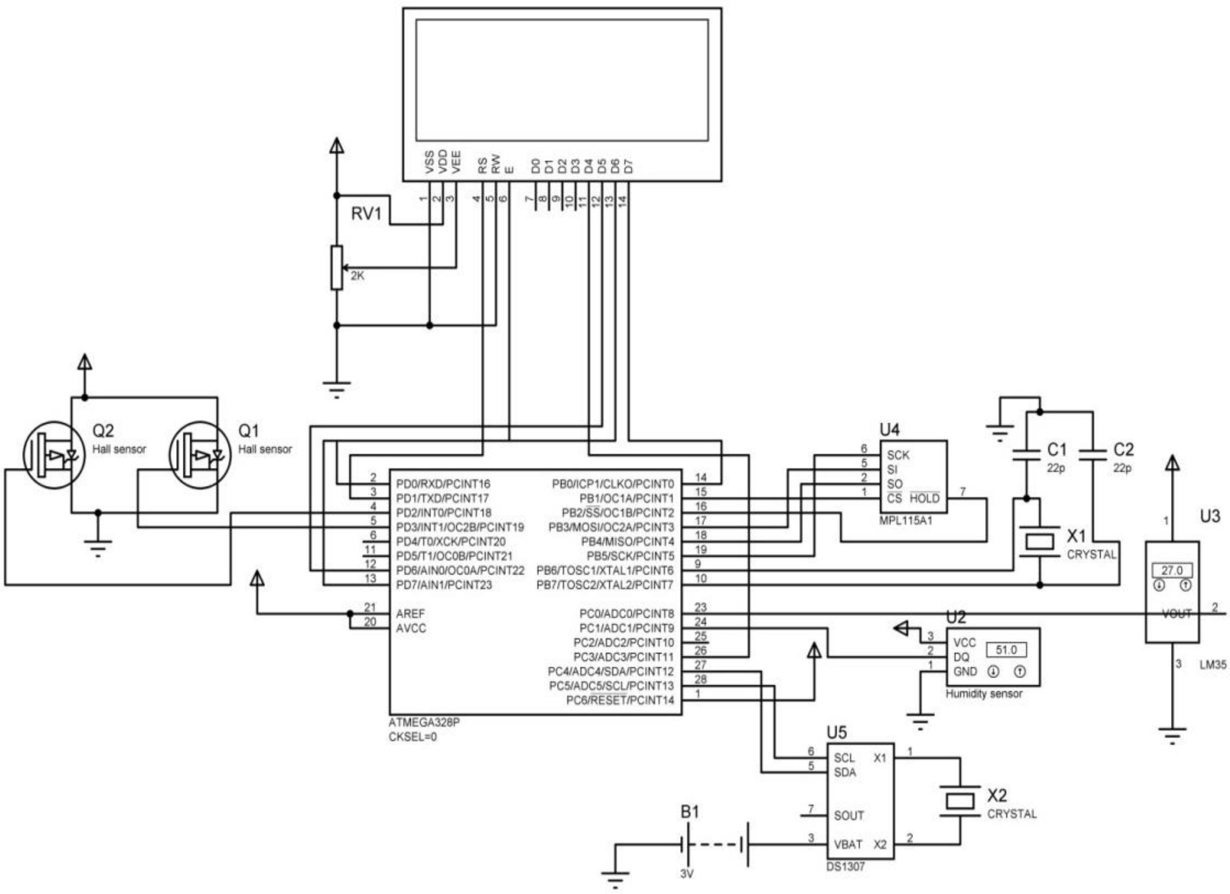

Fig. 6 Schematic of Weather Station