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Design and Development of Embedded System for Measurement of Humidity, Soil Moisture and Temperature in Polyhouse using 89E516RD Microcontroller

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Abstract The present embedded system has been design and developed in order to measure, display and control polyhouse related environmental factors such as humidity, soil moisture and temperature by using 89E516RD microcontroller. In order to maintain favorable condition for plant growth in polyhouse the humidity sensor, soil moisture sensor and temperature sensor along with microcontroller are deployed. The micro-controller based embedded system sense and display information on 16x2 LCD display and also provides automated ON-OFF control action for exhaust fan, heater and fogger. The result in the graphical format shows the response of embedded system under discussion. This system is cost effective, easy handling and has compact hardware.
Keywords *Embedded System; Sensor; Polyhouse; Agrimonics*

1. Introduction

The traditional open field plant growing techniques are facing great challenges due to excessive climatic conditions especially in very less and heavy rainfall areas [1]. The agricultural growth is getting disturbed in timely exports, which results in less crop production and heavy import of agriculture goods. There is a need to look for alternative technologies to increase agricultural yield. The use of efficient inputs must be improved and the latest technological developments must be practiced to fulfill the needs of national as well as export oriented nutritional target foods [2]. The adverse climatic conditions limit severely to the plant growth though out the year or during various seasons of the year. To overcome this, the controlled environment for plant growth has become an essential strategy. The latest practice has shown huge improvement in polyhouse technology in diversified fields such as plant science, soil science, weed science, plant pathology, and water technology and water agronomics. Polyethylene shed net helps to construct a polyhouse which provides artificially controlled environment for plant growth [3]. The controlled environment can be accurately measured and controlled in a polyhouse for improvement in crop productivity, quality and value. The prime objective of the research is to study direct and indirect effects on relative humidity, soil moisture and air temperature in controlled environment of polyhouse. Accurate measurement of these parameters can help to control environmental condition inside polyhouse while inaccurate measurement can be harmful for plant growth. For example relative humidity (above 80-85% RH) may cause disease which can reduce plant transpiration as well as excess increase in temperature inside the polyhouse. It causes excess evaporation of water from plants inside polyhouse. It is observed that relative humidity between 40% to 75% RH (Relative Humidity) and temperature between 20ºC to 30ºC is ideal for plant growth inside polyhouse [4]. By considering all these aspects an Embedded System using 89E516RD microcontroller is developed for the accurate measurement of humidity, soil moisture and temperature and provides automated control action.

2. Related Work

This research work mainly consists of design and development of an embedded system for polyhouse application. This system includes 89E516RD microcontroller with three sensors such as humidity sensor (SY-HS-220), soil moisture sensor (YL-69) and temperature sensor (PT100) employed inside polyhouse [5, 6, 7]. Signal conditioning circuits of respective sensor, data acquisition system, display unit and controlling section have been properly designed. The software required for sensor data acquisition, display and to control humidity, temperature and soil moisture inside polyhouse by using suitable hardware of the system is developed by using Keil µ-vision IDE [8]. The designed system is used for measurement of the mentioned environment condition and results are interpreted.

3. Polyhouse Environmental Factors

3.1. Humidity

Humidity in the atmosphere has its own importance as it governs most of the metabolic and photosynthesis activities of the plants. It has been observed that relative humidity between 40 to 75 percent is needed for plant growth. This is so because very high relative humidity will provide better environment for pathogenic organisms making the plant highly susceptible to diseases [9]. Low relative humidity is also harmful to the plants since it increases the evaporation rate and at the same time enhances the water requirement.

3.2. Temperature

All crops have certain temperature range in which they can grow better. Bellow this range necessary process for plant growth stops and there are chances of ice formation within the tissue, blocking the water necessary for the life process. More ever the ice crystals may have possibly puncture the cells. Under very high or extreme temperatures enzymes become inactive causing necessary processes for plant development get disturbed. Another issue is that the surrounding temperature as well as the soil temperature required for plant growth is very much dependent on light intensity, Carbon di-oxide (CO_2) intake, humidity and air velocity. Thus the temperature may affect the movement of minerals water and food in roots, stems and leaves. This can affect photosynthesis process significantly. Prolonged exposure to low temperature causes loss of flowers and fruits; slowing their growth. On the other side prolonged high temperature will result in loss of flowers, fruits, drying of leaves and slowing down of plant growth. Soil temperature also affects the plant growth because it affects the absorption of water from the soil by the plant [10].

3.3. Soil Moisture

By applying water as per plant requirement can increase plant health, enhance deeper root growth and make the plant ready for sustainable growth. The soil provides nutrition to the plant also give water and food supply. Soil is made up of mineral particles weathered out of rock. In soil, pores are the spaces between mineral particles that allow water to diffuse deep in soil. Soil particles are identified by their size as sand, silt, or clay. The mineral particles are held together by organic matter in soil. Nature of Soil depends on the relative proportions of sand, silt, and clay [11]. The process of returning of moisture from the earth surface to the atmosphere by evaporation method of water and transpiration from plants is known as evapotranspiration. While evaporation is the loss of water as vapor from the soil surface or from moisture on the surface of a leaf. In transpiration the loss of water vapor from different parts of plant takes place. Water is not only lost primarily from the pores on the leaves but also from stems, and flowers. This sensor can be used to find the moisture content in the soil, when the soil is having minimum or no water content, the module output is at high level, and else the output is at low level [12].

4. Embedded System

An embedded system is one that has computer-hardware with software embedded in it as one of its most important component. It is a dedicated microcontroller based system, which may be either an independent system or a part of a larger computing system. Figure 1. shows block diagram of embedded system for the measurement of relative humidity, soil moisture and air temperature inside polyhouse.

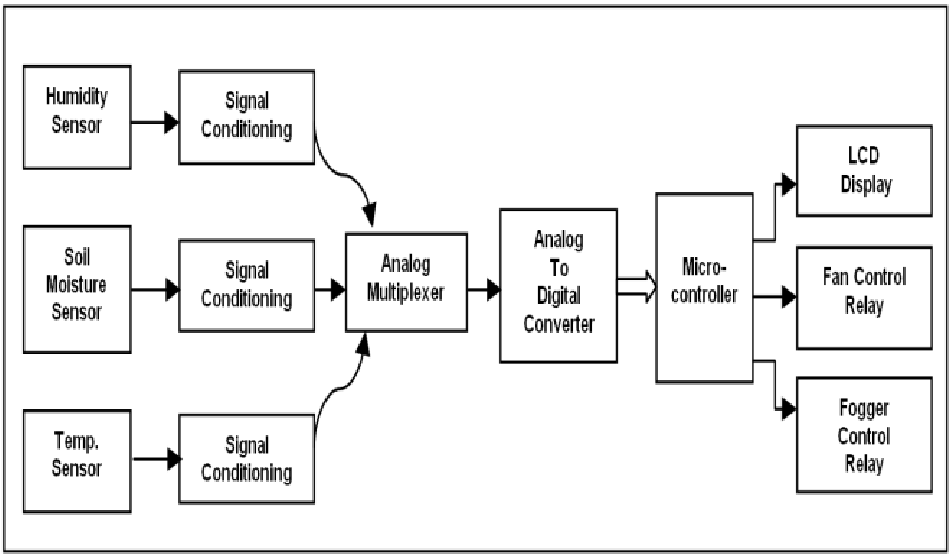


Figure 1: *Block diagram of embedded system*

This embedded system can be divided into six main blocks:

1) Sensor Module
2) Signal Conditioning
3) Analog Multiplexing
4) Analog to Digital converter
5) Microcontroller
6) Display and Control section

5. Sensors

5.1. Humidity Sensor [SY-HS-220]

The humidity sensor is of capacitive type, comprising on chip signal conditioner. However, it is mounted on the PCB, which also consists of other stages employed to make sensor rather smarter. The PCB unit also consists of thermistor and diode for temperature compensation. The humidity sensor used in this project work is highly precise and reliable. It can be a smart sensor, which provides DC voltage depending upon humidity of the surrounding in RH%. This work with +5 Volt power supply and the typical current consumption is less than 3 milliamps. The operating humidity range is 30% RH to 90% RH. The standard DC output voltage provided at 25^0C is 1980 mV (millivolts). The accuracy is ± 5% RH at 25^0C.

5.2. Soil Moisture Sensor (YL-69)

YL-69 moisture sensor is an Electrical resistance Sensor. The sensor is made up of two electrodes. This soil moisture sensor reads the moisture content around it. A current is passed across the electrodes through the soil and the measurement of resistance to the current flow into the soil determines the soil moisture. If the soil has less water resistance, sensor output will be less and thus more current will pass through probes of soil moisture sensor. On the other hand when the soil moisture is low the sensor module outputs a high level of resistance that causes higher output voltage. It means that more moisture in the soil gives the better conductivity or lowers the electrical resistance. These types of sensor are cheap, readily available and easy to install.

5.3. Temperature Sensor (PT100)

PT100, the common resistance temperature detector (RTD) sensor, is used in industry. It has a specified resistance of 100.00 ohms at 0°C and is made of Platinum, which has an accurately defined resistance verses temperature characteristic by drawing of graph. PT100 sensors were originally made with platinum wire wound on a ceramic former but are now made more cheaply by depositing a platinum film. It is important to mention that there are two error characteristics, an offset error (means how far is the output it has at 0°C) and a span or gain error (means how the resistance change with temperature agrees with the theoretical). The gain error depends on the offset error and the impurities in the platinum. PT100 elements are specified over a temperature range of -200°C to 850°C. In order to avoid self-heating of PT100 sensor because of increase in current flow through it, a constant current source excitation circuit has great importance in signal conditioning of temperature circuit.

6. Signal Conditioning Circuits

6.1. Temperature Measurement

Temperature measurement signal conditioning circuit is shown in Figure 2 and circuit's detail description is followed.

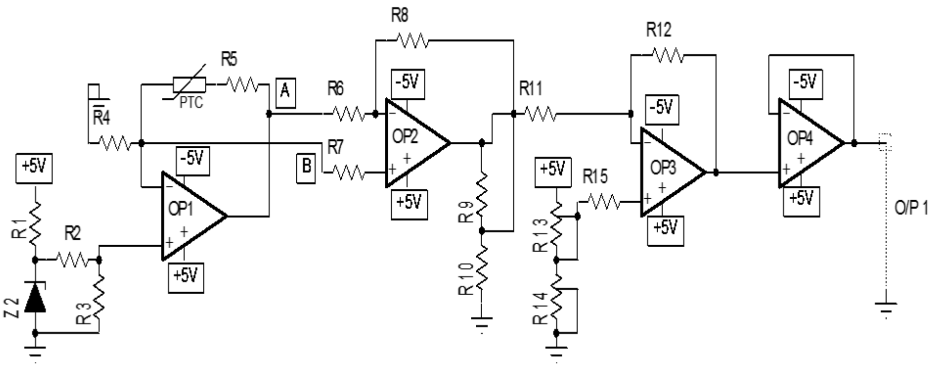


Figure 2: *Signal conditioning circuit for Pt100 temperature sensor*

A. *Constant Current Sourcing Circuit*

The sensor is RTD type, wherein change in resistance takes place due to change in thermal energy [13]. Instead of providing excitation voltage, the sensor is excited by constant current. The constant current source is designed and implemented [14]. The non-inverting input of OPAMP OP1 is connected across a stabilized zener regulator, which has fixed voltage drop of 2.7V across it. This voltage is adjusted at 0.486V by placing a potential divider across zener diode .So this fixed voltage drop is applied at non inverting input of OP1. Due to the virtual ground the voltage appearing at non-inverting terminal of OPAMP OP1 is necessarily equal to inverting terminal of OPAMP OP1. So inverting input terminal is at same potential, means at 0.486V. The current flowing through resistor R4 must be 0.486V/220Ω = 2.21mA. Temperature variation of 0°C to 100°C is considered as a limit for the design, because the temperature inside polyhouse never goes beyond this range. For this range total variation in resistance of PT 100 is 100Ω for 0°C to 138.5Ω for 100°C. The voltage appearing at its non-inverting input is fixed, while voltage appearing at output of OP1 is variable and it is corresponding change in resistance of PT 100, which is a Temperature sensitive sensor. The differential voltages at A & B points are observed. Here R1 acts as current limiting resistor for 2.7V zener diode. It is attempted to provide a constant current of 2.25 mA to temperature sensor PT 100. The total resistance change is from 100 Ω for 0°C to 138.5 Ω for 100 °C. The total change in the resistance is 38.5 Ω. So the total voltage change across PT 100 will be 38.5 × 2.25 mA = 86.625 mV. The range for variation in output voltage decided is 0.0V to 2.0V. Therefore, so the voltage gain requirement is $(2.0/86.625 \times 10^3) \approx 23$ which is further adjusted in differential amplifier stage.

B. *The Differential Amplifier*

The next circuit is of differential amplifier, which amplifies the differential voltages at A and B terminals of output stage of OP1. The extracted signal from the previous stage is applied to both inputs of differential amplifier, which in turn provides the desired gain of 23, which will vary the output in between 0V to 2.0V. The gain of OPAMP OP2 stage is 1+ (R9/R16) = $1+ (2.2 \times 10^3)/100 = 23$.The total output voltage swing will between $V_o = 23 \times 0.0$ V = 0.0 V to $V_o = 23 \times 86.625$ mV = 1.992 V, which is within the expected range of design.

C. *Offset Voltage Compensation Circuit*

The offset voltage resulting from earlier stage must be compensated. For this purpose a circuit is wired about OP-AMP OP3. Resistor R13 and R14 are adjusted to compensate offset voltage.

D. *Buffer Amplifier*

Last stage is a buffer stage is wired using OPAMP OP4. It is used for impedance matching purpose. This circuit also provides unity gain to an input signal. The output of this circuit is provided to the input of Analog Multiplexer circuit of the common data acquisition system. A common data acquisition system is designed and used for both temperatures as well as humidity signal.

6.2. Relative Humidity Measurement

Relative humidity measurement signal conditioning circuit is shown in Figure 3 and circuit's detail description is followed.

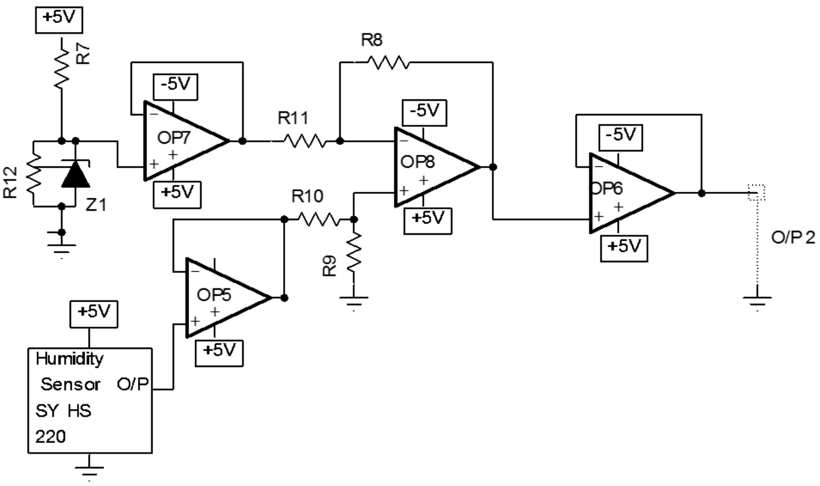


***Figure 3**: Signal conditioning circuit for relative humidity sensor SY-HS-220*

A. *Offset Voltage Compensator*

Voltage driven from IC LM 393 adjustable voltage regulator is applied at inverting input of Subtractor circuit. The output of Subtractor circuit is applied to the input of analog multiplexer circuit.

6.3. Soil Moisture Measurement

The moisture sensor with LM393 comparator chip, model YL-69 is used and it comes with a digital potentiometer as shown in Figure 4. The sensor is consisted of 4 pins: a digital output (0 and 1), an analog output, a VCC, and a ground. The sensor can be powered up by connecting the VCC pin to the 5V pin on the microcontroller Figure 4 below, shows the schematic for the moisture detection sensor module. Analog output is the voltage measurement between two probes of the sensor. For the digital output, it gets set as HIGH when the measured value is greater than the threshold set by the potentiometer and it gets LOW when the measured value is lower than the threshold. However, due to the fact that the digital output is not accurate, the analog output will be used as the analog input to the microcontroller directly connected through jumper wires. Analog output of this circuit is used.

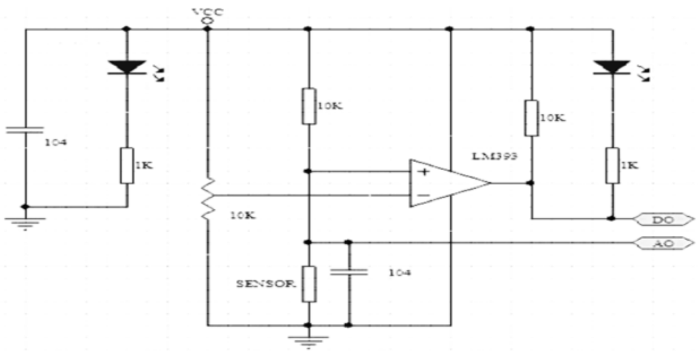


Figure 4: *Soil moisture measurement circuit*

7. Data Acquisition System

Data acquisition system is one of the important part of the circuit. Normally, if there are more than one input signals are appearing at the input of data acquisition system then use of analog multiplexer is essential for selection of each input signal. In present embedded system there are three input signals namely temperature, humidity and soil moisture are considered. Therefore, the analog multiplexer stage is added to fulfill the requirement of data acquisition system. The data acquisition system comprises following stages.

7.1. Analog Multiplexer

Role of multiplexer is to select any one of the input at a time decided by its control select input (controlled by microcontroller) out of many inputs and apply it to the to ease the job of conversion of selected parameter into its corresponding binary (digital) equivalent form by an ADC is of prime importance. This achieved by using analog multiplexer IC 4051. It is 8:1 analog multiplexer which is controlled by 3 control input lines namely A, B and C. We have used pin 11 & 10 as control or select line input A & B while pin no. 9 is not used as select line and is grounded so that maximum four analog inputs can be selected. Pin 13 accepts analog input from Humidity circuit, pin 14 accepts analog input from soil moisture circuit and pin no. 15 accepts analog input from Temperature circuit.

7.2. Analog to Digital Converter (ADC)

Data acquisition plays an important role in the microcontroller based real-time embedded system. If the on-chip ADC does not serve the purpose, on can use the ADC as MAX 1245, MAX 525 (12 bit) or AD 9772, which is highly accurate ADC with sampling rate of 150 MHz and 14-bit resolution. However, these ADC's are costly and increases the cost of system. Therefore, a low cost, high performance analog to digital converter from Intel, 8 bit ADC IC 0804, is selected for present system.

7.3. 89E516RD Microcontroller

It uses the 8051 instruction set and is pin-for-pin compatible with standard 8051 microcontroller devices .It has the following features,

- Operation:– 0 to 40 MHz at 5V
- Program Memory Type :- Flash
- Program Memory :- 72 KB
- CPU Speed :- 10 MIPS
- RAM :- 1KBytes
- Data EEPROM :- 64 bytes

- 16-bit Timers/Counter: - Three
- Four 8-bit I/O Ports (32 I/O Pins) and One 4-bit Port
- Three High-Current Drive Ports :- 16 mA each
- Programmable Watchdog Timer (WDT)
- Programmable Counter Array (PCA)
- Temperature Range (C) :- -40 °C to 85°C
- Operating Voltage Range (V) :- 4.4 Volt to 5.5 Volt

8. Software

Due to promising features of an Integrated Development Environment, IDE, Keil μVision3, this integrated environment is the highly suitable. Therefore the Keil micro Vision3, the evaluation version, is used to develop the software required for present microcontroller based system. When debugging/simulation are satisfactorily completed, the microcontroller is programmed with the .HEX version of the program.

Program Sequence

1) Initialization of Microcontroller
2) Selection of Sensor to read data
3) Process each sensor data information
4) Display on LCD screen
5) Set limit value for Control action
6) ON-OFF Relay action according to set value
7) Repeat step 2 to 6

8.1. Software Description

The Port3 and Port0 are defined as output port for LCD display and port 1 is used as input port for data input from ADC0804. Here the LCD display needs three handshaking signals, Register Select (RS), Read-Write (R/W) and Enable (E), derived from bit addressable Port3 pins P3.5, P3.6 and P3.7, respectively. The software consists of main program and various subroutines. The subroutine & the functions used in this program are as follows.

1) Measurement of temperature: temp();
2) Measurement of Humidity: Humi();
3) Detection of Soil Moisture: Smo();
4) LCD initialization
5) Display of the characters
6) String display
7) Reading of digital data
8) Delay subroutine

9. System Calibration

9.1. Calibration for Soil Moisture

Soil moisture sensor calibration should also be done in line with the manufacturer's specifications. The type of soils and their water requirements are greatly influence the sensor calibration. In this research work, the distance between two probes is kept fixed. A 10K resistor is connected in series with the probe and by applying +5V current passed through it. Soil resistance (Rs) is directly proportional to the moisture present in the soil. If the moisture is absent soil offer infinite resistance and if it is present give the resistance value. By applying the voltage divider rule we have to find out the relationship between soil resistance (Rs) and output voltage across Rs.

V out = Rs/(Rs+10K) * 5

where V out is voltage drop across Rs
Rs is the soil resistance
10Kohm is series resistance
+5V is fixed DC power supply.

9.2. Calibration for Temperature

After successful designing of instrument, it needs calibrate to the engineering unit has a prime importance. Therefore, one should follow the process of calibration. After successful calibration of the system one can implement the same for the purpose for which it has been designed. A particular care is taken to calibrate the system precisely and accurately. To sense the temperature a highly precise temperature sensor PT100 is used. It exhibits linear characteristics. Therefore, a first job is to convert the observed voltage into temperature in ^{0}C, for which a proper hardware is designed. The output voltage was observed in the millivolt range that means the output voltage is temperature dependent. This signal is calibrated to the temperature scale. Following procedure is adapted for calibration.

In the beginning temperature dependent voltage is measured and plotted against the temperature for range from room temperature to 100^{0}C. The data obtained from this experiment is used for analysis, wherein least square method of curve fitting is employed. The expression resulted from least square fitting procedure is

$$y = 0.2x + 4.7$$

Where, y is the resulting output voltage for applied temperature x.

Moreover, as per the standard traditional thermometer the temperature present embedded system's displayed temperature is also measured and comparison is done at Research and Developments Sub-division of Department of Irrigation, Malegaon colony, Baramati, District Pune.

9.3. Calibration of Relative Humidity

The system collects the signal in millivolts. By proper signal conditioning circuitry the humidity dependent signal is produced. However, as per need of sophisticated instrumentation, the parameters must be in respective engineering units. That means the humidity must be measured in RH%. Therefore, the calibration of the device is essential & therefore the system is further subjected to the process of calibration. For calibration of the present system a following procedure is adapted.

In the beginning a humidity dependent voltage is measured for entire range from room temperature conditions to the condensation of water. The experimental arrangement is shown in photograph as shown in figure. It is known that, the condensation of water vapors occurs if air gets saturated with the water vapors. That means condensation of water vapors is nothing but the saturation of air with water vapors. Thus, the voltages are measured up to saturation point. At room temperature the output voltage observed is 1.12mV, whereas that of saturation it is 2.0V. In this way the range of voltage is fixed. This confirms that the system never gets saturated for high humidity level.

Further, the system is subjected for process of calibration. For calibration, the humidity chamber, model M/s Gayatri Scientific Ltd. Mumbai is used. This chamber is available in our laboratory. The humidity from 20 RH% to 98 RH% with accuracy of 1 RH% is applied. The temperature range from 25^0C to 95^0C can be controlled. The temperature as well as humidity of the chamber is controlled by using PID techniques.

Experimental arrangement for calibration with humidity chamber is shown in figure. Keeping temperature constant, humidity applied to the sensor is varied between 20 RH % to 95 RH %. The data regarding output voltage given by the embedded system's circuit is collected. This data of output voltage measured against relative humidity is refined by least squares fitting procedure. This process of data analysis iteratively performed to get the refinement index as small as possible. The sensor module used is rather smart and therefore, it provides linear relation with the applied humidity. The constants observed are used in the firmware. Thus, the system precisely calibrated and hence it shows accurate reading of humidity in RH%.

9.4. Calibration of Embedded System

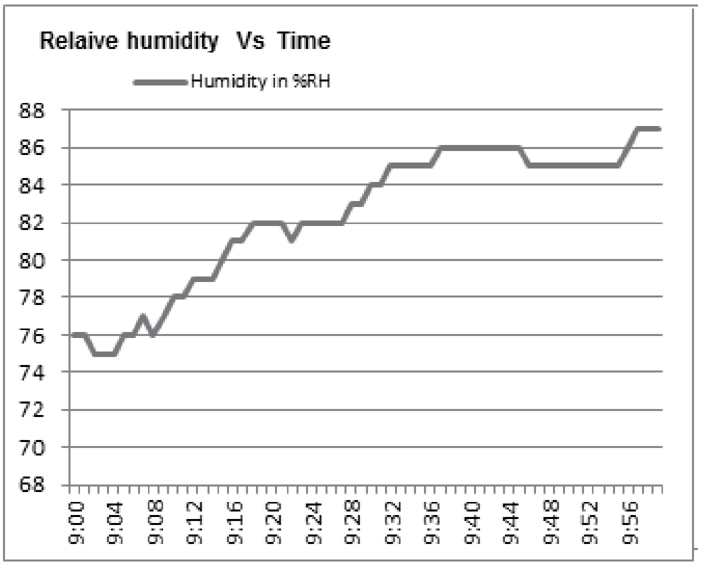
It is necessary to confirm the process of calibration; the system is also subjected to the measurement of humidity of the environment of Research and Developments Sub-division of Department of Irrigation, Malegaon colony, Baramati, District Pune. Actually, in this research and development laboratory the traditional methods of humidity measurement are used. In this laboratory, a method of comparison of dry air and humid air is done by means wet and dry bulb. This method is rather more popular. Therefore, to check the accuracy in the design, it is proposed to implement the system for measurement of humidity at this environment. The data shown by the system under investigation and that of obtained by traditional method of this research laboratory are simultaneously collected for fifteen days. On close inspection of collected data, it is found that humidity readings shown by the present system and that of obtained from traditional method shows close agreement. This supports the calibration process as well as the reliability in the hardware design. Thus, the system is calibrated to actual units.

10. Embedded System Experimental Setup

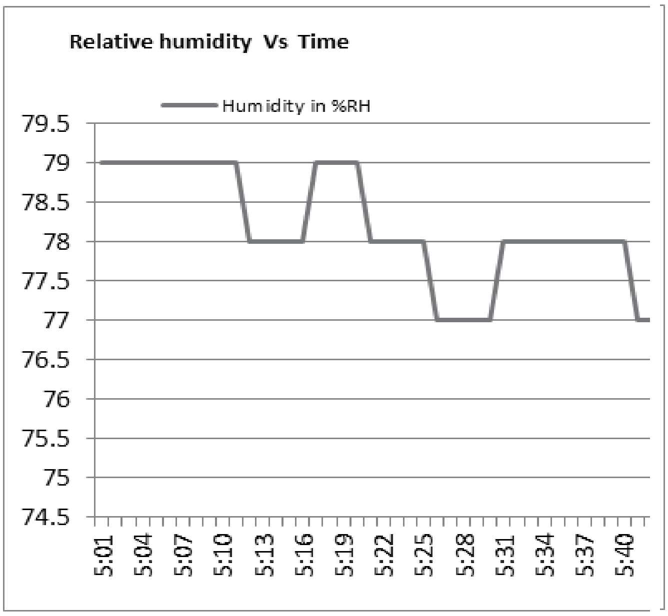
The experimental setup for measurements inside polyhouse was located at Mr. Taware's farmhouse at Kambleshwar, Tehsil Baramati, and District Pune. The temperature, relative humidity and soil moisture related data are collected and plotted in graphical format.

11. Graphical Representation of Results

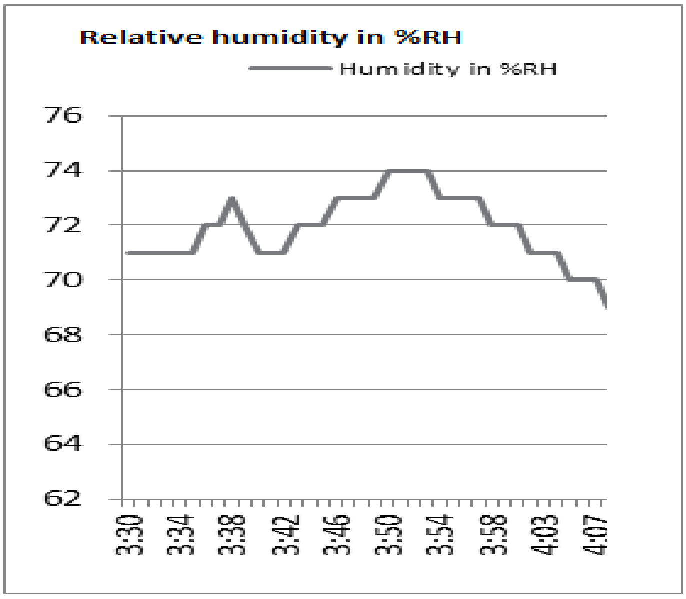
Data obtained from the relative humidity, soil moisture, and temperature sensors reading and recorded information was used to plot following graphs (a)-(g).



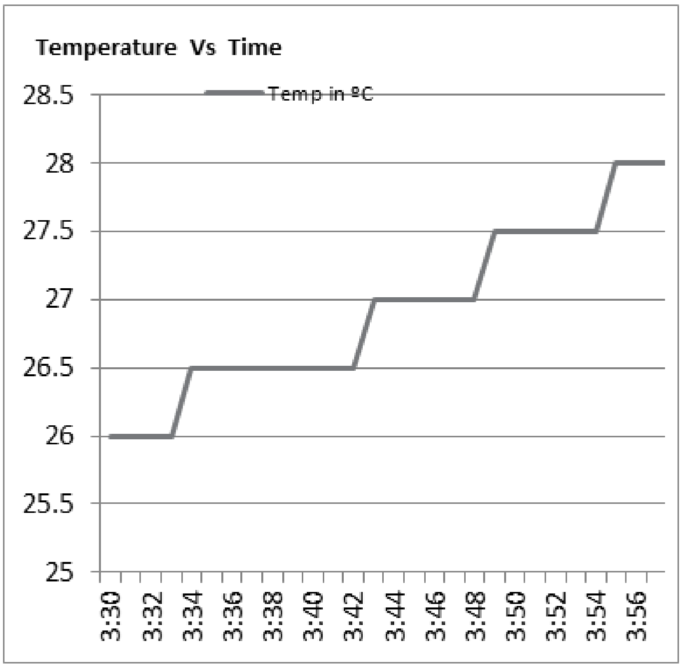
Graph (a)



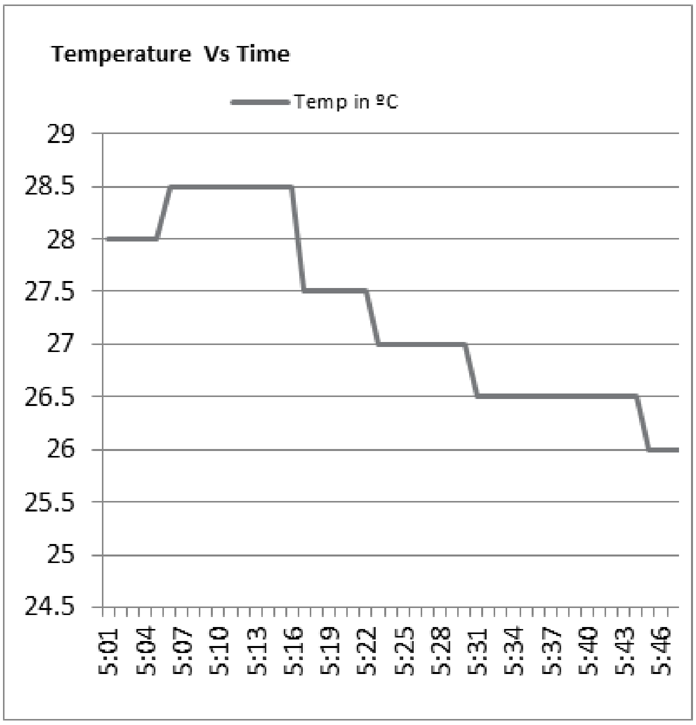
Graph (b)



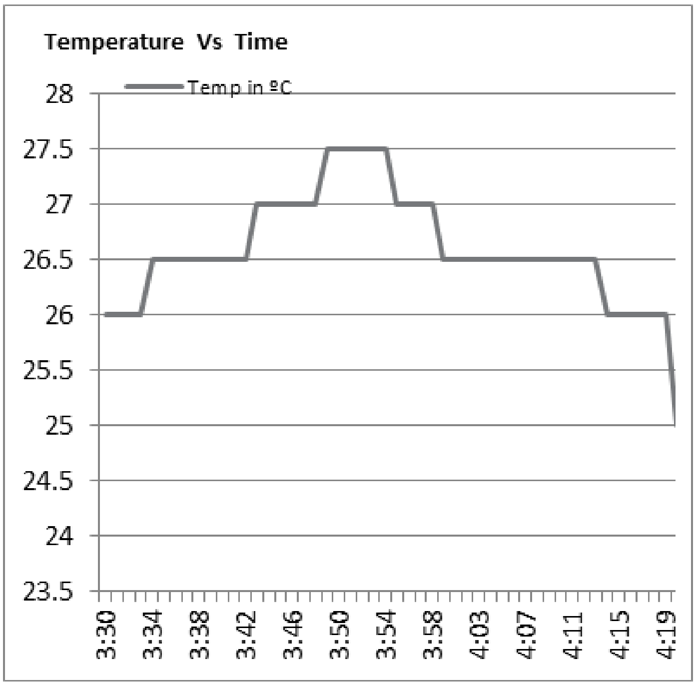
Graph (c)



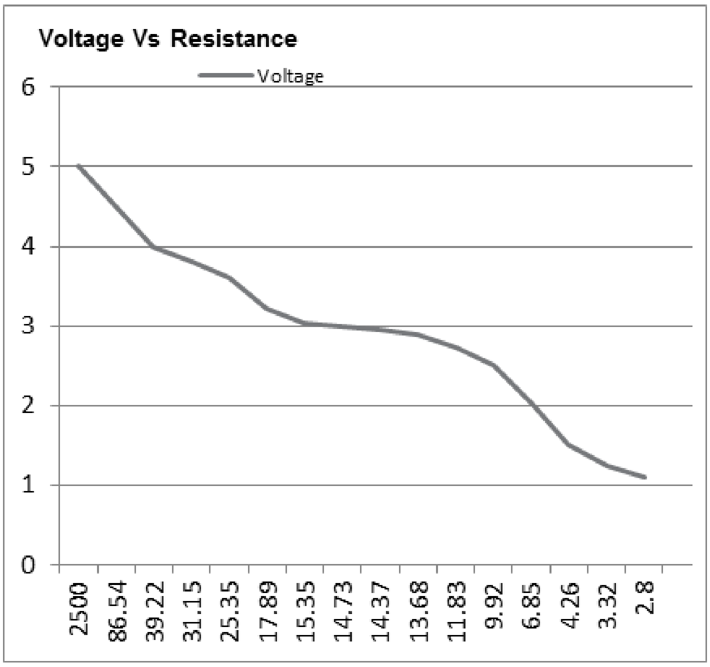
Graph (d)



Graph (e)



Graph (f)



Graph (g) Soil Moisture

12. Results and Conclusion

An embedded system is developed using promising microcontroller 89E516RD, for measurement of temperature and humidity in polyhouse environment. The experiment is carried out for fifteen days inside polyhouse for different time periods. However, typical observations are presented in the form of graph. On inspection of graphs, it is found that, humidity of polyhouse varies with time. Humidity increases when foggers are in on state, whereas, decrease in the humidity is observed when foggers turn off. Thus system tried to work with high reliability and accuracy only for a small size polyhouse.

12.1. Future Scope

Consistent attempt is going on to develop wireless based multi mote single hoping system which can satisfy more accuracy for medium and large area based polyhouses. In futuristic system every single mote will be able to record any possible climatic change in any portion of a polyhouse with a close vicinity of that localized area of a virtually partitioned polyhouse so that all central and corner areas of polyhouse can be under observation at the same time in order to achieve more and more preciseness of climatic parameters which are under observation and attempts will be made for achieving maximum coverage over entire area of a single or more polyhouse under observation at the same time.

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