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A PORTABLE AND FAST RESPONSE DIGITAL THERMO-HYGRO CONTROLLER FOR AGRICULTURAL, COMMERCIAL AND INDUSTRIAL USE

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A digital thermo-hygro controller was designed and fabricated using humidity (HIH-3610) and temperature (LM-35) sensors connected to a programmable microcontroller 16F876 of PIC family. This unit was calibrated with the standard Kestrel 4000 NV Weather Meter and psychrometer. It was tested for humidity and temperature measurements in the Green Houses, Glass Houses, Textile Spinning Units, Agro-climatology and Crop-physiology labs. Statistical analyses, like as T-test, standard deviation on the data obtained were performed to compare its performance with the standard thermo-hygrometers. The error in its performance was only ~5% in humidity and ~2% in temperature measurements. It gave prompt response directly and had low power consumption. Thus, it can be rated as a reliable and an economical three times cheaper replacement of the currently in use expensive imported devices. It is useful for agricultural and industrial sector and where a pre-decided humidity and temperature levels are needed to be monitored.

Keywords: Humidity, temperature, thermo-hygro controller, HIH-3610, LM-35, PIC16F876

INTRODUCTION

Temperature and humidity are two important factors playing their role in natural echo-system. In agricultural growth rooms temperature and humidity both are very important to monitor and control. Qi and Deng (2009) have reported that at 76^{o}F, leaf temperature and its transpiration will be the maximum. For every degree rise above 76^{o}F, plant looses 10% transpiration and at 81^{o}F, the transpiration of leaf goes down to 50%. For optimal leaf growth, the relative humidity (RH) should range between 40-60%. Controlling indoor humidity at an appropriate level is also very important at domestic level since this affects occupants' thermal comfort and indoor air quality.

Humidity is the amount of moisture or water vapor in the atmospheric air. Living beings produce moisture when they breathe or perspire. Through routine household activities like as cooking, showering, bathing, doing laundry, and dishwashing, we add water vapour to indoor air. And more moisture can enter to our indoor atmosphere from the surrounding soil through a basement or crawl space. Arlian *et al.* (1999) has recommended that reducing relative humidity to <50% in homes as one means of reducing dust mite populations in the houses of those who suffer allergies to house dust mites. Because of some activities in the home (e.g., bathing, cooking, opening windows etc.), it may not be possible to keep relative humidity constantly <50%.

The term "humidity" is usually taken in daily language to refer to relative humidity. Relative humidity is the amount of water vapor in a sample of air compared to the maximum amount of water vapor the air can hold at any specific temperature in a form of 0 to 100%. Further, relative humidity is the ratio of the quantity of water vapor actually present in any volume of air to the quantity of water vapor required to saturate the same volume of air at the same temperature. Humidity is very important factor in the preservation of materials, particularly in the storage of food products. Cao and Huang (2001) have reported that when the value of humidity exceeds beyond 50%, the level of bacteria, viruses and dust mites increases in the agricultural goods.

Mitter (2008) has presented the concept and design of miniaturized pressure humidity generator. The generator is suitable for achieving relative humidity ranging from 10% to 95% with uncertainties of under 1% at ambient temperature and can be used for the calibration of relative humidity instruments in the laboratory and on site. We must be sure that our device provides accurate readings. The technical term for this is calibration. When we calibrate our device, we are testing its accuracy by comparing it with an independent standard (Sanchez and Castanera, 2007).

The digital thermo-hygro controller fabricated in this study has a simple circuit. It consists of integrated circuits (ICs), resistors, capacitors, humidity sensor and seven segments LED displays. This unit can measure as well as control the temperature and humidity. It can be used at storage houses where edibles and other agricultural products like tobacco and dried crops are stored. Its use is recommended at all those places, where temperature and humidity are important factors to control like as green houses, agricultural experiments to be carried out in controlled environment at spinning units of textile industry and at the areas of scientific and commercial importance etc.

MATERIALS AND METHODS

The components used in this device were ICs, IC sockets, sensors, transistors, resistors, capacitors, diodes, relays, and LEDs. The other accessories were seven segment LED display, step-down transformer, key board having up, down, select and save switches.

Description and characteristic features of the major components

***1. The Humidity/Moisture Sensor (HIH 3610)*:** In the HIH-3610 Series humidity sensor, the direct input to a controller or other device is made possible by this sensor's linear voltage output. With a typical current draw of only 200 mA, the HIH-3610 Series is ideally suited for low drain, battery operated systems. The HIH-3610 Series delivers instrumentation-quality RH (Relative Humidity) sensing performance in a low cost, solder-able Single In-line Package (SIP). The RH sensor is a laser trimmed thermo-set polymer capacitive sensing element with on-chip integrated signal conditioning. The sensing element's multilayer construction provides excellent resistance to application hazards such as wetting, dust, dirt, oils, and common environmental chemicals. Li *et al*. (2006) worked on a similar device, namely a digital hygrometer which was made up of MSP430F449 MCU and humidity transducer HIH-3610. This hygrometer was able to realize the low-power measurement and guarantee the precision. Its Features are:

- Molded thermo-set plastic housing with cover
- Linear voltage output vs. %RH
- Laser trimmed interchangeability
- Low power design
- High accuracy
- Fast response time
- Stable, low drift performance

2. *The Precision Centigrade Temperature Sensor (LM 35)*: The LM35 series are precision integrated-circuit temperature sensors, which have output voltage linearly proportional to the Celsius Scale (^oC). The LM35 thus has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. A high temperature (700^oC) lithium ion-based CO_2 sensor using Li_2CO_3–$BaCO_3$ binary carbonate and SiO_2:B_2O_3:P_2O_5 (1:2:1) amorphous glassy ceramic oxide as sensing electrode is fabricated. The sensor worked efficiently at 700^oC without any degradation of the sensing material (Satyanarayana *et al.,* 2009). The LM35 does not require any external calibration or trimming to provide typical accuracies of ±0.25°C at room temperature and ±0.75°C over a full −55°C to +150°C temperature range. Low cost is assured by trimming and calibration at the wafer level.

Features Calibrated directly in Celsius (Centigrade)

- Linear + 10.0 mV/°C scale factor
- 0.5°C accuracy guarantee able (at +25°C)
- Rated for full −55°C to +150°C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 µA current drain
- Low self-heating, 0.08°C in still air
- Nonlinearity only ±0.25°C typical
- Low impedance output, 0.1 W for 1 mA load

***3. The Microcontroller (PIC 16F876)*:** This powerful (200 nanosecond instruction execution) and easy-to-program (only 35 single word instructions) CMOS FLASH-based 8-bit microcontroller packs Microchip's powerful Programmable Interface Controller (PIC) architecture into a 28-pin package and is compatible with the PIC16C5X, PIC12CXXX and PIC16C7X devices. The PIC microcontroller is a Multipoint Control Unit (MCU) and is used to measure relative humidity. MCU measures the period of the input signal and it converts into a digital relative-humidity data. The PIC's Console Command Processor (CCP) which is capture/compare/pulse-width module can also detect rising or falling edges every 4 or 16 pulses (Jiménez and Angulo, 2005). PIC16F876 features 256 bytes of electrically erasable programmable read-only memory (EEPROM) data memory, self programming, 5 channels of 10-bit Analog-to-Digital (A/D) converter, 2 additional timers, 2 capture/compare/PWM functions, the synchronous serial port can be configured as either 3-wire Serial Peripheral Interface (SPI) or the 2-wire

Inter-Integrated Circuit (IIC) bus and a Universal Asynchronous Receiver Transmitter (USART). All of these features make it ideal for an advanced level A/D applications in automotive, industrial appliances and consumer applications.

Features
(http://www.futurlec.com/Microchip/PIC16F876.shtml)

- High-Performance RISC CPU
- Only 35 single word instructions to learn
- All instructions are single cycle (1μs) except for program branches
- Operating speed: DC - 20MHz clock input
- 8 k Bytes Flash Program Memory
- 368 Byte RAM Data Memory
- 256 Byte EEPROM Data Memory
- In-circuit serial programming

PERIPHERAL FEATURES

- Two 8-bit timer/counter(TMR0,TMR2) with 8-bit programmable prescalar
- One 16 bit timer/counter(TMR1)
- Two Capture, Compare, PWM module
- 10-bit, 5-channel Analog-to-Digital converter
- Synchronous Serial Port (SSP) with SPI (Master mode) and I2C (Master/Slave)
- Universal Synchronous Asynchronous Receiver Transmitter with 9-bit address detection
- Two Analog Comparators
- Watchdog Timer (WDT) with separate RC oscillator

SPECIAL MICROCONTROLLER FEATURES

- 100,000 erase/write cycle Enhanced FLASH program memory
- 1,000,000 erase/write cycle Data EEPROM memory typical
- Power saving SLEEP mode
- Programmable code protection
- Selectable Oscillator Options
- Self-reprogrammable under software control

CMOS TECHNOLOGY

- Low power, high speed CMOS FLASH technology
- Fully Static Design
- Low Power Consumption

I/O AND PACKAGES

- 22 I/O pins with individual direction control
- 28-pin DIP

4. Three-Terminal Positive Voltage Regulators**:** The LM78XX series of three-terminal positive regulators are available in the (transistor outline) TO-220 package which is commonly used for transistors, silicon-controlled rectifiers, and integrated circuits with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents (http:// www.fairchildsemi.com/ ds/ LM%2FLM7810.pdf).

Features

- Output Current up to 1A
- Output Voltages of 5, 6, 8, 9, 10, 12, 15, 18, 24
- Thermal Overload Protection
- Short Circuit Protection
- Output Transistor Safe Operating Area Protection

TECHNIQUE**:** In this unit, an alternating voltage (220V) was applied at the input of a step-down transformer that gave 12V output which was further fed to four diodes 1N 4001(A bridge Rectifier) which gave 12V DC output which was made ripple free by the use of filter capacitors. This filtered 12V DC was then fed to a relay unit for its operation. The majority of components required 5V for their operation. For this purpose, LM 7805 (3-terminal voltage regulator) was employed that converted 12V DC into 5V DC. In this way, all the components needing 5V for their operation were connected to the output of IC 7805. This voltage was fed at pin 20 of the PIC 16F876 microcontroller as a supply voltage. Pin 2 and pin 3 of the microcontroller were control inputs and LM 35 (temperature sensor) and HIH 3610 (humidity sensor) were coupled to both of them respectively. Shield wires were wrapped on the legs of both the sensors to protect them from light and noise interference. A resistance of 100 Ω and a capacitor of 10 μF were soldered between the outputs of both the sensors and inputs (pin 2 and pin 3) of the microcontroller. This was done to mitigate the noise and ripples signals to be generated from the surrounding components which can be picked up by the sensors that can cause fluctuation in the display of humidity and temperature. Other input controls were provided from key board i.e., using its up, down, select and save keys as switch in such a way that these were connected to pins 14, 15, 16 and 17 of the microcontroller respectively. A resistance of 10 kΩ soldered at key board unit, worked as pull up resistance which provided ‘1’ (ON) state at outputs of buttons. But when any one key was pushed down, it was grounded and gave ‘0’ (OFF) state at its output. At pin 5 of the microcontroller, a 2.5V signal was available which served as a reference voltage). An IC, LM 336 (Zener diode) was connected to pin 5 through resistance and capacitor. Pin 9 and pin 10 worked as the crystal inputs of microcontroller with working frequency of 4 MHz. It was a crystal oscillator, considered as the heart of the processor which worked on clock pulse. Processor could not work without it. Pin 6 and pin 7 worked as relay’s output i.e., for humidity relay and temperature relay respectively. Pins 21-27 worked as output display for segments a, b, c, d, e, f, g respectively of 7 segments LED display. Pin 28 was attached to decimal point (dp) in the 7 segment LED display whose common anode was successively connected to the positive 5V supply line via three PNP transistors A733. Pin 11, 12, and 13 have three digit selected pins, namely LSD (least significant digit), NSD (next significant digit) and MSD (most significant digit) respectively which were also connected to common anode of the 7 segment LED display through three PNP transistors A733. The most right 7 segment LED (i.e. LSD) after dp was used to display ‘t’ with temperature read out and ‘H’ with humidity reading. Its pin 8 and pin 19 were grounded.

***Functioning of the Device*:** When the device was switched on, it showed the values of temperature and humidity one by one, e.g., it displayed the readings ‘30 t’ and ‘45 H’ for temperature and humidity respectively existed in the environment to which the unit was exposed. The programming of microcontroller was such that it sent signal to the relay unit to switch on LEDs if the ambient readings of temperature and humidity are less than the reference values saved by the user with key board. For example, if the user presses the ‘select’ button, it will begin to show only temperature value (again pressing this button, it will show only humidity value). Now the user can increase or decrease the values and then one can save the desired value, e.g., suppose the user saves the temperature value as ‘40 t’ and humidity value as ‘50 H’. Now if the user takes the above case (30 t and 45 H readings of environment), then both the LEDs will be ON. Now if these readings increase from saved values (40 t and 50 H), both LEDs will be turned OFF through relay, operated by microcontroller. It will again switch ON when the ambient readings decrease by 2 units from the saved values, e.g. if the temperature reading increases from ‘40 t’, temperature LED will switch OFF through relay. It will again switch ON if its reading falls to ‘38 t’ (i.e. two unit less than the saved value). Similar is the case with the humidity. In this way, device can control both the temperature and humidity in the environment, increasing from pre-selected values saved by the user. The LEDs can be replaced by humidifier, dehumidifier, sprayer, electric fan, electric heater etc., if these are connected to relay unit. So the relay unit can turn these devices ON or OFF by the microcontroller, thus maintaining the required values of temperature and humidity in the respective place/area. The complete circuit diagram of this device is shown in Figure 1.

***Performance Test*:** The performance of the digital thermo-hygro controller was studied by comparing its temperature and relative humidity readings with the standard devices like Kestrel 4000 NV (Pocket Weather Meter), thermo-hygro meter and psychrometer (dry and wet thermometer) etc. The temperature differences between the wet and dry junctions of the thermocouple were used to calibrate the relative humidity of air. The measured relative humidity was compared to a commercial humidity meter and showed good agreement. The working of this device was similar to that on which Abdul Wahab *et al.* (1995) worked. A series of large-scale laboratory experiments were conducted with the help of this unit to study the heat-induced moisture movement in a bentonitic (an absorbent aluminum silicate) clay buffer region. In the experimental investigations, hygro-thermal phenomena were induced by a cylindrical heater which was placed within the compacted buffer material (Selvadurai, 1996). The calibration was done at different places where temperature and humidity were important factors; e.g., green houses, glass houses, agro-climatology lab, spinning units and crop-physiology lab etc. This device was simple in use with easy to read in a plainly red digital 7 segment LEDs.

RESULTS AND DISCUSSION

The collected data about temperature and humidity

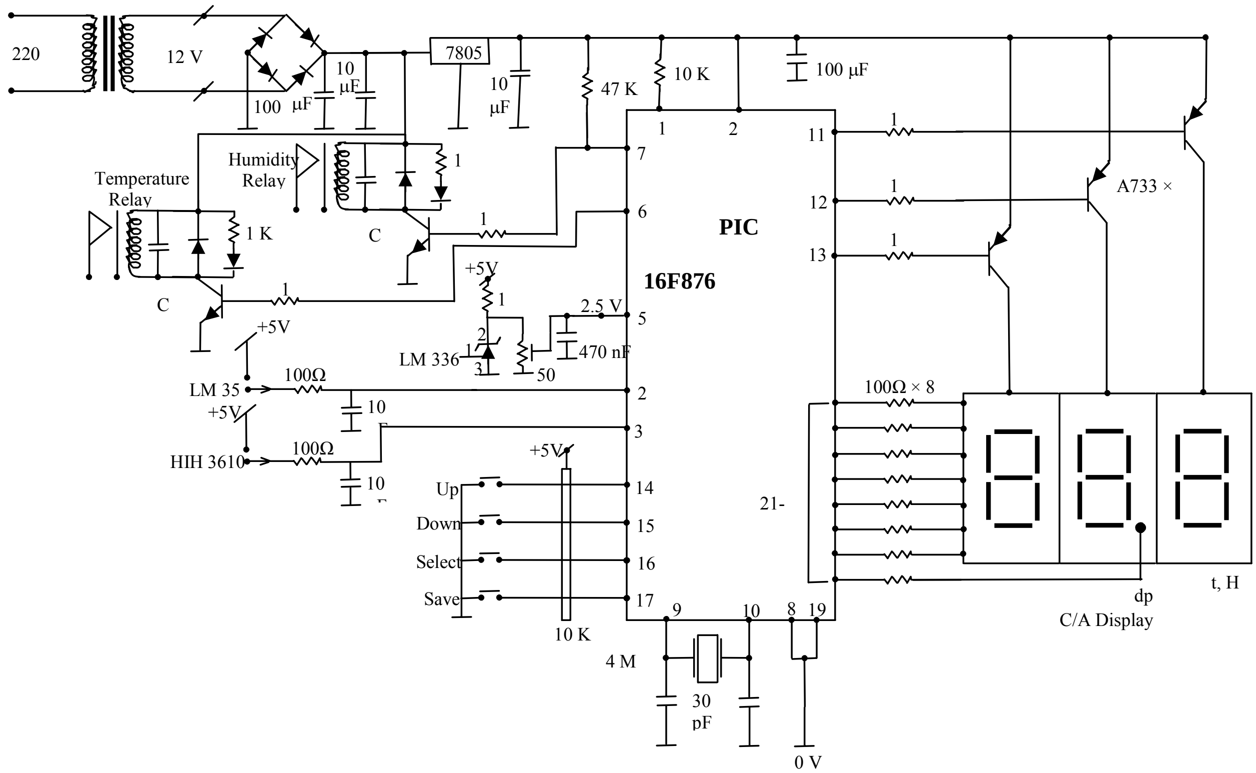

Figure 1. Complete circuit diagram of the Digital Thermo-Hygro Controller

were compared with the standard devices and comparative statistics on this data is presented in Table 1.

The data in Table 1 show that the differences between the CVs (coefficients of variation) of standard and fabricated devices for temperature and humidity are small; therefore, the performance of this unit was compatible to the standard device.

The similar type of studies has been reported by other researchers such as Han *et al*. (1999) who have reported about porous polycrystalline silicon (PPS) based conductivity sensors. The properties of the sensor were modeled and demonstrated with several experimental results. Rittersma *et al.* (2000) described a mixed signal; low power circuit design for temperature and humidity measurement and control unit. This circuit could measure the temperature to an accuracy of 1°C in the range of -20°C to 60°C and measure humidity to an accuracy of 10%RH in the range of 40%RH to 90%RH. The results obtained for this device are also similar to those as reported by Cao and Huang (2001).

Tables 2 and 3 show t-test employed to compare the mean differences in observations of Fabricated and Standard devices. The data related to p-values in both the tables show that there is no significant difference for both the parameters between the readings of Fabricated and Standard devices. In addition, the mean differences were negligible. From the 95% confidence interval for differences, it is concluded that if the experiment with this device is conducted 100 times, there would be at least 95% chances that the

Table 1. Comparative statistics of the data about temperature and relative humidity taken from Fabricated and Standard devices

Parameter	Mean	St. Dev.	CV	Min	Max	Range
Temperature Fabricated	34.56	2.86	8.28	30.00	39.00	9.00
Temperature Standard	34.37	2.78	8.09	30.00	39.00	9.00
Rel. Humidity Fabricated	45.11	17.79	39.43	22.00	75.00	53.00
Rel. Humidity Standard	42.73	18.03	42.19	21.00	72.00	51.00

Table 2. The significance of difference between Fabricated and Standard observations for temperature taking for all the data

t-Test

Hypothesis	**Assumptions**	**t-test**	**df**	**p-value**	**Mean Diff.**	**95% C.I. of Difference**	
						Lower	Upper
H_o: Temp. Fabricated –Temp. Standard = 0	variances are equal	0.241	52	0.810	0.18519	-1.35563	1.72600
H_1: Temp. Fabricated- Temp. Stand ≠ 0	variances are not equal	0.241	51.96	0.810	0.18519	-1.35566	1.72603

Table 3. The significance of difference between Fabricated and Standard observations for relative humidity taking all the data

t-Test

Hypothesis	**Assumptions**	**t-test**	**df**	**p-value**	**Mean Diff.**	**95% C.I of Difference**	
						Lower	Upper
H_o: Hum. Fab –Hum. Stand = 0	variances are equal	0.488	52	0.628	2.37778	-7.40289	12.15844
H_1: Hum. Fab – Hum. Stand ≠ 0	variances are not equal	0.488	51.99	0.628	2.37778	-7.40293	12.15849

obtained data will indicate almost zero differences or in other words we would be 95% confident that the true difference between Fabricated and Standard devices was almost zero. This fact is also revealed in Figure 2 and 3 which show a similarity in performance between the Fabricated and Standard device.

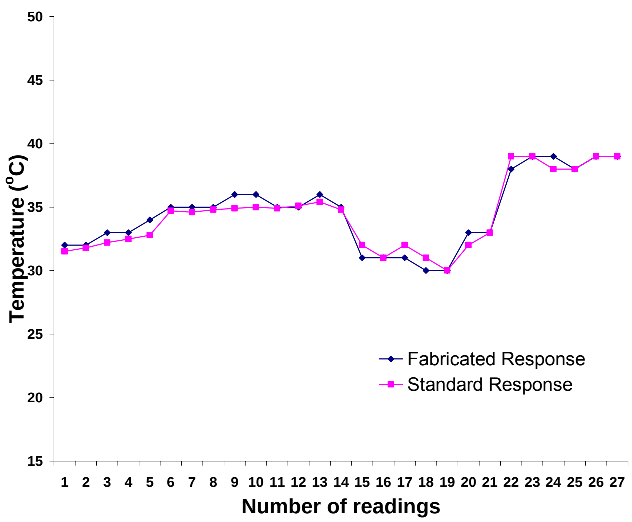

Figure 2. Comparison of Fabricated and Standard devices for temperature taking all the data

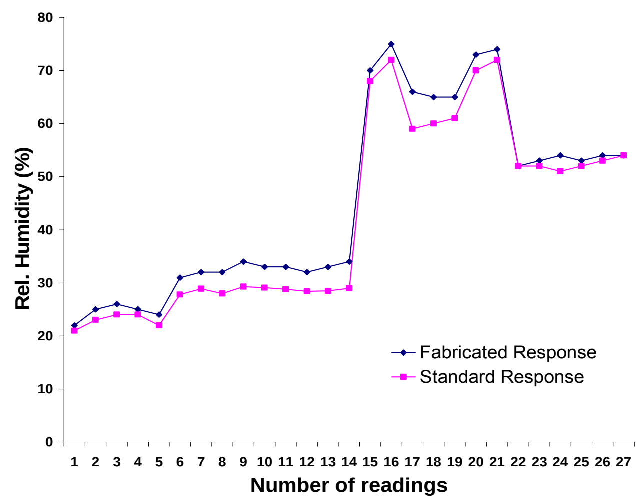

Figure 3. Comparison of Fabricated and Standard devices for relative humidity taking all the data

CONCLUSIONS

The fabricated digital thermo-hygro controller showed an excellent performance at all the searched locations/industrial places/green houses/any selected area where it was tested. The merits of this device are:

- It takes short time in the measurement of relative humidity and temperature of environment;
- We get direct and easy readout of the measurements from it;
- It is portable;
- It is easy to operate at every test site;
- Manually adjustable.

Basing on its merits, performance and percentage of reliability as obtained in the data acquainted, it is suggested that this is a useful and economical device which has potential to be commercialized and its fabrication process can be taken up with large scale integrated technology.

Future Recommendations

- Decimal readout can be added.
- The existing device doesn't show the temperature and humidity readings simultaneously. This ability can be developed by doing certain modification in the circuitry of this device.

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