HUMIDITY CONTROL SYSTEM FOR ROLLING AND FERMENTING ROOM OF A TEA FACTORY

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Declaration

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Signature: Date:

The above candidate has carried out research for the Masters under my supervision.

Signature of the supervisor: Date:
Dr. D. P. Chandima

Abstract

This thesis presents a research carried out to develop a humidity control system for tea rolling and fermenting room of a tea factory. During the rolling process, cell breakage causes the mixing of enzymes with other chemical compounds, and fermentation starts and continues throughout the rolling and roll breaking processes. Further fermentation is allowed to continue on fermenting racks for such time as desirable. Rolling room operation should be geared for ventilating and humidifying to control those fermentation reactions at desired levels. Moisture is an essential requirement for enzyme activity and lack of humidity leads to surface drying of dhools and loosing the liquor properties of tea. During all rolling room processes, a humid atmosphere should surround dhools and hygrometric difference between 2-3^{0}F is satisfactory. Humidification also helps in reducing the room temperature up to the level of ambient wet bulb.

Since British introduced tea to Sri Lanka, almost all the factories still use wet and dry bulb hygrometers to observe the level of humidity during rolling and fermenting processes and use manually switchable humidifiers. Tea industry is still very reluctant to give-up wet and dry bulb difference method and move to work with relative humidity. Even Tea Research Institute in Sri Lanka is still using wet and dry bulb difference method.

This research automates same art with digital wet and dry bulb sensors and reads level of relative humidity using a digital humidity sensor as an addition. While providing traditional dry-wet (D-W) control mode, the controller also provides humidity control mode for the customers to choose. Displaying relative humidity level at traditional dry-wet mode addresses the knowledge gap of tea makers to move to the direct humidity control mode from traditional wet and dry bulb difference method. The developed humidity control system addresses the lapses of previous products and performs satisfactorily compared to widely used low resolution alcohol wet and dry bulb hygrometers and automatically switches ON or OFF relevant humidifiers to maintain the desired humidity level.

Acknowledgement

I would like to extend my sincere gratitude to the project supervisor, Dr. D. P. Chandima who guided me throughout the project where finally it could be completed with promising outcomes and within the allocated time. I also grateful to all academic and non academic staff of the Department of Electrical Engineering, Faculty of Engineering, University of Moratuwa for facilitating me in many ways on my M.Sc. studies. I specially thank Mr. Gerry Galahitiyawa and Mr. Chamindra of Tea Research Institute, Ratnapura, Finally, I should thank my colleagues, friends and individuals who have not mentioned here personally, in making this research project a success.

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List of Abbreviations

Abbreviation	**Description**
D-W	Dry temperature - Wet temperature
RTD	Resistance Temperature Detector
HS1101	Humirel HS1101 Relative Humidity Sensor
DHT22	DHT22 digital Humidity and temperature sensor
DS18B20	DS18B20 digital, factory calibrated temperature sensor
SHT11	SHT11 digital humidity and temperature sensor
NTC	Negative Thermal Coefficient
A/D	Analog to Digital
%RH	Relative Humidity
OTP	One Time Programmable
LSB	Least Significant Bit
MSB	Most Significant Bit
ACK	Acknowledge
DC	Direct Current
ICSP	In Circuit Serial Programming
PID	Proportional Integral Derivative
PCB	Printed Circuit Board
PIC	Peripheral Interface Controller
MCU	MicroController Unit
eeprom	Electrically Erasable Programmable Read Only Memory

1 INTRODUCTION

1.1 History of Tea in Sri Lanka

A British citizen, James Taylor [1] started the first commercial tea plantation in 1867. He cleared 19 acres of forest in the district of Hewaheta and started the plantation in Loolecondera estate in Kandy. In1872, he started putting up a large tea factory in Loolecondera and after that it started manufacturing of packeted tea. In 1875, Taylor was able to send the first shipment of Ceylon tea to London Tea Auction.

1.2 Rolling

The leaves are rolled by applying mechanical pressure to break up the cells during rolling and extract the cell sap. A tea roller is shown in figure 1.2-a. After 30 minutes, the leaves, still damp from the sap, are sieved to separate the finer leaves. These are spread out immediately for fermentation, while the remaining coarse leaves are rolled for a further 30 minutes under higher pressure. If necessary, this process is repeated several times. A short rolling time produces larger leaf grades, while longer rolling breaks the leaves up more resulting in smaller grades. During the rolling process, the cell sap runs out and reacts with oxygen, thus triggering the fermentation process. At the same time, the essential oils responsible for the aroma are released.

Figure 1.2-a Tea Roller

Figure 1.2-b Roller Table

The significance of rolling is on the forming of Black Tea's quality and appearance, especially strip-shaped tea. Rolling will break the leaf cell and can push out cell sap, promoting the enzymatic oxidization of polyphenols. This is what brings about Black Tea's aroma, colour and flavour. Rolling determines the strip shape of Black Tea, the leaves shrink during rolling, and these are then twisted into tight thin strips. As the cell sap is squeezed out to the surface, dry tea leaves will become a dark glossy colour. Soluble substances rolled in leaves are easier to be dissolved, increasing the density of tea liquid.

1.3 Fermentation (Oxidation)

Fermentation [2] of black tea is a series of chemical changes prompted by enzymes during the making process [3]. It mainly refers to the oxidization of polyphenols process. Fermentation is the key process determining Black Tea's quality. It promotes the oxidization of polyphenol in the tea leaf with the help of enzymes; meanwhile other chemical substance will change. Although this is referred to as fermentation, it became recognised around 1901 as an oxidization process initiated by the tea enzymes. The characteristic coppery colour and fermented tea aroma is a gauge to completion of the fermenting process. This is a fine art of the factory tea maker.

1.4 Five significant factor in Fermentation

1.4.1 Temperature

The proper temperature for fermentation [3] is usually 2 – 6℃ higher than normal room temperature, sometimes even a greater difference is required. 30℃ is best temperature for fermentation; therefore the room temperature should be between 24 – 25℃.

1.4.2 Humidity

Results from an experiment at The Hunan Tea Research Institution prove that high humidity is better for fermentation. When humidity is at 63% - 83%, motley spots and dark shades in the leaves can increase the percentage by up to 25% - 32.5% in tea leaves; while humidity rises to 89% - 93%, they will decline to 16% - 18.6%. Consequently, the fermentation room should be kept in humid condition. Ideally it should be at 95% humidity or higher.

1.4.3 Ventilation

Keeping the fermentation room ventilated provides sufficient oxygen for chemical changes, as well as removing the carbon dioxide produced during fermentation. It's normal practice to install an exhaust fan on the wall of the fermentation room, or to keep opening the door or windows to let fresh air in.

1.4.4 Laying

When the leaves are ready for fermentation, they will be laid on floor or fermenting racks. Yet how the leaves are laid out will affect the ventilation of fresh air and the temperature of the leaves. If the leaves are laid too thick, they will be lack of fresh air and be warmed up quickly; on the contrary, if the leaves are laid too thin, they will lose heat easily. The leaves are usually laid in the thickness of 8 - 10 centimetres. It's a very precise process but we strive for the best results.

1.4.5 Fermentation

Fermentation begins with the rolling. After the process has started fermentation will take 3 - 5 hours in spring due to lower temperatures. In summer and autumn, fermentation only takes2 - 3 hours because of the heat. The tea master is critical as the characteristics of incoming tea varies. He must rely on touch, smell, and sight. Processed leaves generate heat quickly, and the tea master must maintain an ambient temperature of 28-30 Celsius / 82-86 Fahrenheit with 90-95% relative humidity.

When the master determines the dhool is appropriate for the specific blend, the dhool is sent to (Firing) drying to stop the oxidation process.

Figure 1.4-a Floor Fermentation

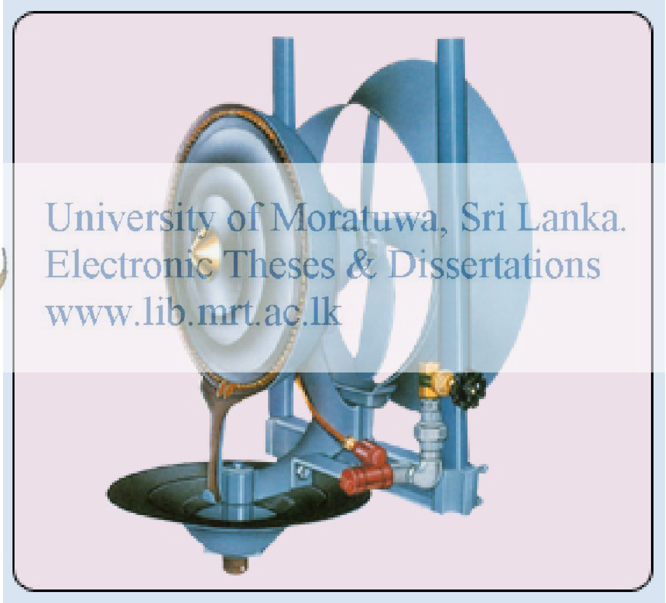


Figure 1.4-b Most common centri-spot humidifier

1.5 Study of Previous Implementation

In 2005, our company introduced an automated humidity control system for rolling room of a tea factory. It was a Korean product and implemented according to the Sri Lankan tea makers requirement. The traditional Wet and Dry bulb difference (D-W) method was implemented using Resistance Temperature Detectors (RTDs) [4]. A standard refrigerator controller was redesigned to interface the two sensors and a new type of humidifier as shown in figure 1.5-c was also introduced. Rolling room was divided into three zones and few humidifiers were grouped to a zone (to reduce the cost) and number of humidifiers in a zone decided upon size of the rolling room. Controller panel consisted of four controllers dedicating three units for controlling inside humidity zones and fourth unit for just observing outside wet and dry bulb temperature difference. The new humidifier was able to break water into very fine mist where particle size is less than 5 microns and was impressive and very popular in tea industry.

Figure 1.5-a Sensor Unit

Figure 1.5-b Controller Panel

Figure 1.5-c Humidifier Unit

Later we found that the sensory system is having following problems.

- Probes were non linear and having deflections compared to mercury/alcohol hygrometers.
- Contact errors due to longer sensor wires.
- When wet and dry bulb difference was maintained between 2-3°F, condensation occurred on metallic surface of the dry Probe and readings became erroneous. Sometimes the dry Probe required wiping off to reactivate the system.

Apart from the above mentioned problems, following drawbacks were also present.

- Expensive
- Large zones were created when rolling room was large and humidity was measured at only one point to switch ON or OFF all the humidifiers in that particular zone. Installing one sensory system and a controller for each humidifier was not financially viable.
- Sensor Probes were incompatible with standard RTDs like PT100, PT1000 etc.
- Temperature gradient was hardcoded and only ±20°F calibration was provided. Sometimes it was not sufficient to calibrate the sensor.
- The reparability was very low and required to send defective controllers to the manufacturer.
- Wet and dry bulb difference (D-W) was shown negative in many occasions where theoretically incorrect.

Figure 1.5-d Faulty D-W Measurements

1.6 Scope of the present work

The scope of this research is to develop a cost effective, more accurate, robust sensing system with enhanced features to measure humidity in a rolling room by the traditional wet and dry bulb difference method as well as direct humidity measurement and thereby control the humidifiers.

- Developing a cost effective sensory system and a humidifier controller based on PIC microcontroller at about 10% of the imported product cost.
- Rectifying the known drawbacks to sensory system (Linearity, calibration, errors due to condensation on probes/sensors and contact errors).
- Introducing direct humidity measurements to the traditional tea makers and providing a cross reference between dry - wet difference and humidity. So that tea industry will refer a humidity level to be maintained in rolling room rather than referring wet and dry bulb difference in future.

- Measuring temperature at high humidity levels is a very challenging task and measuring humidity directly is more accurate and easy.
- Each humidifier can be equipped with a sensory system and a controller due to very low cost. This improves the humidity distribution in the rolling and fermenting area.
- Alfa numeric display and menu driven system simplifies the user interface and parameter adjustments do not require a user manual unlike the numeric displays with numbers or abbreviations to refer parameters.
- Factory calibrated sensors provide easy interchanging ability and higher accuracy.

2 LITERATURE AND TECHNICAL SURVEY

2.1 Literature Survey

This research is mainly based on a product launched by our company and the Sri Lankan tea industry. Few research papers [5], [6], [7] were also found regarding implementation of wet and dry bulb hygrometer in a digital manner for various industries but in many years back.

2.2 Sensor Survey

The initial step of the project was to find out suitable and affordable sensors in the market. Following sensors were studied and some of them were tested.

1. Thermisters
2. RTDs
3. Thermocouple
4. Humirel HS1101 analog humidity sensor
5. DHT22 digital Humidity and temperature sensor
6. DS18B20 digital, factory calibrated temperature sensor
7. SHT11 factory calibrated digital humidity and temperature sensor with on chip heater.

2.3 Thermisters (3.3k NTC)

Sensor selection was started with a 3.3kΩ Thermister with negative thermal coefficient (NTC) and tested as it was very cheap and freely available in the market. One thermister was encapsulated in a metal cover and the gap was filled with some sand and sealed. Encapsulation was essential for the wet bulb sensor but unfortunately the expected dry-wet difference was not achieved. Also fairly large mass attached to the sensor caused to smooth the fine temperature variations in the atmosphere. It was difficult to have a good heat transfer between thermister and metal cover due to poor contact.

Also considering equation (1), mass of the metal cover was reduced by shortening it but was not a success.

$$Q = m.s.\theta \qquad (1)$$

where

Q is amount of heat
m is mass
s is specific heat
θ is temperature difference

Apart from that, thermisters have an exponential behavior and required to linearize and calibrate in any case used for the project. Though it is freely available, there is no manufacturer's data sheet for particular thermister we buy from local market and accuracy, hysteresis, temperature gradient etc are unknown.

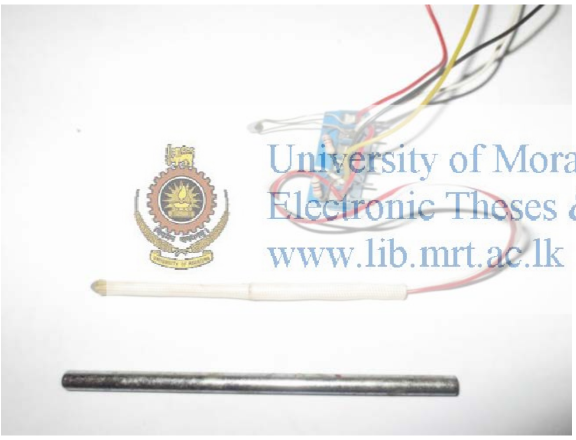


Figure 2.3-a First sensor pair tested

2.4 Thermocouples

Different types of thermocouples [8], [9] are found for different purposes. Selection of thermocouple should consider the application, temperature measurement range, type of environment, connector type and error.

Table 2.4-a Common Thermocouple Temperature Ranges

Calibration	Temperature Range	Std. Limits of error	Spec. Limits of error
J	0°C to 750°C (32°F to 1382°F)	Greater of 2.2°C or 0.75%	Greater of 1.1°C or 0.4%
K	-200°C to 1250°C	Greater of 2.2°C or	Greater of 1.1°C or

	(-328°F to 2282°F)	0.75%	0.4%
E	-200°C to 900°C ((-328°F to 1652°F)	Greater of 1.7°C or 0. 5%	Greater of 1.0°C or 0.4%
T	-250°C to 350°C (-328°F to 662°F)	Greater of 1°C or 0.75%	Greater of 0.5°C or 0.4%

Table 2.4-b Probes with metal sheath, straight cable, and stripped ends

J, K	±4.0°F (±2.2°C), and ±0.4% of reading above 32°F (0°C); ±2.0% of reading below 32°F (0°C)
T	±1.8°F (±1.0°C), and ±0.4% of reading above 32°F (0°C); ±0.8% of reading below 32°F (0°C)
E	±3.6°F (±2.0°C), and ±0.4% of reading above 32°F (0°C); ±0.5% of reading below 32°F (0°C)

Different types of thermocouples

Type K

This is the most common thermocouple type that provides the widest operating temperature range. Type K thermocouples generally will work in most applications because they are nickel based and have good corrosion resistance.

Positive leg is non-magnetic (Yellow), negative leg is magnetic (Red).

Traditional base-metal choice for high temperature work.

Appropriate for use in oxidizing or inert atmospheres at temperatures up to 1260ºC (2300ºF).

Vulnerable to sulfur attack (refrain from exposing to sulfur-containing atmospheres).

Perform best in clean oxidizing atmospheres.

Not recommended for use under partially oxidizing conditions in vacuum, or when subjected to alternating cycles of oxidization and reduction.

Type J

This is the second most common thermocouple. It is a good choice for general purpose applications (if moisture is not present).

Appropriate for use in vacuum, air, reducing, or oxidizing atmospheres to 760ºC (1400ºF) in the heavier gage sizes.

The expected service life of the finer sized wires is limited due to the rapid oxidation of the iron wire at temperatures above 540ºC (1000ºF).

Avoid use in sulfurous atmospheres above 540ºC (1000ºF).

Limited subzero use due to rusting and embrittlement of the iron conductor.

Positive (iron) wire is magnetic (white), negative is non-magnetic (red).

Type E

Neither wire is magnetic but negative wire is red, positive is purple.

Recommended for use to 900ºC (1600ºF) in oxidizing or inert atmospheres.

Appropriate for low temperature to about –230ºC (-380ºF).

Has the highest output emf of any standardized type.

Vulnerable to sulfur attack, do not expose to this type of atmosphere.

Perform best in clean oxidizing atmospheres.

Not recommended for use (except in short periods):

Under partially oxidizing conditions.

When subjected to alternating cycles of oxidation and reduction.

In vacuum.

Type T

Neither wire magnetic – Positive is blue, negative is red.

When used in air:

Moisture resistant.

Very stable.

Useful to 370ºC (700ºF).

Higher temperature use possible when used in vacuum, or in reducing or inert atmospheres.

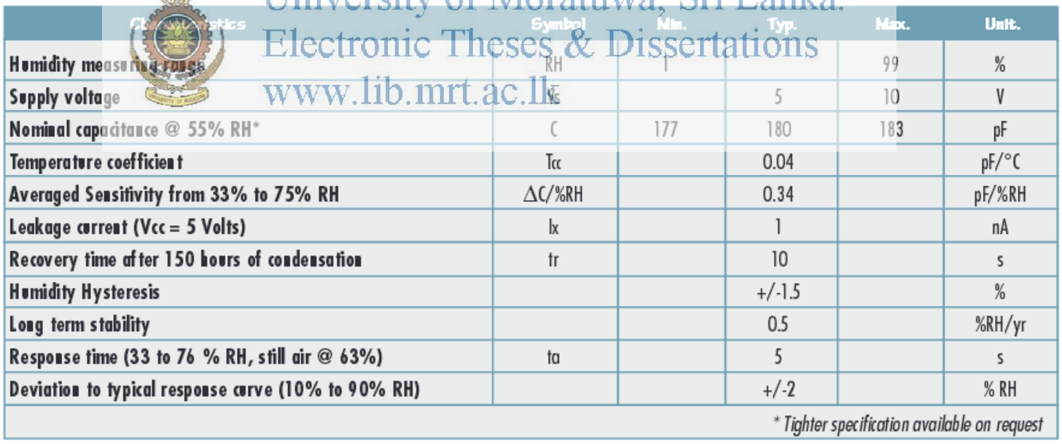
Appropriate for use down to –200ºC (370ºF). Special selection may be required of the materials.

2.5 Humirel HS1101 Relative Humidity Sensor

Figure 2.5-a Humirel HS1101 Relative Humidity Sensor

The Humirel HS1101 humidity sensor [10] is a cost-effective solution for measuring relative humidity within ±5% accuracy. The sensor's design is based on a unique capacitive cell; therefore, by using simple RC circuit wiring it is easy to interface with any microcontroller.

Table 2.5-a Characteristics of HS1101



Characteristics	Symbol	Min.	Typ.	Max.	Unit.
Humidity measuring range	RH	1		99	%
Supply voltage	Vs		5	10	V
Nominal capacitance @ 55% RH*	C	177	180	183	pF
Temperature coefficient	Tcc		0.04		pF/°C
Averaged Sensitivity from 33% to 75% RH	ΔC/%RH		0.34		pF/%RH
Leakage current (Vcc = 5 Volts)	Ix		1		nA
Recovery time after 150 hours of condensation	tr		10		s
Humidity Hysteresis			+/-1.5		%
Long term stability			0.5		%RH/yr
Response time (33 to 76 % RH, still air @ 63%)	ta		5		s
Deviation to typical response curve (10% to 90% RH)			+/-2		% RH

** Tighter specification available on request*

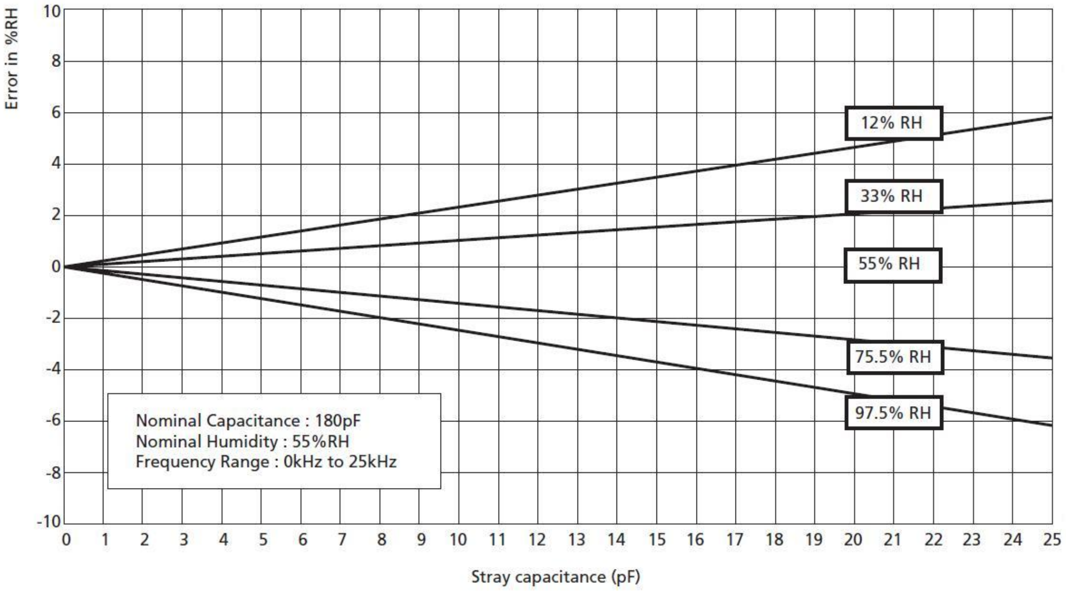


Figure 2.5-b Measurement Error vs. Stray Capacitance

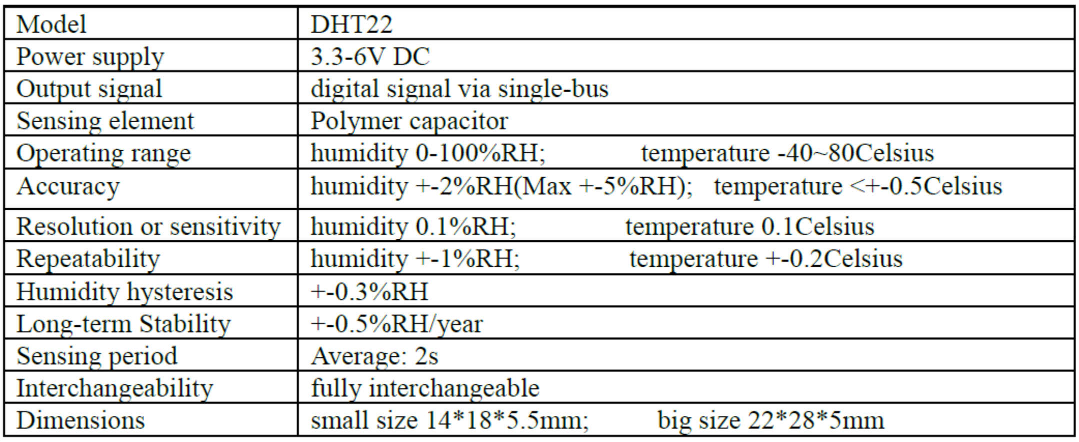
2.6 DHT22 / AM2302 Digital-output relative humidity & temperature sensor

Figure 2.6-a DHT22/ AM2302 digital output relative humidity and temperature sensor

Features of DHT22/ AM2302 digital output relative humidity and temperature sensor [11] are as follows.

- Low cost
- 3 to 5V power and I/O
- 2.5mA max current use during conversion (while requesting data)
- Good for 0-100% humidity readings with 2-5% accuracy
- Good for -40 to 80°C temperature readings ±0.5°C accuracy
- No more than 0.5 Hz sampling rate (once every 2 seconds)

Table 2.6-a Specifications of DHT22 / AM2302



Model	DHT22
Power supply	3.3-6V DC
Output signal	digital signal via single-bus
Sensing element	Polymer capacitor
Operating range	humidity 0-100%RH; temperature -40~80Celsius
Accuracy	humidity +-2%RH(Max +-5%RH); temperature <+-0.5Celsius
Resolution or sensitivity	humidity 0.1%RH; temperature 0.1Celsius
Repeatability	humidity +-1%RH; temperature +-0.2Celsius
Humidity hysteresis	+-0.3%RH
Long-term Stability	+-0.5%RH/year
Sensing period	Average: 2s
Interchangeability	fully interchangeable
Dimensions	small size 14*18*5.5mm; big size 22*28*5mm

2.7 Sensirion SHT 11 digital humidity and temperature sensor

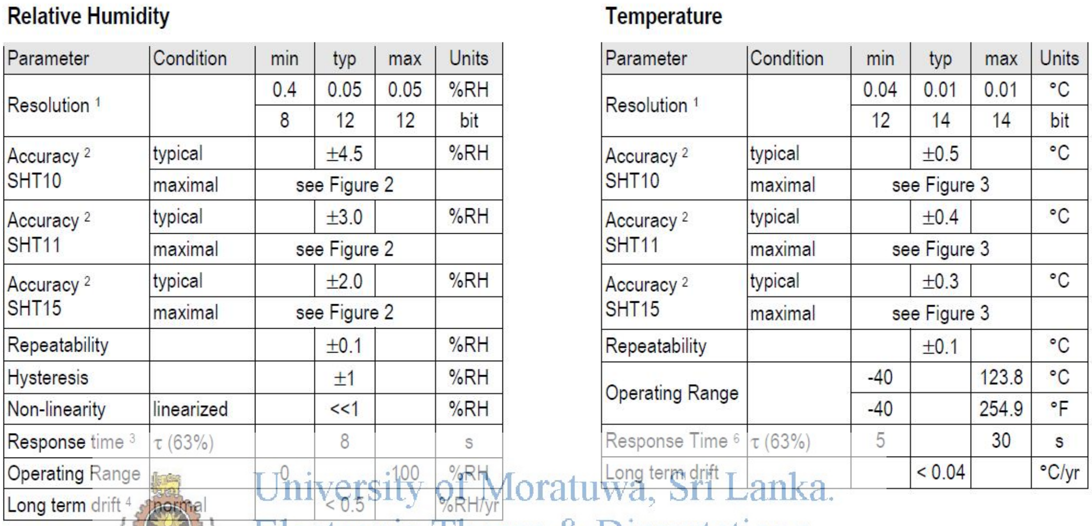
Figure 2.7-a Sensirion SHT11 digital temperature and humidity sensor

Sensirion SHT11 digital temperature and humidity sensor [12] has following features.

- Fully calibrated digital sensor. Each SHT11 sensor is calibrated in precision humidity chamber.
- Consists of a Capacitive Sensor element for measuring %RH, a band gap sensor for measuring temperature, a 14 bit A/D and on-chip heater.
- 1 wire serial communication
- Temperature measurement at 14 bit resolution (0.01°C) and accuracy between ± 0.4 to ± 0.75°C for purpose of this project.
- Relative humidity at 12 bit resolution (0.05 %RH) and accuracy between ±3 to ± 5 %RH

SHT11 consists of a capacitive sensor for measuring relative humidity, and a band-gap sensor for measuring temperature. Apart from that, the chip also contains an amplifier, A/D converter, one time programmable (OTP) memory, on-chip heater and a digital interface. Both sensors are seamlessly coupled to a 14bit analog to digital (A/D) converter and a serial interface circuit. Each SHT11 is calibrated in a precision humidity chamber and the calibration data is stored in the OTP memory on the chip. This calibration data is used as an error look up table and the measured data can be linearized with the calibration data in the chip.

Table 2.7-a SHT11 sensor performance



Relative Humidity

Parameter	Condition	min	typ	max	Units
Resolution [1]		0.4	0.05	0.05	%RH
		8	12	12	bit
Accuracy [2] SHT10	typical		±4.5		%RH
	maximal	see Figure 2			
Accuracy [2] SHT11	typical		±3.0		%RH
	maximal	see Figure 2			
Accuracy [2] SHT15	typical		±2.0		%RH
	maximal	see Figure 2			
Repeatability			±0.1		%RH
Hysteresis			±1		%RH
Non-linearity	linearized		<<1		%RH
Response time [3]	τ (63%)		8		s
Operating Range		0		100	%RH
Long term drift [4]	normal		< 0.5		%RH/yr

Temperature

Parameter	Condition	min	typ	max	Units
Resolution [1]		0.04	0.01	0.01	°C
		12	14	14	bit
Accuracy [2] SHT10	typical		±0.5		°C
	maximal	see Figure 3			
Accuracy [2] SHT11	typical		±0.4		°C
	maximal	see Figure 3			
Accuracy [2] SHT15	typical		±0.3		°C
	maximal	see Figure 3			
Repeatability			±0.1		°C
Operating Range		-40		123.8	°C
		-40		254.9	°F
Response Time [6]	τ (63%)	5		30	s
Long term drift			< 0.04		°C/yr

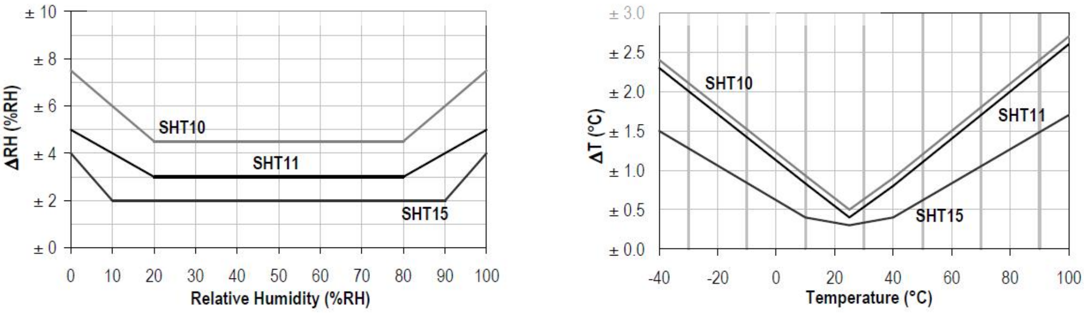


Figure 2.7-b %RH and temperature tolerances

SHT11 was selected as the dry temperature and humidity sensor for the research project.

2.8 Dallas / Maxim integrated DS18B20 12 Bit 1-wire digital temperature sensor

Figure 2.8-a Dallas / maxim integrated DS18B20 digital temperature sensor

Dallas / maxim integrated DS18B20 digital temperature sensor [13]

- Output temperature data is calibrated in degrees Celsius.
- 1-Wire® Interface Requires Only One Port Pin for Communication
- Requires No External Components
- Can Be Powered from Data Line; Power Supply Range is 3.0V to 5.5V
- Measures Temperatures from -55°C to +125°C (-67°F to +257°F)
- ±0.5°C Accuracy from -10°C to +85°C
- 12 Bits resolution. 4 Bits for fraction. (0.0625 °C)

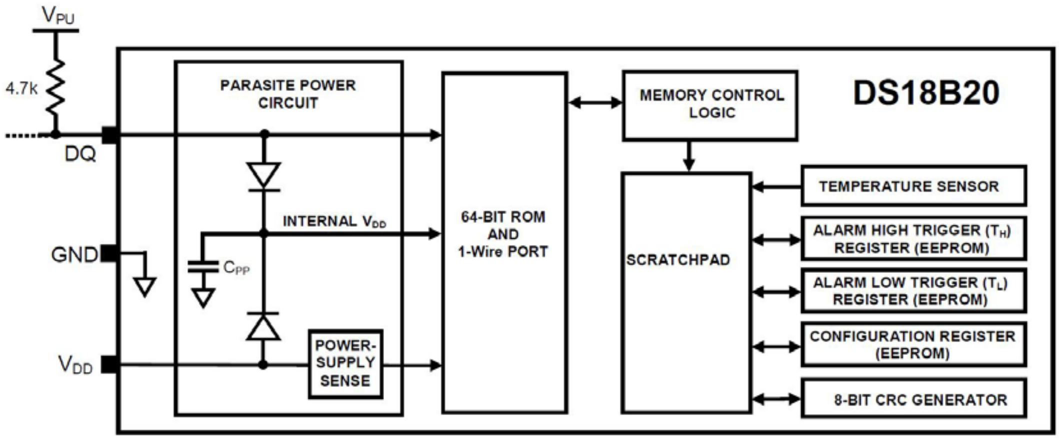


Figure 2.8-b Block diagram of DS18B20

The DS18B20 is a direct to digital sensor and temperature value can be read directly without any conversions. The default and highest resolution is 12bits and the temperature increment is 0.0625°C per step.

DS18B20 was selected as the wet temperature sensor for the research project.

2.9 Summary of Sensor Study

Summary of the sensor study is listed in table 2.9-a.

Table 2.9-a Sensor comparison summery

	NTC Thermistor	**Platinum RTD**	**Thermocouple**	**HS1101**	**DHT22/AM2302**	**DS18B20**	**SHT11**
Sensor	Ceramic (metal oxide spinel)	Platinum wire wound or metal film	Thermoelectric	Capacitive sensor	capacitive humidity sensor and a thermistor	Semiconductor	Capacitive sensor for %RH, Bandgap sensor for Temperature
Temperature Range (typical)	-100 to +325˚C	-200 to +650˚C	-200 to +1750˚C	1% to 99%	-40 to 80˚C 0 to 100 %RH	-55 to 125˚C	-40 to 125˚C 0 to 100 %RH
Accuracy (typical)	0.05 to 1.5 ˚C	0.1 to 1.0˚C	0.5 to 5.0˚C	±5 %RH	±0.5˚C ±2 - 5 %RH	±0.5˚C	±0.4˚C ±3 %RH
Long-term Stability @100˚C	0.2˚C/year (epoxy) 0.02˚C/year (glass)	0.05˚C/year (film) 0.002˚C/year (wire)	Variable, some types very prone to aging	0.5 %RH/year	±0.5 %RH/year	-	<0.5 %RH/year <0.04˚C/year
Output	NTC Resistance -4.4%/˚C typical	PTC resistance 0.00385Ω/Ω/°C	Thermo voltage 10µV to 40µV/°C	Analog (variable capacitance)	16bit Temp 16 bit %RH	12 Bit	14 bit Temp 12 bit %RH
Linearity	Exponential	Fairly linear	Most types nonlinear	Fairly linear	linearized	linearized	linearized
Power Required	Constant voltage or current	Constant voltage or current	Self-powered		3.3 – 5.5V	3 - 5.5V	2.4 - 5.5V 3mW
Response Time	Fast 0.12 to 10 S	Generally slow 1 to 50 S	Fast 0.10 to 10 S		5 S	-	Temp - 5 to 50 S %RH - 8 S
Lead Resistance Effects	Low resistance parts only	Very susceptible.3 or 4-wire configurations required	None over short runs. TC extension cables required.			No	No
Remarks					Not a true sensor manufacturer		
Cost	Low to moderate	Wire-wound – High Film - Low	Low		4USD	5USD	15USD

3 IMPLEMENTATION OF HARDWARE

Implementation of hardware is based on PIC18F452 microcontroller. Sensirion SHT11 is selected as dry temperature and humidity sensor and Dallas/Maxim DS18B20 is selected as wet temperature sensor. Chapter 3 explains the implementation of digital psychrometer and developed humidity controller.

3.1 Dry Probe and Humidity Sensor (SHT11)

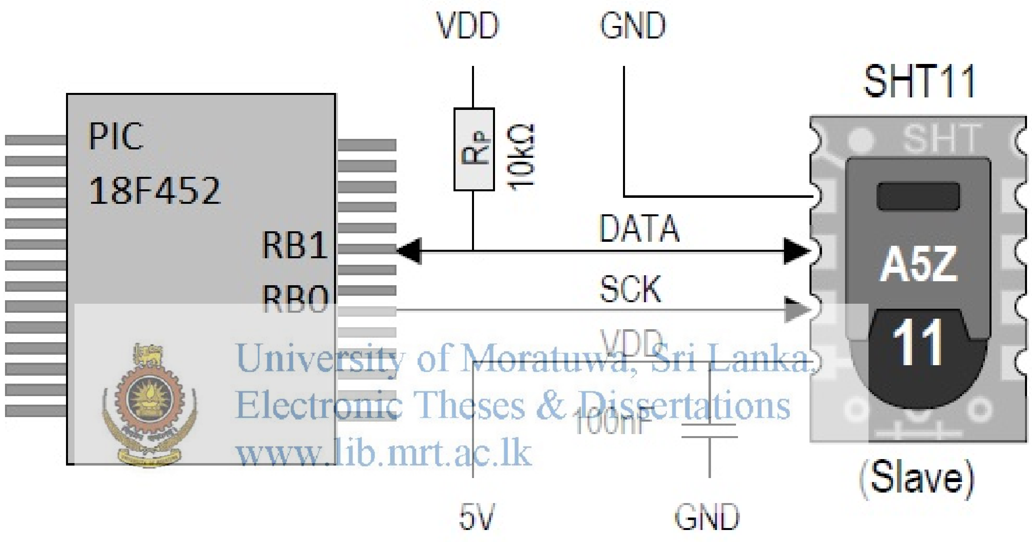


Figure 3.1-a Connecting SHT11 to Microcontroller

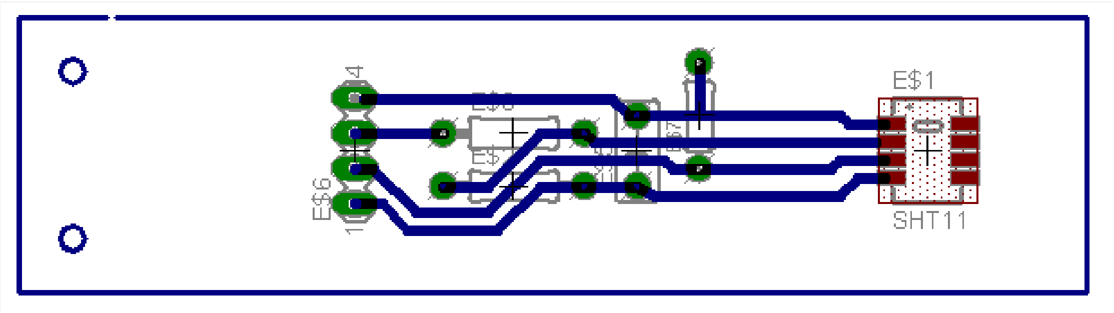


Figure 3.1-b PCB pattern of SHT11 sensor board

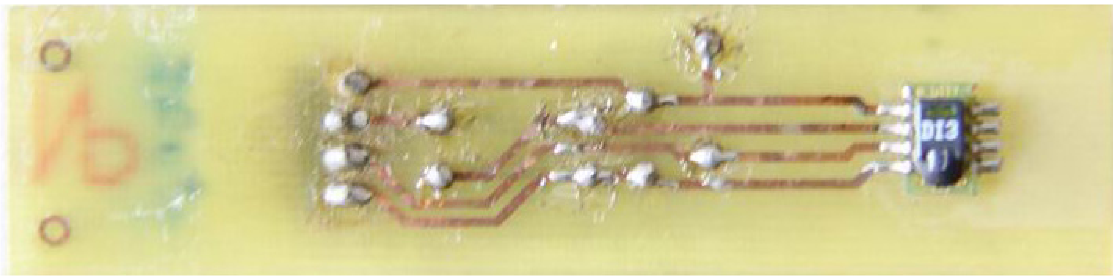
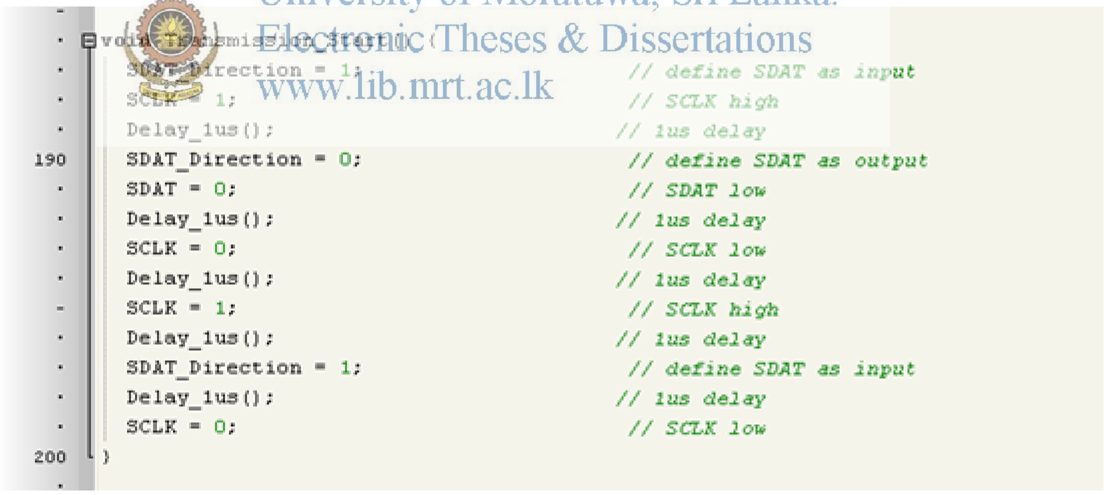


Figure 3.1-c SHT11 sensor board

SHT11 needs to reset the communication at first. Then data transmission can be started. Microelectronika’s MikroC compiler has no built in routines for this.

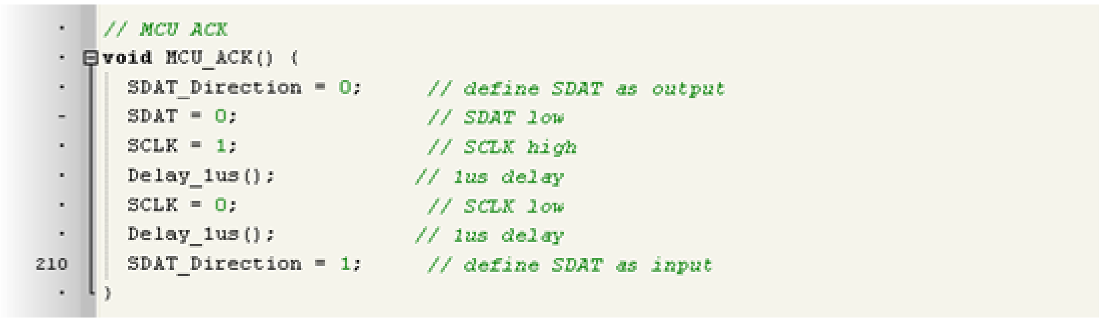
```
void SHT_Reset() {
  SCLK = 0;                                    // SCLK low
  SDAT_Direction = 1;                          // define SDAT as input
  for (i = 1; i <= 18; i++)                   // repeat 18 times
    SCLK = ~SCLK;                               // invert SCLK
}
```

Figure 3.1-d SHT11 Communication Reset Function



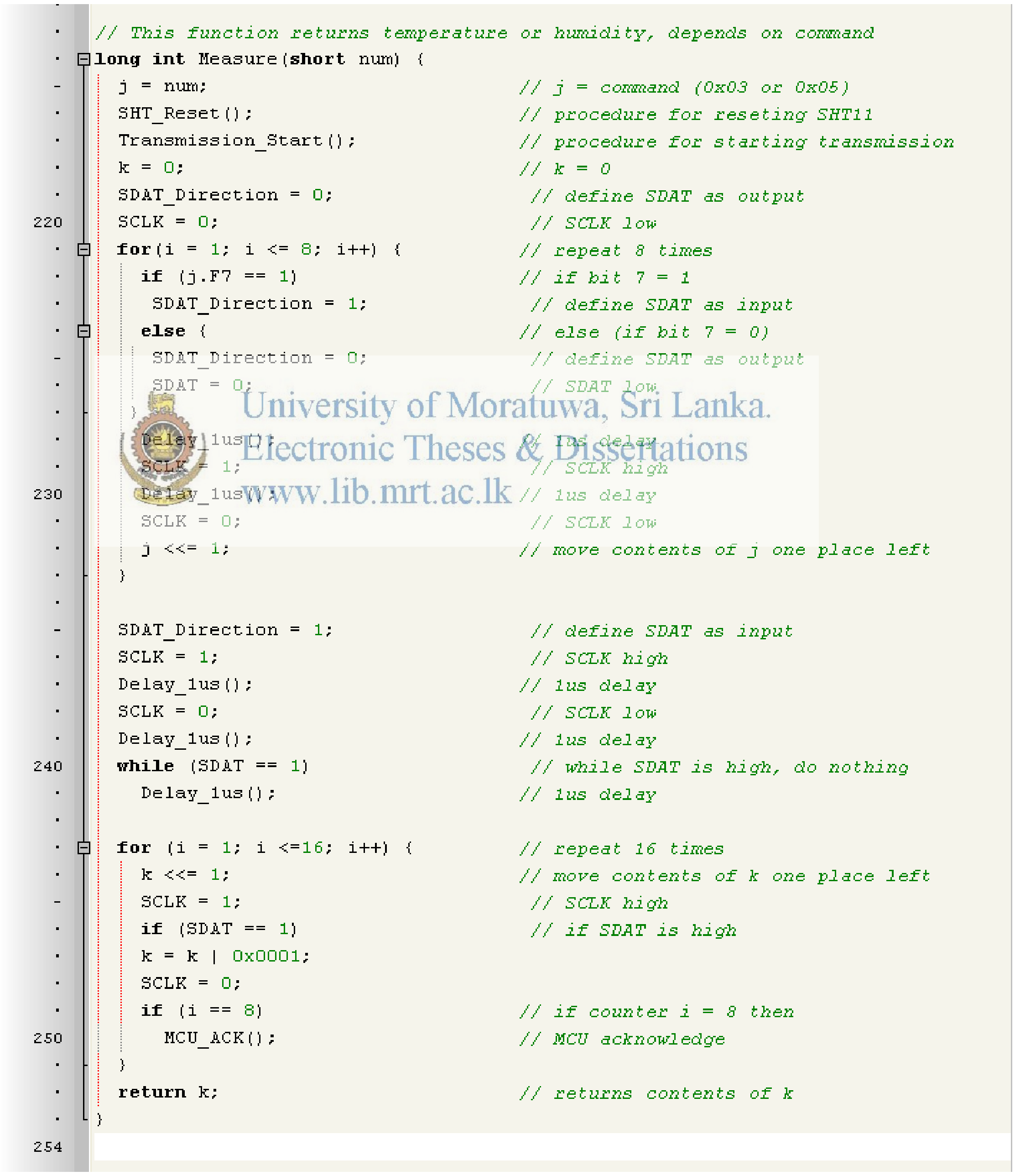
```
void Transmission_Start() {
  SDAT_Direction = 1;                          // define SDAT as input
  SCLK = 1;                                    // SCLK high
  Delay_1us();                                // 1us delay
  SDAT_Direction = 0;                          // define SDAT as output
  SDAT = 0;                                    // SDAT low
  Delay_1us();                                // 1us delay
  SCLK = 0;                                    // SCLK low
  Delay_1us();                                // 1us delay
  SCLK = 1;                                    // SCLK high
  Delay_1us();                                // 1us delay
  SDAT_Direction = 1;                          // define SDAT as input
  Delay_1us();                                // 1us delay
  SCLK = 0;                                    // SCLK low
}
```

Figure 3.1-e SHT11 Transmission Start Function



```
// MCU ACK
void MCU_ACK() {
  SDAT_Direction = 0;      // define SDAT as output
  SDAT = 0;                // SDAT low
  SCLK = 1;                // SCLK high
  Delay_1us();            // 1us delay
  SCLK = 0;                // SCLK low
  Delay_1us();            // 1us delay
  SDAT_Direction = 1;      // define SDAT as input
}
```

Figure 3.1-f SHT11 MCU Acknowledge Function



```
// This function returns temperature or humidity, depends on command
long int Measure(short num) {
  j = num;                                // j = command (0x03 or 0x05)
  SHT_Reset();                            // procedure for reseting SHT11
  Transmission_Start();                   // procedure for starting transmission
  k = 0;                                  // k = 0
  SDAT_Direction = 0;                      // define SDAT as output
  SCLK = 0;                                // SCLK low
  for(i = 1; i <= 8; i++) {               // repeat 8 times
    if (j.F7 == 1)                        // if bit 7 = 1
     SDAT_Direction = 1;                   // define SDAT as input
    else {                                // else (if bit 7 = 0)
     SDAT_Direction = 0;                   // define SDAT as output
     SDAT = 0;                             // SDAT low
    }
    Delay_1us();                          // 1us delay
    SCLK = 1;                              // SCLK high
    Delay_1us();                          // 1us delay
    SCLK = 0;                              // SCLK low
    j <<= 1;                              // move contents of j one place left
  }

  SDAT_Direction = 1;                      // define SDAT as input
  SCLK = 1;                                // SCLK high
  Delay_1us();                            // 1us delay
  SCLK = 0;                                // SCLK low
  Delay_1us();                            // 1us delay
  while (SDAT == 1)                        // while SDAT is high, do nothing
    Delay_1us();                          // 1us delay

  for (i = 1; i <=16; i++) {              // repeat 16 times
    k <<= 1;                              // move contents of k one place left
    SCLK = 1;                              // SCLK high
    if (SDAT == 1)                         // if SDAT is high
    k = k | 0x0001;
    SCLK = 0;

    if (i == 8)                           // if counter i = 8 then
      MCU_ACK();                          // MCU acknowledge
  }
  return k;                               // returns contents of k
}
```

Figure 3.1-g Measuring Humidity & Temperature from SHT11

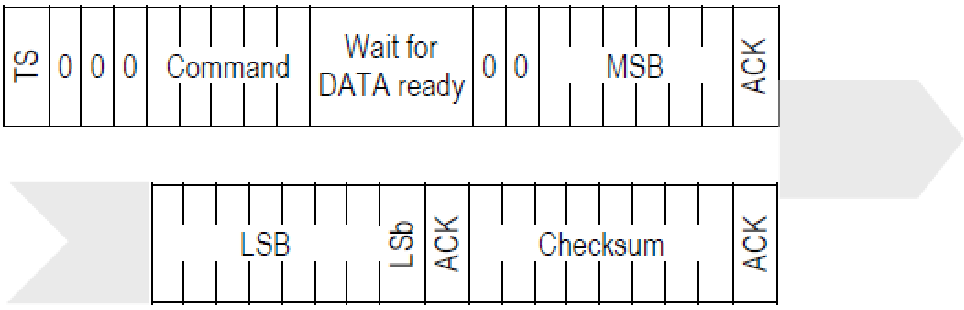


Figure 3.1-h Overview of Measurement Data Sequence.

Before taking a measurement, calibration data stored in OTP memory is reloaded by the following command and a 10msec delay should be provided.

```
write_status_reg(0x02);          // OTP reload
delay_ms(10);                     // according to datasheet
```

To measure temperature and humidity, measure () function is used and that issues the transmission start command, address bits (000), command (00011 to measure temperature and 00101 to measure humidity), get the acknowledgement from sensor and read the measured data.

```
SOt = Measure(0x03);        // measuring temperature (0x03 is for temperature)
SOrh = Measure(0x05);       // measuring humidity (0x05 is for humidity)
```

Conversion of signal output for relative humidity is given by equation (2).

$$RH_{linear} = C_1 + C_2.SO_{RH} + C_3.{SO_{RH}}^2 \ (\%RH) \tag{2}$$

Where

RH_{linear}	is humidity to be measured
SO_{RH}	is humidity readout or signal output for relative humidity

Table 3.1-a Humidity conversion coefficients for the project

$\boldsymbol{SO_{RH}}$	$\boldsymbol{C_1}$	$\boldsymbol{C_2}$	$\boldsymbol{C_3}$
12 bit	-2.0468	0.0367	-1.5955E-6

Conversion of signal output for temperature is given by equation (3).

$$T = d_1 + d_2.SO_T \tag{3}$$

where

T	is temperature to be measured

SO_T is temperature readout or signal output for temperature

Table 3.1-b Humidity conversion coefficients for the project.

VDD	d_1 (°C)	d_1 (°F)	SO_T	d_2 (°C)	d_2 (°F)
5V	-40.1	-40.2	14bit	0.01	0.018

Temperature compensation of humidity signal

When the temperature is significantly different from 25°C (77°F), humidity signal should be compensated against temperature. The temperature correction is roughly about 0.12%RH/°C @ 50%RH. Compensated relative humidity can be derived from the equation (4).

$$RH_{true} = (T_{°C} - 25).(t_1 + t_2.SO_{RH}) + RH_{linear} \qquad (4)$$

Where RH_{true} – true humidity value when temperature compensation is done.

Table 3.1-c Temperature compensation coefficients.

SO_{RH}	t_1	t_2
12 bit	0.01	0.00008

3.2 Wet Probe (DS18B20)

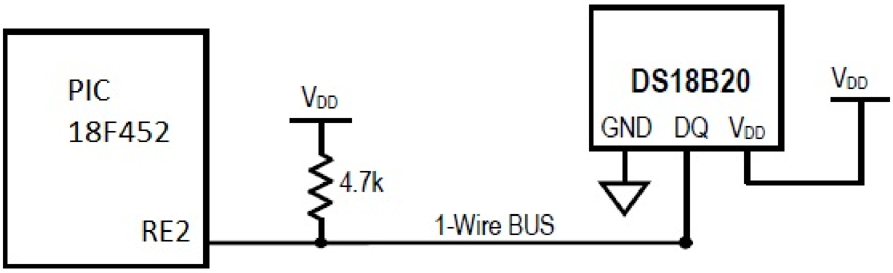


Figure 3.2-a Interfacing DS18B20 Wet Temperature Sensor

Transaction sequence

The transaction sequence for accessing the DS18B20 is as follows:

Step 1. Initialization

Step 2. ROM Command (followed by any required data exchange)

Step 3. DS18B20 Function Command (followed by any required data exchange)

All communication with the DS18B20 begins with an initialization sequence that consists of a reset pulse from the master followed by a presence pulse from the DS18B20. When the DS18B20 sends the presence pulse in response to the reset, it is indicating to the master that it is on the bus and ready to operate.
During the initialization sequence the bus master transmits (T_X) the reset pulse by pulling the 1-Wire bus low for a minimum of 480µs. The bus master then releases the bus and goes into receive mode (R_X). When the bus is released, the 5kΩ pull-up resistor pulls the 1-Wire bus high. When the DS18B20 detects this rising edge, it waits 15µs to 60µs and then transmits a presence pulse by pulling the 1-Wire bus low for 60µs to 240µs.

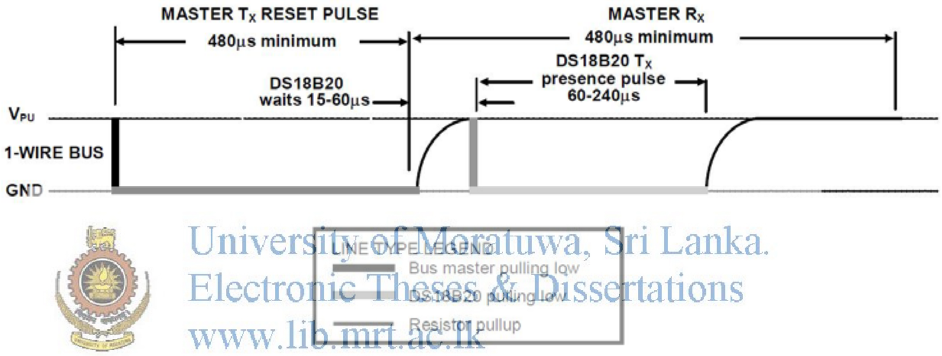


Figure 3.2-b Timing Diagram of Initialization

MickroC compiler provides a library for 1-wire bus and following three commands can be used to communicate with DS18B20.

Library Routines

OW_Reset
OW_Read
OW_Write

Table 3.2-a One Wire Rsest

Prototype	**unsigned short** Ow_Reset(unsigned short *port, unsigned short pin);
Returns	0 if the device is present 1 if the device is not present
Description	Issues OneWire reset signal for DS18B20.

	Parameters : port: OneWire bus port pin: OneWire bus pin
Usage	Ow_Reset(&PORTE, 2);

Table 3.2-b One Wire Read

Prototype	unsigned short Ow_Read(unsigned short *port, unsigned short pin);
Returns	Data read from an external device over the OneWire bus.
Description	Reads one byte of data via the OneWire bus. Parameters : port: OneWire bus port pin: OneWire bus pin
Usage	unsigned short tempw; … tempw = Ow_Read(&PORTE, 2); //Read wet temperature

Table 3.2-c One Wire Write

Prototype	void Ow_Write(unsigned short *port, unsigned short pin, unsigned short par);
Returns	Nothing.
Description	Writes one byte of data via the OneWire bus. Parameters : port: OneWire bus port pin: OneWire bus pin par: data to be written

Usage	Ow_Write(&PORTE, 2, 0xCC); //Skip Rom
	Ow_Write(&PORTE, 2, 0x44); //Covert temperature
	Ow_Write(&PORTE, 2, 0xBE); //Read Scratch pad

Reading DS18B20 Wet Temperature Sensor

Communication should be reset to start.

```
Ow_Reset(&PORTE, 2);                    // Onewire reset signal Port E.2
```

As only one DS18B20 is used in the 1 wire bus, addressing 64-bit ROM code to identify a particular device can be ignored.

```
Ow_Write(&PORTE, 2, 0xCC);              // Issue command SKIP_ROM
```

Following command will start the temperature conversion.

```
Ow_Write(&PORTE, 2, 0x44);              // Issue command CONVERT_T
```

After conversion, communication should be restarted and read two byte temperature from scratchpad memory.

```
   Ow_Reset(&PORTE, 2);
   Ow_Write(&PORTE, 2, 0xCC);          // Issue command SKIP_ROM
   Ow_Write(&PORTE, 2, 0xBE);          // Issue command READ_SCRATCHPAD

   tempw =  Ow_Read(&PORTE, 2);
   tempw = (Ow_Read(&PORTE, 2) << 8) + tempw;
```

LS Byte

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
2^3	2^2	2^1	2^0	2^{-1}	2^{-2}	2^{-3}	2^{-4}

MS Byte

Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8
S	S	S	S	S	2^{-2}	2^{-3}	2^{-4}

S = sign, S=0 for positive and S=1 for negative

3.3 Humidity Controller

A new humidity controller was designed and developed to interface with selected sensors and to control the humidifiers. The humidity controller is based on PIC 18F452 [14] microcontroller which is a cheap but yet powerful enough for the project. 7805 and 7812 DC regulators are on board to regulate the input and power on indicators are also located for easy trouble shooting. Though it is able to operate at 20MHz, PIC 18F452 is used at 4MHz for the purpose. A RESET button and In Circuit Serial Programming (ICSP) connector is provided on board for convenience of programming. A 20 character 4 line (20x4) dot matrix LCD display which is based on Hitachi's HD44780 has been used. After studying and working with various compilers such as PIC Basic Pro, CCS C, Hitec C etc, Microelektronica MicroC was selected as the compiler. MicroC has one-wire library to communicate with DS18B20 wet temperature sensor and some help is also available to communicate with SHT11 dry temperature and humidity sensor. All parameters used in the user interface and the operating mode (wet and dry bulb difference mode or humidity control mode) are written to eeprom memory and loss of power or restarting doesn't affect the humidity control function. It's a simple ON/OFF controller implemented as same as the previous product and that simplifies the hardware design of the total project. If a PID controller is adopted, the humidity controller would be more advanced but needs a variable speed humidifier or more hardware (Variable speed drive etc) to control the humidifiers.

All schematics and circuit boards were designed using Eagle 4.16 PCB design software. Heating and Toner transferring method was used to transfer the PCB design on copper clad boards and etched with Ferric Chloride (FeCl3). All these efforts made the humidity controller to be produced at less than 10% of the imported product.

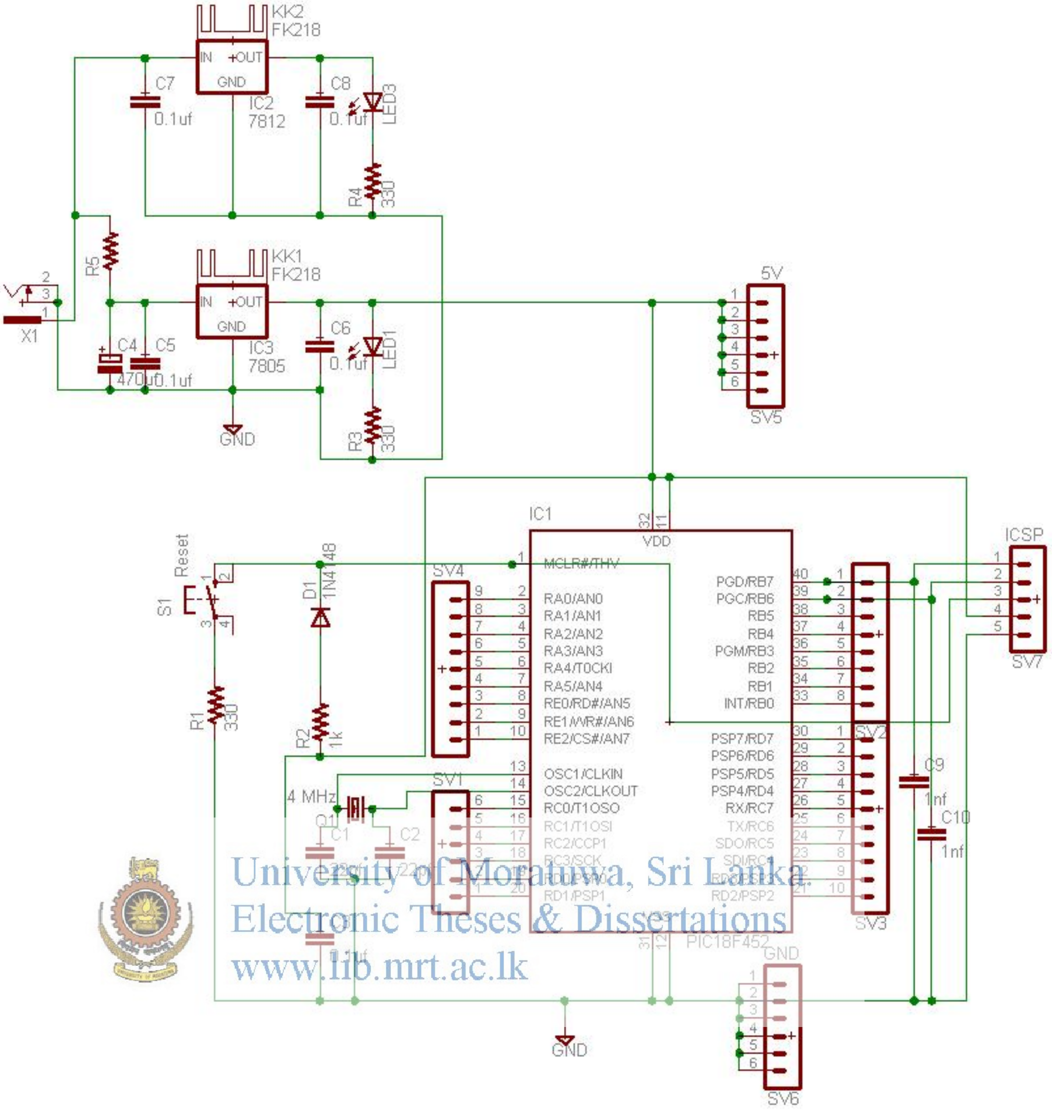


Figure 3.3-a Schematic of Humidity Controller main circuit

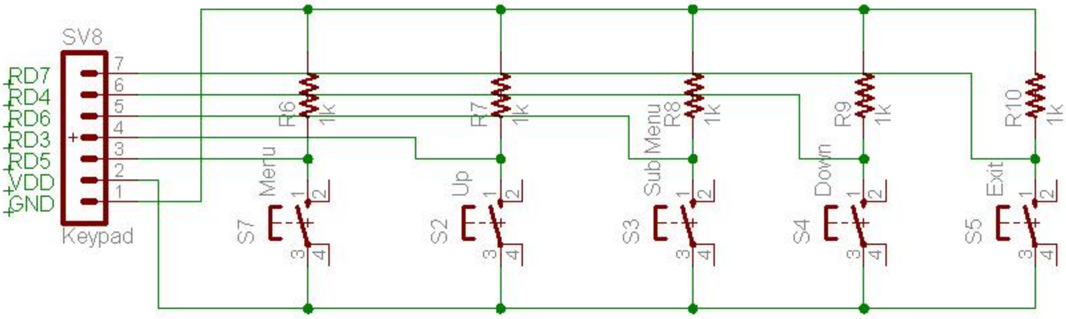


Figure 3.3-b Schematic of Humidity Controller keypad

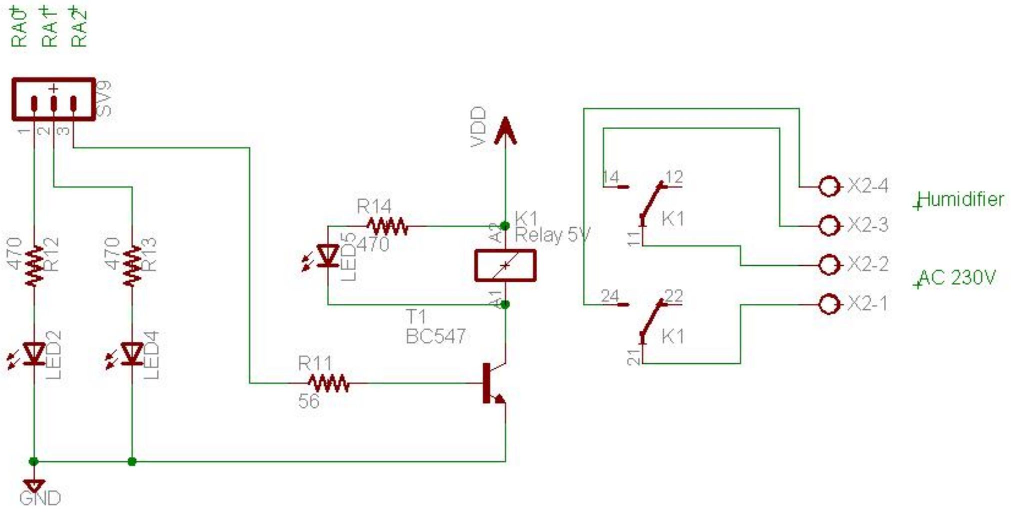


Figure 3.3-c Schematic of Humidity Controller switching circuit

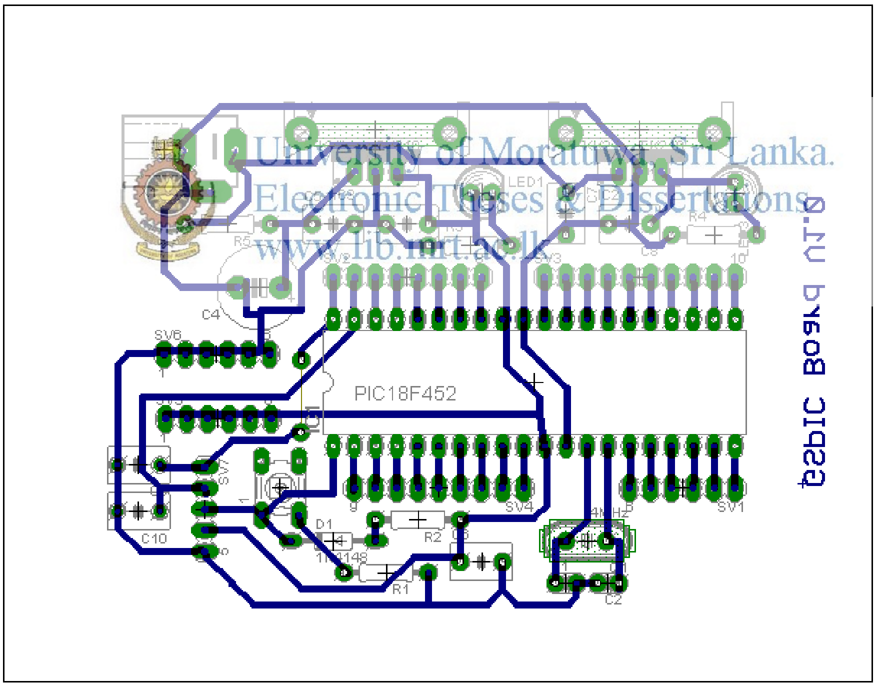


Figure 3.3-d PCB pattern of Humidity Controller main circuit

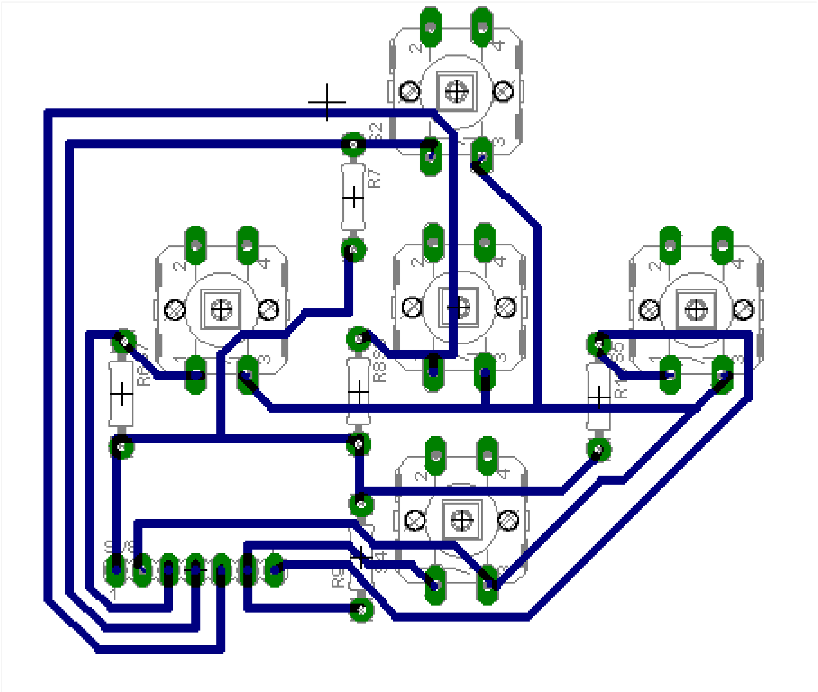


Figure 3.3-e PCB pattern of Humidity Controller keypad

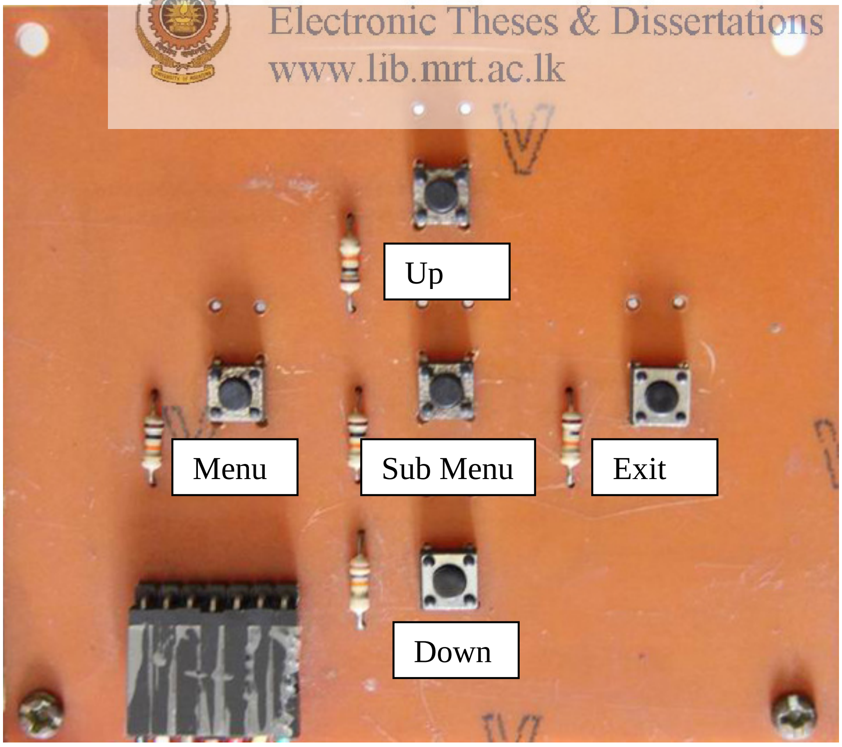


Figure 3.3-f Key Pad Functions

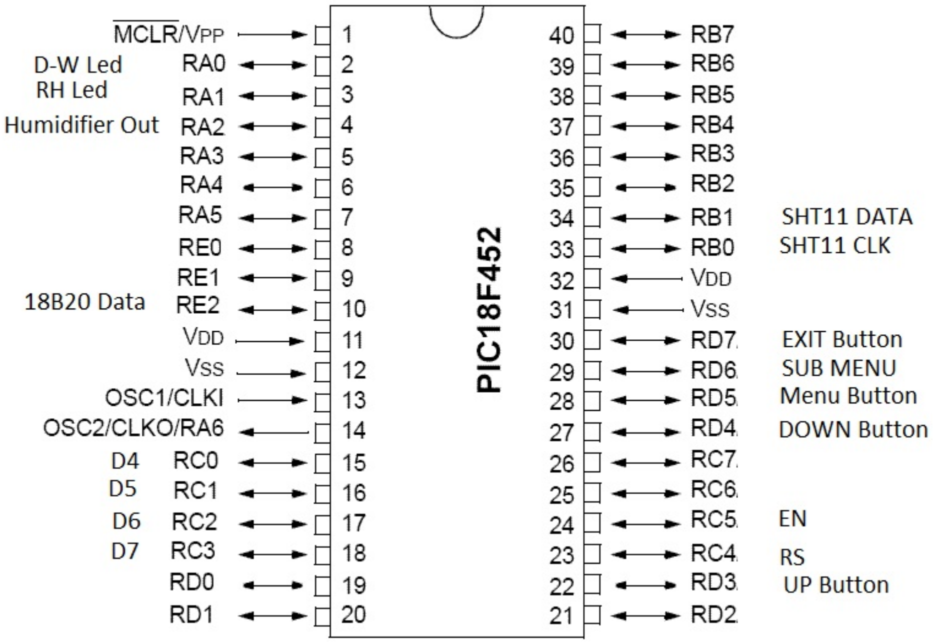


Figure 3.3-g. PIC microcontroller connections

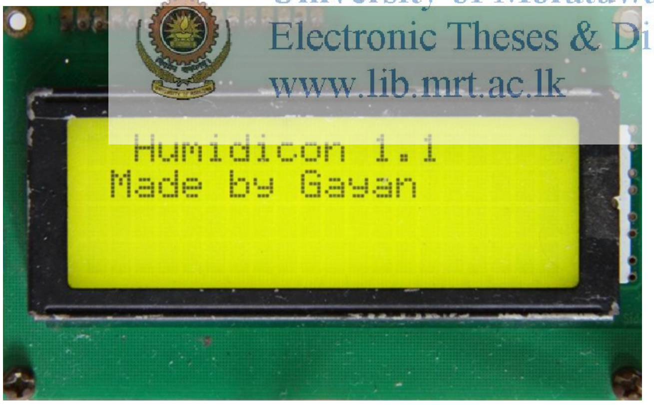


Figure 3.3-h 20 character x 4 line LCD Display

LCD display connections are listed in table 3.3-a

Table 3.3-a LCD connections to MCU

Pin	Function	Description	Connection
1	VSS	Ground	0 V
2	VDD	Positive supply	+5V
3	Vo	Contrast adjustment	Contrast adjustment preset
4	RS	Register select 0-command, 1-data	Microcontroller pin RC4
5	R/W	Read/Write 0-write, 1-read	0 V

6	E	Clock Enable	Microcontroller pin RC5
7	D0	Bit0	Not used in 4-bit operation
8	D1	Bit1	Not used in 4-bit operation
9	D2	Bit2	Not used in 4-bit operation
10	D3	Bit3	Not used in 4-bit operation
11	D4	Bit4	Microcontroller pin RC0
12	D5	Bit5	Microcontroller pin RC1
13	D6	Bit6	Microcontroller pin RC2
14	D7	Bit7	Microcontroller pin RC3
15	LED+	Backlight anode	+5V
16	LED-	Backlight cathode	0 V

Figure 3.3-i PIC based humidity controller

Figure 3.3-j. Digital Psychrometer

3.4 User Interface and Parameter Adjustment

All modes, parameter adjustments, calibration data are written to MCUs eeprom memory and will not be changed due to restarting or power failures. However restarting will result to show a main screen. User Interface provides following prompts/functions.

1. **Main Screen**

   There are three main screens according to user's choice. However tea industry is get used to Fahrenheit.

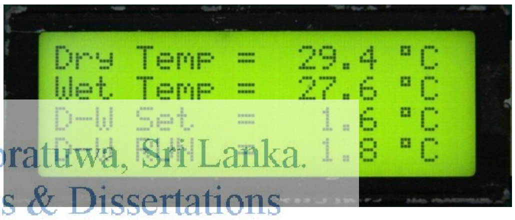
   a. D-W mode in Fahrenheit

   b. D-W mode in Celsius

   c. %RH mode

```
Dry Temp =  85.1 °F
Wet Temp =  81.5 °F
D-W Set  =   3.0 °F
D-W RUN  =   3.6 °F
```

Figure 3.4-a in Fahrenheit



```
Dry Temp =  29.4 °C
Wet Temp =  27.6 °C
D-W Set  =   1.6 °C
D-W RUN  =   1.8 °C
```

Figure 3.4-b in Celsius

```
RH% Set  =  90.0
RH% RUN  =  84.0
```

Figure 3.4-c %RH mode

2. **Set Value**

   Required D-W difference or humidity level can be set by the user. D-W difference will be shown according the selected temperature unit.

3. **Temperature Unit**

   Temperature unit can be either Fahrenheit or Celsius.

4. **Mode**

   Operating mode can be selected either D-W or %RH mode.

5. **Calibration**

   Though the sensors are factory calibrated, they may not tally up to 0.1°F. In case of SHT11 and DS18B20 readings are not similar both sensors are dry or when comparing readings with reference to another measurement device, a ±10.0°C or ±10.0%RH is available. However if SHT11 and DS18B20 cannot give the same dry temperature reading within their accuracy limits, particular sensor should be replaced. SHT11 can shift its measurement range temporary sue to prolong exposure of high humidity levels. That cane be corrected with the sensor heating function. Sub menu button will rotate the following three parameters to adjust.

   a. Dry Temperature
   b. Wet Temperature
   c. %RH

6. **Hysteresis**

   A software coded hysteresis is provided for both D-W and %RH modes to prevent faster ON OFF status changes.

   a. D-W
   b. %RH

7. **Sensor Heating**

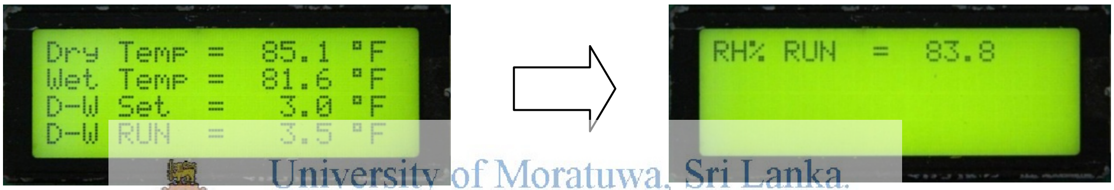
   SHT11 is programmed to heat automatically once in every hour to avoid offsetting the sensor measurements. Apart from that sensor heating can be manually activated by pressing UP button during a main screen.

```
Sensor Heating...
```

Figure 3.4-d Switching on-chip Heater & Heating SHT11

8. **Cross Referencing**

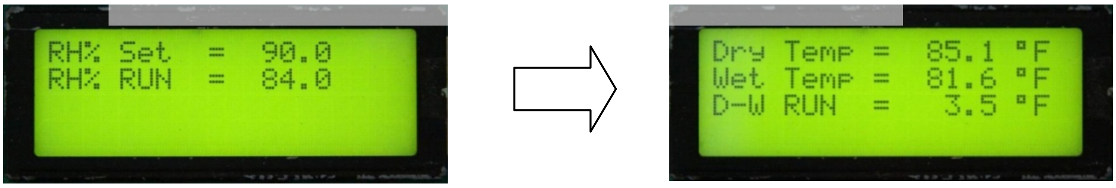
   While operating in D-W or %RH mode, measurements of the other mode can be seen by pressing DOWN button. This will help those who are in tea industry to get an idea about relative humidity compared to wet and dry bulb difference.



```
Dry Temp =   85.1 °F
Wet Temp =   81.6 °F
D-W Set  =    3.0 °F
D-W RUN  =    3.5 °F
```

```
RH% RUN  =   83.8
```

Figure 3.4-e %RH value in D-W mode



```
RH% Set  =   90.0
RH% RUN  =   84.0
```

```
Dry Temp =   85.1 °F
Wet Temp =   81.6 °F
D-W RUN  =    3.5 °F
```

Figure 3.4-f D-W in %RH mode

4 Results and Analysis

4.1 Results

The developed humidity control system was tested at Tea research Institute Ratnapura successfully. Digital psychrometer was closely placed with an alcohol wet and dry bulb hygrometer and few measurements were taken. Unfortunately the capacity of humidifiers were not enough to keep the wet and dry bulb difference below 3°F but able to compare the results. The resolution of wet and dry bulb hygrometer used for the test was 2°F which is not acceptable to read a difference of 3°F. Unfortunately it is widely used in tea industry.

Another two tests were carried out in an 8ft x 9ft x12ft fully closed room, where the humidifier used has enough capacity to humidify the room. Results of the tests are listed in table 4.1-a and table 4.1-b. Digital psychrometer was placed very closely to an alcohol wet and dry bulb hygrometer and humidifier was kept away as possible to avoid direct exposure to humidity stream. Humidity is emitted as very tiny water droplets less than 5 microns in size, and should be diffused in air. Exposing SHT11 to direct humidity stream sometimes cause to offset the sensor and was avoided during the testing. Readings were taken every 1 minute while controlling the humidifier. A hysteresis difference of 0.3°F was set to switch ON the humidifier when D-W at 3°F and to switch OFF when at D-W 2.7°F. Due to the time taken to diffuse water vapor to atmosphere and increase the relative humidity and also due to the response time of DS18B20 and SHT11sensors, actual humidity control slightly exceeds to set condition. As wet and dry bulb difference between 2°F - 3°F is accepted for tea industry, the developed controller works satisfactorily within the limit. The comparison of readings of alcohol wet and dry bulb hygrometer and developed digital psychrometer has drawn below.

There was no benchmark system to analyze the errors of digital wet and dry temperature sensors of developed humidity controller. However it was compared with an alcohol type wet and dry bulb hygrometer where accuracy of unit not specified by the manufacturer (Brannan Thermometers, England) [15]. Typically accuracy of an alcohol thermometer is about ±1.5°C.

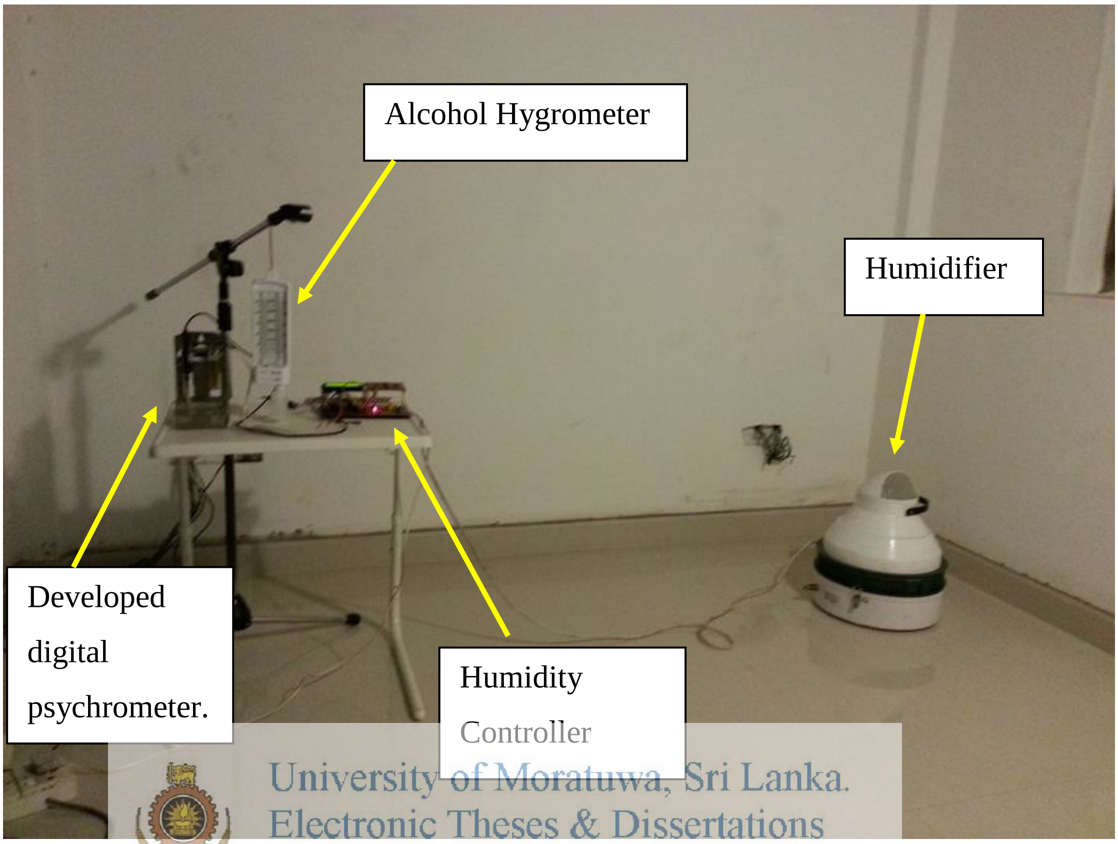


Figure 4.1-a Instrument setup for testing inside a fully closed room

Table 4.1-a Test results of D-W mode carried out in a fully closed room

time (mins)	Developed unit				Alcohol hygrometer			%RH calculated with D-W digital	Humidifier status
	Dry °F	Wet °F	D-W digital °F	% RH	Dry °F	Wet °F	D-W Alcohol °F		
0	85.4	79.7	5.7	78.9	86.0	80.0	6.0	77.9	1
1	84.9	79.8	5.1	83.5	86.0	80.0	6.0	80.0	1
2	83.6	80.2	3.4	88.4	84.0	80.0	4.0	86.3	1
3	82.9	80.4	2.5	91.7	84.0	80.0	4.0	89.7	0
4	82.9	80.9	2.0	94.2	84.0	80.0	4.0	91.7	0
5	83.1	81.1	2.0	93.2	84.0	80.0	4.0	91.7	0
6	83.3	81.3	2.0	92.2	84.0	82.0	2.0	91.8	0
7	83.6	81.5	2.1	91.4	84.0	82.0	2.0	91.4	0
8	84.0	81.5	2.5	90.3	84.0	82.0	2.0	89.8	0
9	84.3	81.6	2.7	88.8	84.0	82.0	2.0	89.1	0
10	84.3	81.5	2.8	88.7	84.0	82.0	2.0	88.7	1
11	84.3	81.5	2.8	90.8	84.0	82.0	2.0	89.7	0
12	83.8	81.6	2.2	92.3	84.0	82.0	2.0	91.0	0
13	83.8	81.6	2.2	91.9	84.0	82.0	2.0	91.0	0
14	84.0	81.8	2.2	92.0	84.0	82.0	2.0	91.0	0
15	84.2	82.0	2.2	91.1	84.0	82.0	2.0	91.0	0
16	84.3	82.0	2.3	89.8	84.0	82.0	2.0	90.7	0
17	84.5	82.0	2.5	88.7	84.0	82.0	2.0	89.9	0
18	84.5	81.8	2.7	87.9	84.0	82.0	2.0	89.1	1
19	84.5	81.6	2.9	88.9	84.0	82.0	2.0	88.3	1
20	84.0	81.6	2.4	92.9	84.0	82.0	2.0	90.2	0
21	83.6	81.8	1.8	93.4	84.0	82.0	2.0	92.6	0
22	83.8	82.0	1.8	93.0	84.0	82.0	2.0	92.6	0
23	84.0	82.0	2.0	92.5	84.0	82.0	2.0	91.8	0
24	84.2	82.0	2.2	92.0	84.0	82.0	2.0	91.0	0
25	84.3	82.2	2.1	91.4	84.0	82.0	2.0	91.5	0
26	84.5	82.2	2.3	90.9	84.0	82.0	2.0	90.7	0
27	84.5	82.2	2.3	90.2	84.0	82.0	2.0	90.7	0
28	84.7	82.2	2.5	89.1	84.0	82.0	2.0	89.9	0
29	84.7	82.0	2.7	88.6	84.0	82.0	2.0	89.1	0
30	84.9	82.0	2.9	88.0	84.0	82.0	2.0	88.4	0
31	84.7	81.6	3.1	89.8	84.0	82.0	2.0	87.6	1
32	84.2	81.8	2.4	92.8	84.0	82.0	2.0	90.3	0
33	83.8	82.0	1.8	94.6	84.0	82.0	2.0	92.6	0
34	83.8	82.4	1.4	95.0	84.0	82.0	2.0	94.2	0
35	84.0	82.4	1.6	94.2	84.0	82.0	2.0	93.4	0

Table 4.1-b Test results of %RH mode carried out in a fully closed room.

time (mins)	Developed unit				Alcohol hygrometer		D-W Alcohol °F	Humidifier status
	%RH	Dry °F	Wet °F	D-W digital °F	Dry °F	Wet °F		
0	90.4	85.1	82.7	2.4	84.0	82.0	2.0	0
1	89.9	85.1	82.7	2.4	86.0	82.0	4.0	1
2	92.8	84.7	82.5	2.2	84.0	82.0	2.0	0
3	93.7	84.5	82.9	1.6	84.0	82.0	2.0	0
4	93.6	84.5	82.9	1.6	84.0	82.0	2.0	0
5	93.2	84.7	82.9	1.8	84.0	82.0	2.0	0
6	91.8	84.9	82.9	2.0	84.0	82.0	2.0	0
7	90.9	85.1	82.7	2.4	86.0	84.0	2.0	0
8	90.4	85.1	82.7	2.4	86.0	82.0	4.0	0
9	90.5	85.2	82.9	2.3	86.0	82.0	4.0	0
10	89.6	85.2	82.7	2.5	86.0	84.0	2.0	1
11	92.5	84.9	82.9	2.0	84.0	82.0	2.0	0
12	94.1	84.7	82.9	1.8	84.0	82.0	2.0	0
13	94.5	84.5	83.1	1.4	84.0	84.0	0.0	0
14	93.4	84.7	83.3	1.4	84.0	84.0	0.0	0
15	93.4	84.9	83.3	1.6	86.0	84.0	2.0	0
16	92.9	85.1	83.3	1.8	86.0	84.0	2.0	0
17	91.7	85.2	83.3	1.9	86.0	84.0	2.0	0
18	91.0	85.4	83.3	2.1	86.0	84.0	2.0	0
19	89.8	85.2	82.9	2.3	86.0	84.0	2.0	1

4.2 Analysis

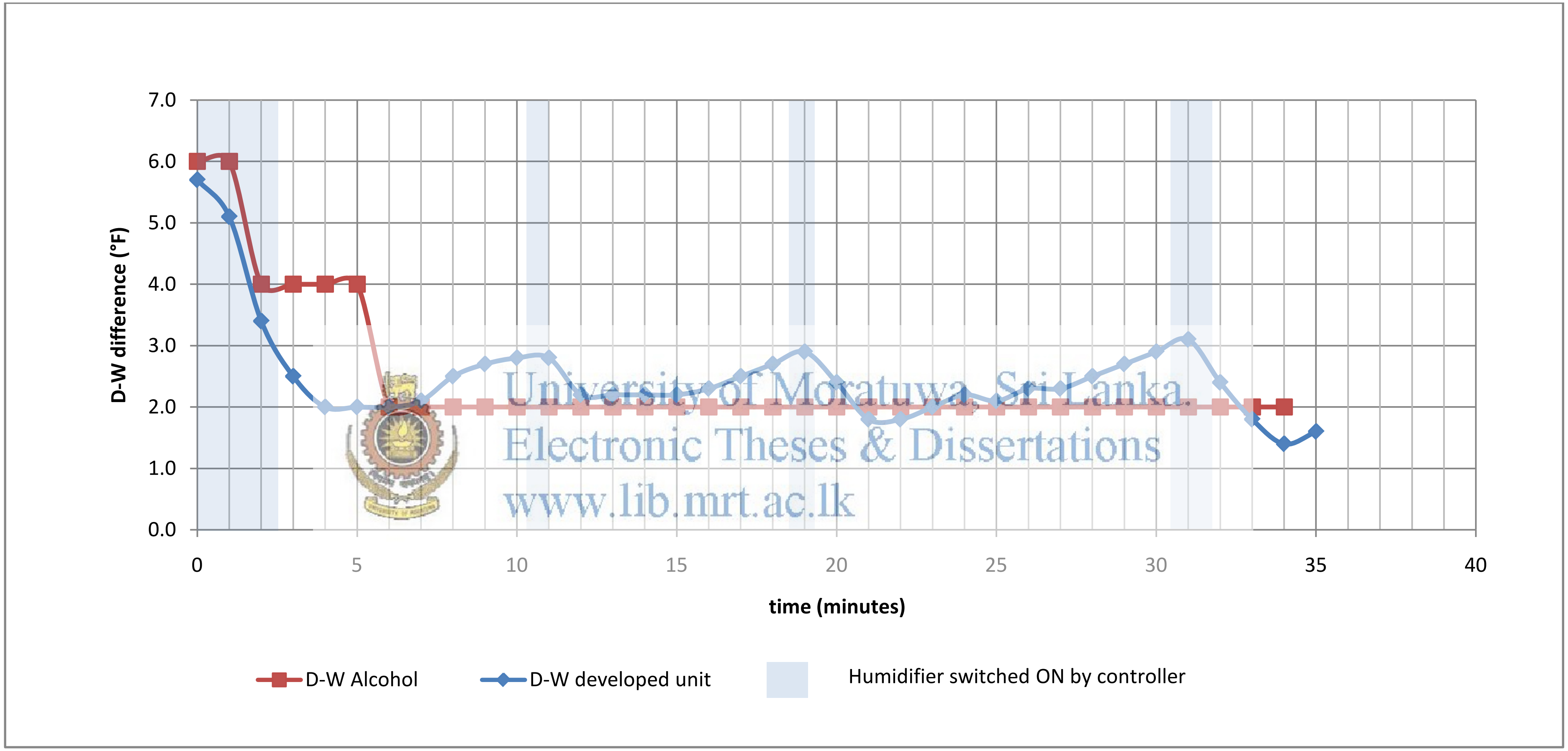


Figure 4.2-a D-W measured with Alcohol hygrometer and developed unit (D-W control mode)

Humidifier was operated in D-W mode and set to switch on at D-W 3°F and switch off at D-W 2.7°F.

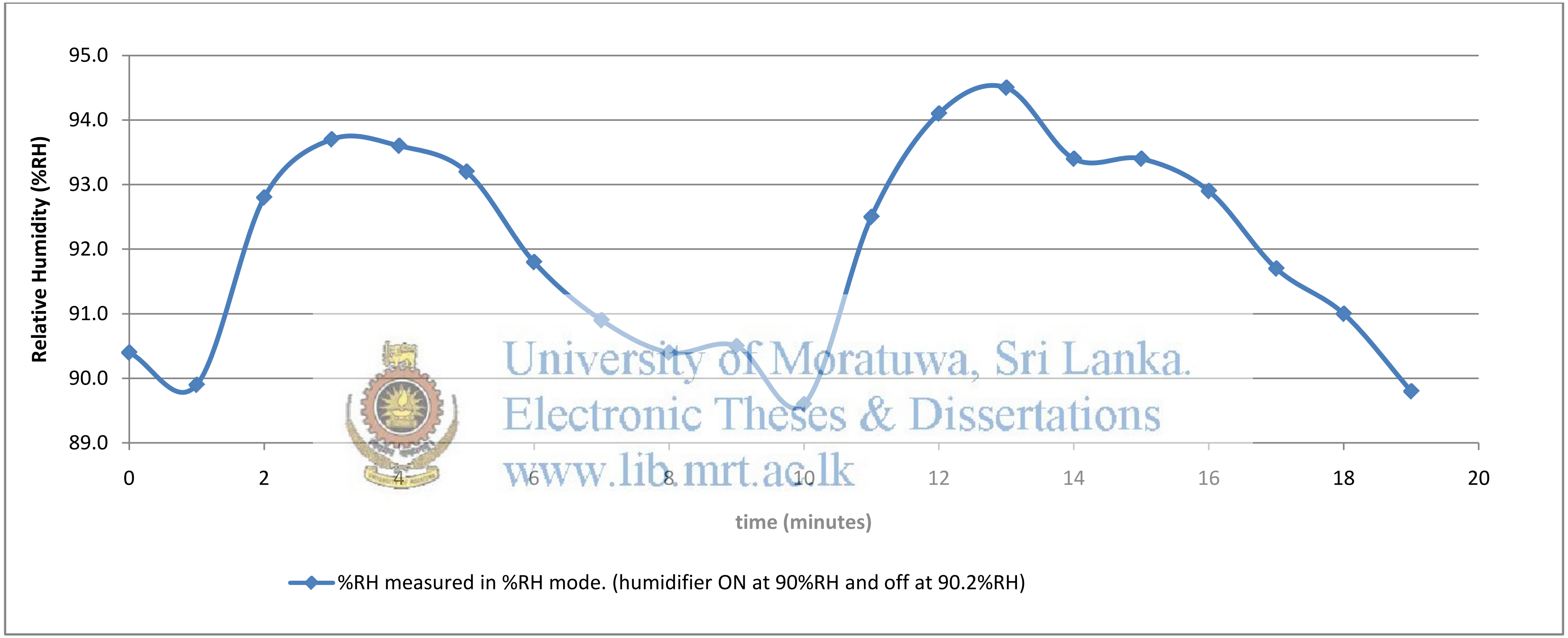


Figure 4.2-b Relative humidity measured using SHT11 in %RH mode

Controller was operated in %RH mode. Humidifier was switched on when humidity falls down to 90% and cut off at 90.2%. Humidifier was not pointed towards sensor and it takes some time to diffuse water vapour in atmosphere and changes to take place in humidity.

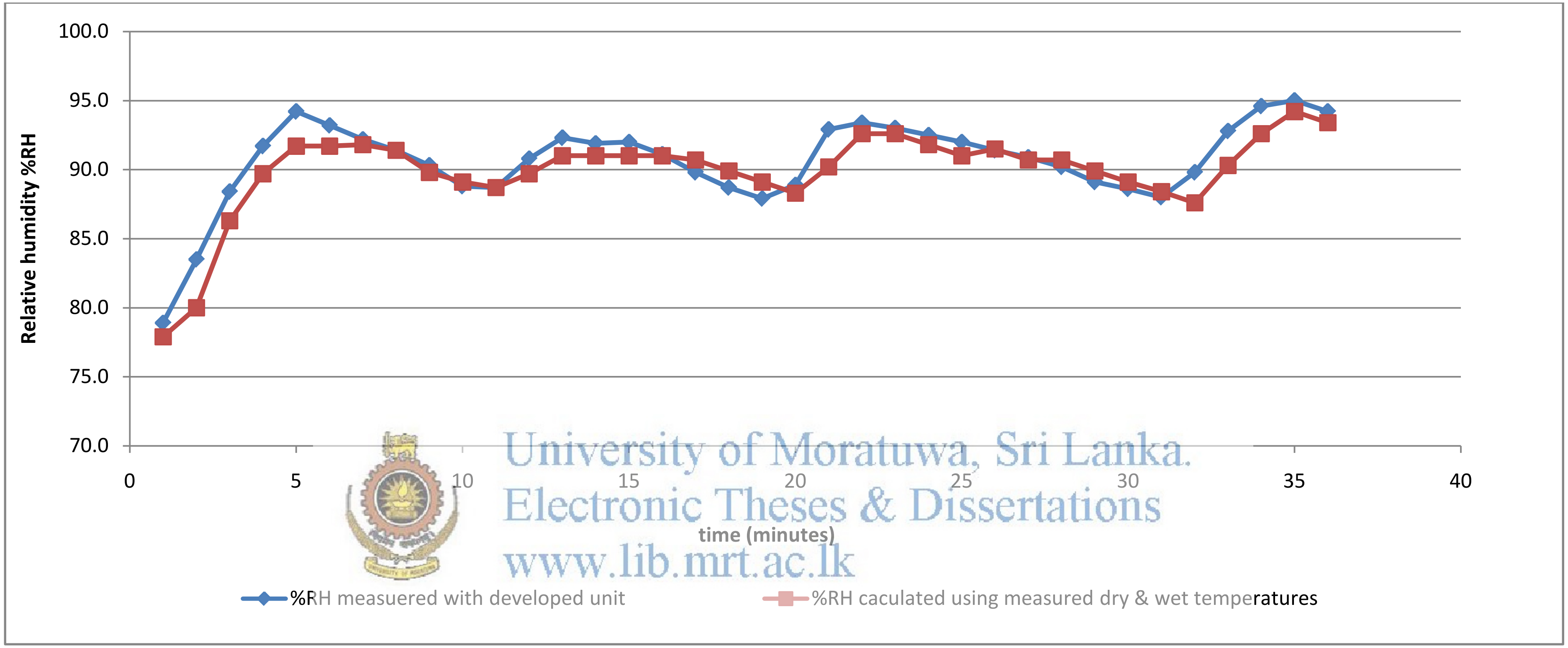


Figure 4.2-c Relative humidity measured with developed unit vs. calculated using measured wet & dry bulb temperatures

Dry temperature, wet temperature and relative humidity were recorded every minute and relative humidity was calculated from dry and wet temperature readings using a web calculator and compared with measured relative humidity. Relative humidity calculated using dry and wet temperatures also follows the same pattern of measured humidity but lagging behind. According to the datasheet of SHT11, response to humidity is faster than response to temperature. Therefore this comparison proves that the developed sensory system performs accurately as per specifications.

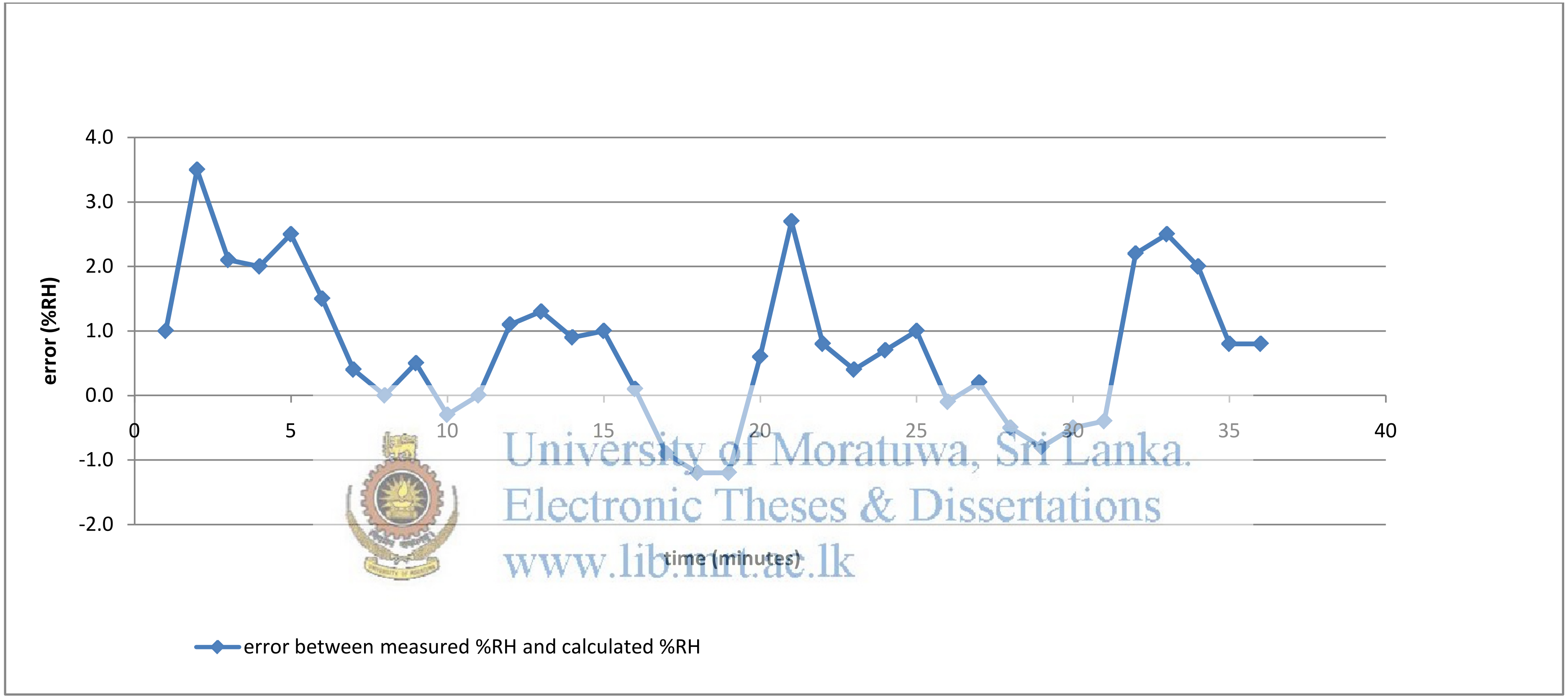


Figure 4.2-d Error between measured humidity and calculated humidity using developed unit

Accuracy of humidity measurements of SHT11 varies from ±3%RH to ±5%RH in the range of 80%RH to 100%RH. Only one reading is ±3.5 %RH and all other readings are well within the range.

5 Conclusion and Discussion

5.1 Conclusion

Almost all the drawbacks related to the sensory system are corrected by selecting most appropriate sensors. Errors due to poor accuracy, non linearity, contact resistance, lack of high accuracy and high resolution calibrating instruments etc are corrected by selecting appropriate factory calibrated digital sensors. Selected sensors SHT11 and DS18B20 are capable of taking measurements in very high humidity levels for longer period and sensor heating function has been implemented for that purpose. Cost of the sensory system and humidity controller is less than 10% of the imported product. Accuracy of the measurements are better than alcohol wet and dry bulb hygrometers used in tea factories and also better than the imported product. No time D-W was shown a negative number. Though there is no benchmark model to evaluate the accuracy of the developed unit, results and analysis proves that the sensory system performs within the manufacturer's tolerance levels.

Figures 4.2-a and 4.2-b show some overshoot for both D-W and humidity control modes. This is mainly due to the delay in diffusing water vapour in atmosphere and changes to take place in humidity. This delay varies upon volume to be humidified, distribution of humidity and the distance between humidifier and digital psychrometer. During that period, humidifier emits an additional amount of water to the atmosphere resulting an over humidified space.

Results wise, controlling wet and dry bulb difference between 2-3°F or maintaining relative humidity between 90-95% is well acceptable for tea industry. However the overshoots are reduced when environment is properly ventilated. If air refreshment is 10 times per minute, ON time of humidifier increases and off times reduces. Also overshoot can be eliminated if the speed of humidifier is controlled by a PID control system and is properly tuned. PID controller can be implemented by software and speed controlling of humidifier requires a variable speed drive.

Apart from that method there are couple of other methods to limit the overshoot. One method is to use Pulse Width Modulation (PWM) to operate the humidifier. ON duty of the pulse can be calculated based on wet and dry bulb difference or the difference between reference and actual humidity levels. Other method is to calculate the amount of water vapour to be disbursed according to the humidity requirement and operate the humidifier for that time period. Modelling and simulating the rolling room and humidifier placement can improve the uniformity of temperature and humidity distribution.

The selected two sensors were compromised due to ability of purchasing from international seller and availability. As an example, SHT15 of SHT1X family is fully interchangeable and more accurate compared to SHT11 but not available during the time of development. Otherwise accuracy could be improved in temperature by ±0.1°C and relative humidity by ±1.

There are some other expensive humidity sensors like Vaisala Humicap which uses their own "warmed probe" [16] or XHEAT technology to measure humidity at extreme conditions but at a very high price. Wormed probe technology uses a composite heating element bonded together with humidity sensor and heating keeps the probe at several degrees higher than the ambient temperature. This ensures that water will not condense on the sensor and ambient is calculated from measured value by the probe. InXHEAT technology, the embedded heater can increase the temperature of the sensor up to 100°C in 30 seconds and cool down it rapidly to ambient in another 30seconds. The heating level is very high and cooling is much faster than the SHT11 used in the project. However tea industry cannot afford such an expensive technology and doesn't require high precision measurements. The on-chip heater in SHT11 can only increase the temperature by 10°C and is not recommended to use continuously. Sensor heating algorithm I have implemented is limited to 10°F as sensor takes 20 seconds to heat up and 100 seconds to cool down. Though the sensor is permitted to heat up by 10°C (18°F), it was limited to 10°F due to the longer time period taken for heating and cooling back to ambient. Until the sensor is cooled down to ambient, readings are incorrect and unable to operate humidifiers.

5.2 Future developments

At present, sensor system and humidifier is having one to one connection system. But sensors and humidifiers will be placed like a mesh grid and each sensor will have four humidifiers in the close proximity. A neural network may improve the uniformity of humidity in the Rolling and Fermenting room as a whole.

Fermentation of tea is actually an oxidation and fermenting area should be properly ventilated. Higher ventilation needs more humidity to produce and will consume more energy. Thus there is no research related to oxygen requirement for better fermentation of tea. I believe it’s good to control both humidity and ventilation for better fermentation.

Data logging is also important to analyze the humidity distribution with time. Desired humidity levels may not be achieved when a humidifier is malfunctioning, higher amount of air refreshment or wind, lower ambient humidity level in dry season etc.

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Appendices: