

**REMOTE HUMIDITY AND TEMPERATURE REAL TIME
MONITORING SYSTEM FOR STUDYING SEED BIOLOGY**

by

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DECLARATION

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any university, and to the best of my knowledge and belief, it does not contain any material previously published, written or orally communicated by any other person except where due reference is made in the text.

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Thiruparan Balachandran

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ABSTRACT

REMOTE HUMIDITY AND TEMPERATURE REAL TIME MONITORING SYSTEM FOR STUDYING SEED BIOLOGY

This thesis discusses the design, prototyping, and testing of a remote monitoring system that is used to study the biology of seeds under various controlled conditions. Seed scientists use air-tight boxes to maintain relative humidity, which influences seed longevity and seed dormancy break. The common practice is the use of super-saturated solutions either with different chemicals or different concentrations of LiCl to create various relative humidity. Therefore, no known system has been developed to remotely monitor the environmental conditions inside these boxes in real time. This thesis discusses the development of a remote monitoring system that can be used to accurately monitor and measure the relative humidity and temperature inside sealed boxes for the study of seed biology. The system allows the remote and real-time monitoring of these two parameters in five boxes with different conditions. It functions as a client that is connected to the internet using Wireless Fidelity (Wi-Fi) technology while Google spreadsheet is used as the server for uploading and plotting the data. This system directly gets connected to the Google sever through Wi-Fi and uploads the sensors' values in a Google spread sheet. Application-specific software is created and the user can monitor the data in real time and/or download the data into Excel for further analyses. Using Google drive app the data can be viewed using a smart phone or a tablet. Furthermore, an electronic mail (e-mail) alert is also integrated into the system. Whenever measured values go beyond the threshold values, the user will receive an e-mail alert.

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CHAPTER 1

INTRODUCTION

The need of measuring physical parameters plays an important role in science and technology. In modern days, sensors are used not only for this purpose but also in every day of our lives. A sensor is an electronic component that translates the physical parameters into electrical signals [1]. In early days, these sensors were usually coupled with complex electronic systems or with large computers in order to monitor and control various parameters. Those systems were complex, expensive, and large in size.

Advancement in technology grew rapidly with the introduction of microcontrollers. The advancement of these chips has made it possible to replace the above-mentioned complex electronic systems and resulted in designing simple and cost effective platforms to interface these sensors in an efficient manner. A microcontroller is a device that has a Central Processing Unit (CPU), Random Access Memory (RAM), Read Only Memory (ROM), timers, counters, Analog to Digital (A/D) converters, Input/Output (I/O) ports, and/or other peripherals on a single chip [2]. Applications of microcontrollers are numerous and they range from simple applications such as toys to complex applications such as fly-by-wire, medical applications, robotics, etc. The improvement in fabrication technology has led to manufacturing microcontroller internal components at the scale of nanometers, which not only provides small footprint but also provides efficiency in power consumptions, higher speeds, and lower costs [3].

1.1 Communication Protocol

Development in communication modules and protocols immensely support the implementation of remote and real time monitoring systems based on microcontrollers.

The light-weighted nature of these protocols allows an easy implementation using a microcontroller. These communication modules include Wireless Fidelity (Wi-Fi), Bluetooth, ZigBee, and Global System for Mobile Communication (GSM) [4, 5]. These modules have their own advantages and drawbacks. Table 1 below gives a technical comparison of these protocols.

Table 1. Technical Comparison of the Communication Protocols

Protocol	ZigBee	Wi-Fi	Bluetooth	GSM
Data Rate	20, 40 and 250 Kbits/s	11 and 54 Mbits/s N can go much higher than that	1 Mbits/s	9 Kbits/s
Range	10 – 50 m	50 - 100 m	10 m	
Operating Frequency	868 MHz	2.5 and 5 GHz	2.4 GHz	1.9 GHz and 850MHz
Direct Access to Internet	No	Yes	No	Yes

Out of these modules, Bluetooth, RF, and ZigBee can transfer the data only between same modules or to a computer. To implement a remote monitoring system, these communication modules cannot be used, because they have range limitation.

By using the Internet, data can be sent to any part of the world. Therefore, using the internet is the best option to implement a remote monitoring system. However, a Zigbee, Bluetooth, or GSM does not have the capability to send data directly to an internet sever. In order to send data to the internet server, a computer needs to be used along with these communication modules. But by using Wi-Fi and GSM modules, the data can be transferred directly to an internet server from which it can be viewed from any part of the world. A GSM module needs a dedicated line to transfer the data while a Wi-Fi module can be used with an existing network or a common Wi-Fi environment. Because of the high data transfer in Wi-Fi, streaming the data is very easy. This allows an easy implementation of a real-time monitoring. These days almost all places are equipped with Wi-Fi. Therefore, using a Wi-Fi module to transfer data to an internet server is the most cost effective, efficient, and applicable method in real-time and remote monitoring system [6].

1.2 Seed Biology

Seeds play an important role in nature and in human nutrition. Seeds contain an embryo (or embryos) that is often surrounded by endosperm, and protected by a seed coat [7]. The embryo develops inside the seeds, resulting in root emergence, called germination, and shoot emergence. During germination the seed acts as a reproductive unit and ensures the survival of the plant. Seeds of many species are prevented from germinating due to some type of dormancy [8]. Several factors can break dormancy, but the most important ones are high or low temperatures interacting with water contents of

the seed. Once dormancy is overcome, germination can occur and a new plant forms [9]. Temperature and moisture also affect seed viability and their longevity.

Relative humidity influences the moisture content of seeds and their biology. High relative humidity (> 75%) promotes hydrolytic reaction and respiration, which increase the amount of loosely bound water molecules. The increased mobility of water molecules could lead to seed deterioration, which could reduce the seed viability [10, 12]. A low relative humidity (18- 25%) leads to a reduced mobility of water molecules, which slows down the diffusion driven reactions and lengthens seed longevity. Furthermore, for maximum longevity, seeds should be maintained at relative humidity between 3 and 8% [10]. Thus, the relative humidity needs to be controlled during seed storage.

Relative humidity also plays a key role during the dormancy break of seeds that require warm temperatures [13, 14, 15]. Seed after-ripening is a dormancy break treatment that occurs at warm temperatures in which seeds are stored for a prolonged period of time [16]. Whereas seeds of some species break dormancy during warm-moist conditions, those of other species need warm-dry conditions. Thus, there is a gradient of relative humidity over which after-ripening occurs.

To control relative humidity for examining the effects on seed longevity and on seed dormancy break, the common practice is to use closed containers with saturated solutions of chemicals that create different relative humidity. However, these supersaturated solutions cannot be accepted as accurate without being checked. Checking is

usually done every once in a while by opening the containers and using a relative humidity probe [17]. As shown in Figures 1 and 2, seeds are placed into sealed containers or seed boxes (polycarbonate enclosed electrical boxes) and then the containers are inside incubators at desired test temperatures. Super saturated solutions are poured into the bottom of each box to create a relative humidity at a specific level. One such method uses LiCl. By varying the amount of this chemical dissolved in distilled water, various relative humidities can be produced [18]. Alternatively, incubators that can control both humidity and temperature might be used. However, several incubators would be needed simultaneously to carry out this intended research resulting in increase of cost and required space.



Figure 1. Sealed Polycarbonate Electrical Enclosure or Box Used to Store Seeds
(Photo from Dr. J. Walck, Dept. of Biology, MTSU)



Figure 2. Storage of Box Inside an Incubator

(Photo from Dr. J. Walck, Dept. of Biology, MTSU)

1.3 Problem Statement

Real-time monitoring systems have applications in many critical fields, such as plant sciences. In seed biology, for example, real-time remote systems are needed for accurate monitoring of temperature and relative humidity conditions when examining dormancy break and longevity of seeds. Failure to monitor the critical parameters could lead to errors when interpreting the dormancy and longevity data. A component with a

combination of real-time monitoring and an alert system is needed for seed biologists to monitor the conditions at any given time and from any part of the world. This helps to reduce the man power needed for a manual monitoring in addition to reducing the risks possibility of repeating an experiment, which is usually time consuming.

Sealed electrical boxes containing super saturated solutions to control the relative humidity are currently being used to study after-ripening and longevity of seeds. A system that can measure and monitor the relative humidity and temperature inside five boxes (each with a different LiCl solution) with remote and real-time monitoring capabilities will be designed, built, and tested. The results will be analyzed and compared to expected values using various concentrations of LiCl in distilled water. Furthermore an email alert functionality also will be integrated into the system.

CHAPTER 2

LITERATURE REVIEW

For many years, researchers and engineers have been working on real time and remote monitoring systems to serve their various needs. For example, a “Low-power hybrid wireless network for monitoring infant incubator” was published by Shin et al. (2004). They have designed a wireless network for monitoring infant incubators using Infra-Red (IR) and RF modules [19]. This system monitors the temperature and humidity of infant incubators and sends the data to a host computer when the host computer requests for the data through IR communication. It sends the ID of the slave device and when an ID is received and if it matches with a slave device, the slave will send the data to the host computer through RF module. In this study, two-way communication platform was used; one is to send request to slave devices (IR) and another is to send data to the host (RF). National Instrument LabView software was used to plot the data using a computer. Some of the drawbacks of this system are: To implement this system, a host computer and a LabView software are needed, which increased the cost, limited the range, and provided no alert method to notify the user. Limit in range is due to using RF.

Another system has been designed by Wen-Tsai Sung and Ming-Han Tsai outlined in their publication titled: “Multi-Sensor Wireless Signal Aggregation for Environmental Monitoring System via Multi-bit Data Fusion” using ZigBee, a protocol based on the Institute of Electrical and Electronics Engineers 802.15.4 (IEEE 802.15.4). As shown in Figure 3, sensor nodes send the data to a ZigBee motherboard that collects the data from

all nodes and sends them to the user computer through a Universal Serial Bus (USB).

This system uses low power, has a low cost, and is small in size. The disadvantages of this system are low data transfer rate, short distance data transmission, and remote monitoring is not implemented [20].

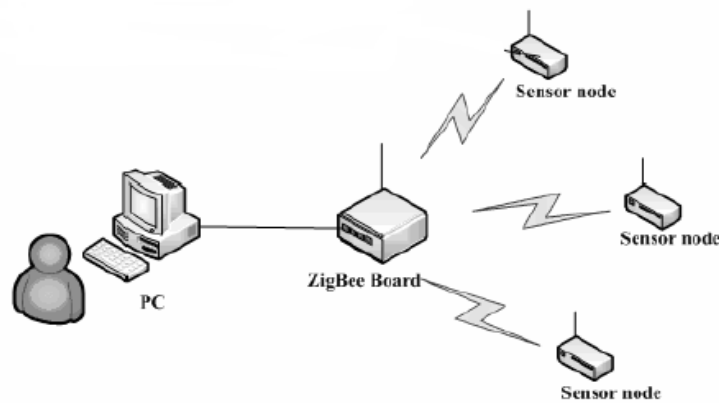


Figure 3. Wireless Sensor Network Using ZigBee Protocol (taken from reference 20)



Figure 4. Cellular Temperature Monitoring System

Figure 4 shows a cellular temperature monitoring system available on the market. It is manufactured by a company called “Temperature@lert ” [21]. This system is capable of measuring temperature and if the temperature goes out of range, it alerts the user through e-mail. This system allows the use of up to four wired temperature sensors. Maximum Sampling rate of this system is 12 samples per minute. This system costs \$450 and each sensor costs \$35. The system with four sensors costs around \$600. Since this system uses cellular network, the company provides a monthly plan that costs around \$31/ month. This system has several drawbacks and is not suitable for our purpose. By using this system only the temperature can be measured and it also cannot be monitored on real time. It is very challenging to use this inside the building, because in some labs cellular network coverage is not available. The system does not only have a onetime cost, however, every month the user has to keep paying for the monthly cellular plan as well. Moreover, the cellular plan and the data server are maintained by the company. This makes the user rely on the company forever.



Figure 5. Temperature Relative Humidity Transmitter [22]

Another temperature and humidity transmitter is a product available from Cooper Atkins[22]. As shown in Figure 5, it is a 3.5 by 1.5 by 1 inch small device embedded with temperature and relative humidity sensors. This device transmits the data using 900 MHz RF signal to the host computer. It has a transmitting range of up to 2500 ft. This device can be powered by 2/3 A size LiMnO₂ battery and the battery life is 2-5 years. The company provides the application software that collects the data and plots them in real time. Drawbacks of the systems are: since the sensors are built within the device, it is not possible to use the device in the current experiment setup. The containers are going to be placed in the incubator. The shielding property of the incubator will not allow the RF

signal to be transmitted. Remote monitoring is limited to 2500 ft and no alert feature is implemented.



Figure 6. Egg Temperature Relative Humidity Data Logger [23]

There are several temperature and relative humidity data loggers that are available on the market [23]. These data loggers save the temperature and relative humidity data over long periods. The data can be retrieved later using a personal computer or using specific hardware. The company “OMEGA” has produced egg temperature humidity data loggers. As shown in figure 6 this data logger has the size of an egg and it responds to the environment in the same way as a real egg does. Record start time and sampling rate can be programmed using a computer. Once it is configured, it can be placed in the experiment environment. This device comes with user replaceable battery and a non

volatile memory. This memory can hold 32,767 readings and retains the data even after battery is discharged. Average battery life is one year. This device is not suitable for our experimental setup. If we use this device inside the box, the box has to be opened each time a reading is needed. Each time the box is opened, the relative humidity and temperature of the seed boxes will be disturbed. In addition, No alert feature or real time monitoring is implemented.



Figure 7. Temperature Relative Humidity Controlled Incubator [24]

Temperature and relative humidity controlled incubators are available on the market [24]. Figure 7 shows one of the leading incubators on the market. It has temperature and relative humidity control system and data logging capability. Surface heating technology is used throughout the incubator. This incubator can log the data for ten years. The company provides the software needed to set the parameters of interest and retrieve the data. Drawbacks of using these chambers: one has to replace all the temperature controlled incubators that are available now in the biology department, which will be cost prohibitive. In addition, these incubators are big in size and more space is needed in a lab. Using one incubator at a time, results in only one experiment that can be carried out at a certain temperature and relative humidity. Normally seed experiments take several months. If these incubators are going to be used, it will take long time to complete the research at different humidity levels.

CHAPTER 3

SYSTEM DESIGN AND METHODOLOGY

In this section, details about the processing board, steps for designing the firmware for the microcontroller, uploading the program, sensor interfacing, and the data acquisition methods are discussed. Furthermore, testing the system and designing the case for the final product is also discussed. Figure 8 below shows a block diagram of the system architecture and interconnection between modules. The monitoring system consists of Processing board, LCD display and a Wi-Fi module. The sensors are connected to the monitoring system via a 2-wire interface. The Wi-Fi module is authenticated to the Wi-Fi access point with a Wi-Fi Protected Access Pre-Shared (WPA-PSK) authentication mechanism. So the data collected from sensors are processed in the system and then passed to the wireless router and from there get routed to the Google docs via a Wide Area Network (WAN). If the user has an internet connection, he or she can view the data in real time from any part of the world by connecting to Google sever. This can be done by logging into the Google account. Google spreadsheet is being used as the server. Software is created to view the data as a graph online in real time. An E-mail alert feature also implemented.

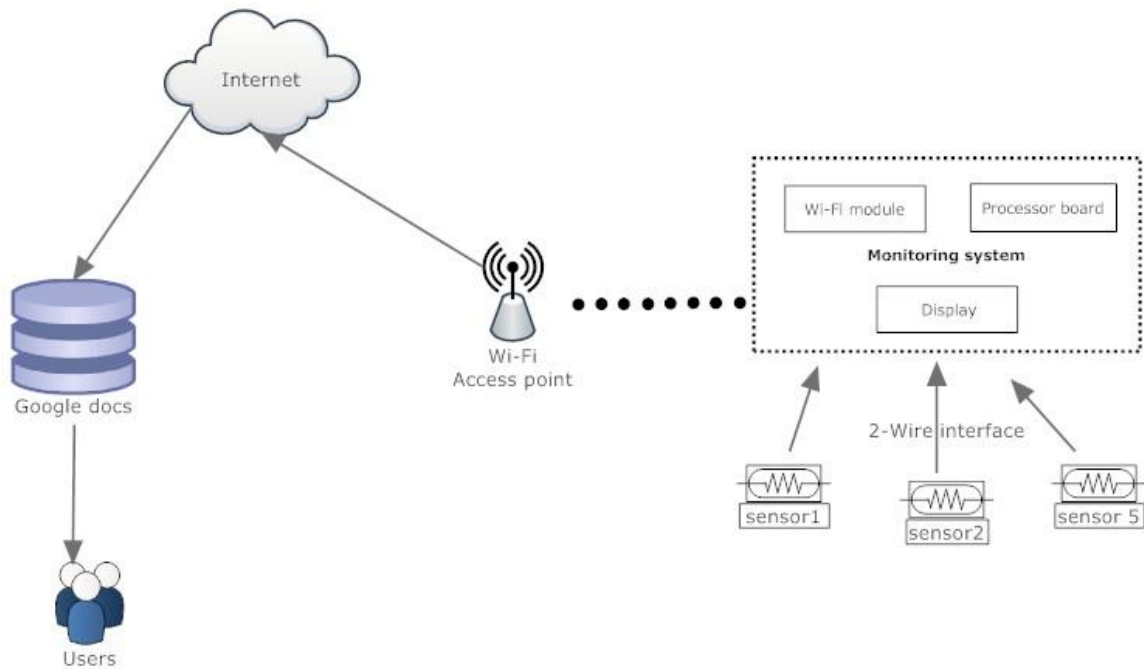


Figure 8. Overall Structure of the System

3.1 Processing Board

Arduino UNO3 is used as the main processing device. The functionality of this processing board is reading the sensor values and transferring them to the Wi-Fi module and LCD. Arduino UNO3 has an ATmega microcontroller, which is a 8-bit Alf Vegard Risc processor (AVR) and has 23 programmable input/output pins. Through the firmware of the microcontroller these pins can be set as either inputs or outputs of the microcontroller. The board also contains 5 V and 3.3 V voltage regulators, 16 MHz quartz oscillator, a Universal Serial Bus (USB) to serial converting chip and

other electronic components such as resistors, capacitors and light emitting diodes (LEDs).



Figure 9. Main Processing Board[25]

As shown in Figure 9, these components are mounted on a single board and the inputs/outputs are wired to standard connectors. This standard implementation allows adding interchangeable modules to this microcontroller board easy without any soldering. The microcontroller is factory programmed with boot loader. Once the microcontroller is powered, this boot loader will start executing. This boot loader will then run the actual firmware from the flash memory. Firmware is downloaded to the flash memory through computer using USB cable. Other devices, such as the Wi-Fi shield, sensors, and the LCD, get their power from this main processing board.

3.2 The Wi-Fi Module

A Wi-Fi shield from Arduino is used in this project to connect the device to the internet through Wi-Fi. This Wi-Fi shield is featured with HD104 chip. This chip handles Wireless LAN 802.11b/g protocol communication with low power consumption.

Network stack software libraries are available for free. These libraries support Wired Equivalent Privacy (WEP), Wi-Fi Protected Access, Pre-Shared Key (WPA-PSK) and WPA-2-PSK security. The communication between the main processing board and the Wi-Fi shield is done through Serial Peripheral Interface Bus (SPI) protocol.

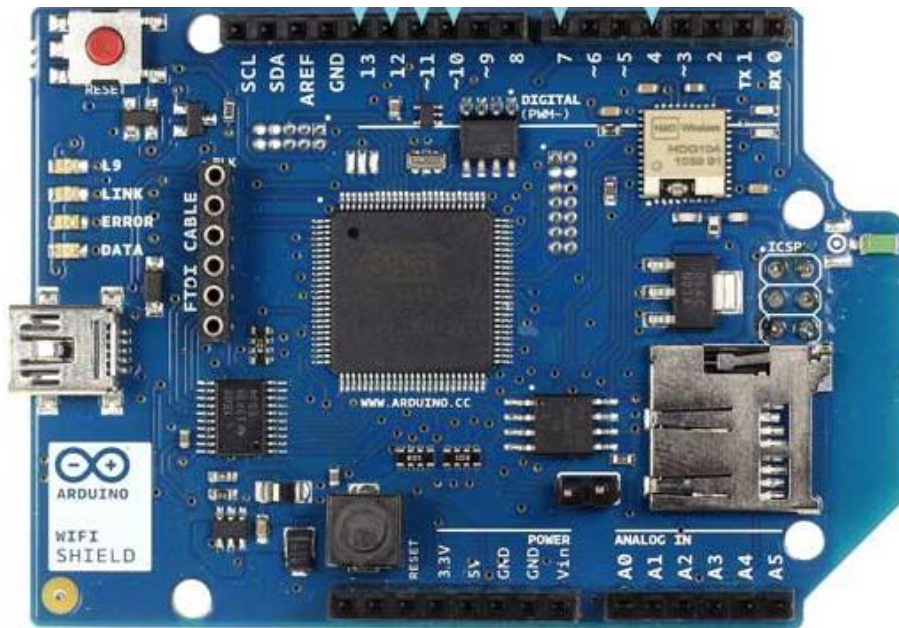


Figure 10. Wi-Fi Shield [26]

Figure 11 shows the circuit connection between main processor and the Wi-Fi shield. Pin numbers 11, 12 and 13 are SPI data in, SPI data out, and SPI clock of the main processor

board, respectively and they are connected to pin number 50, 51 and 52 of the Wi-Fi shield, respectively. Pin number 10 and 7 of the main processor board are connected to pin number 10 (chip select) and 8 (hand shake) of the Wi-Fi shield.

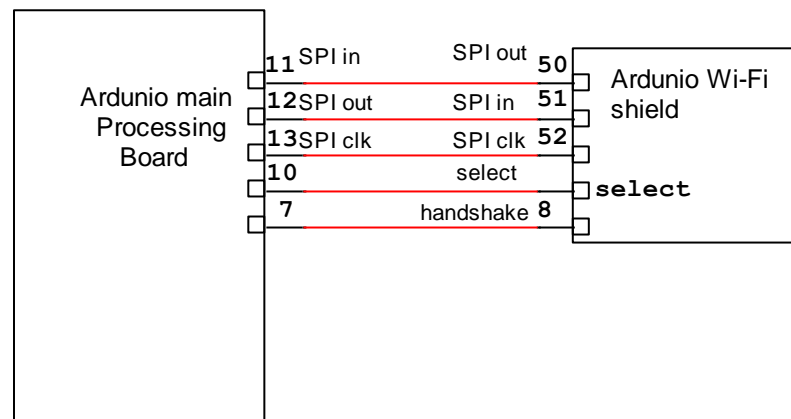


Figure 11. Connection Between Wi-Fi Shield and Main Processing Board

3.3 Humidity and Temperature Sensors

There are several types of sensors available in the market. Relative humidity strongly depends on the temperature of the surrounding air. Therefore it is required to keep humidity sensor and the temperature sensor very close as much possible. It is very ideal if both sensors are in the same chip as a one single sensor that measure both relative humidity and temperature. There are industry calibrated sensors as well as non-calibrated sensors available on the market. Calibrating the temperature sensor is quite easy but calibrating the relative humidity sensor requires more effort and instruments. Therefore, choosing an industry calibrated sensor is the preferred to reduce errors and save time.

Reliability, long term stability, fast response, number of pins needed to interface and needed processing power are some other factors considered to select the suitable sensor.

By considering these factors the SHT75 from Sensirion is chosen in this system.

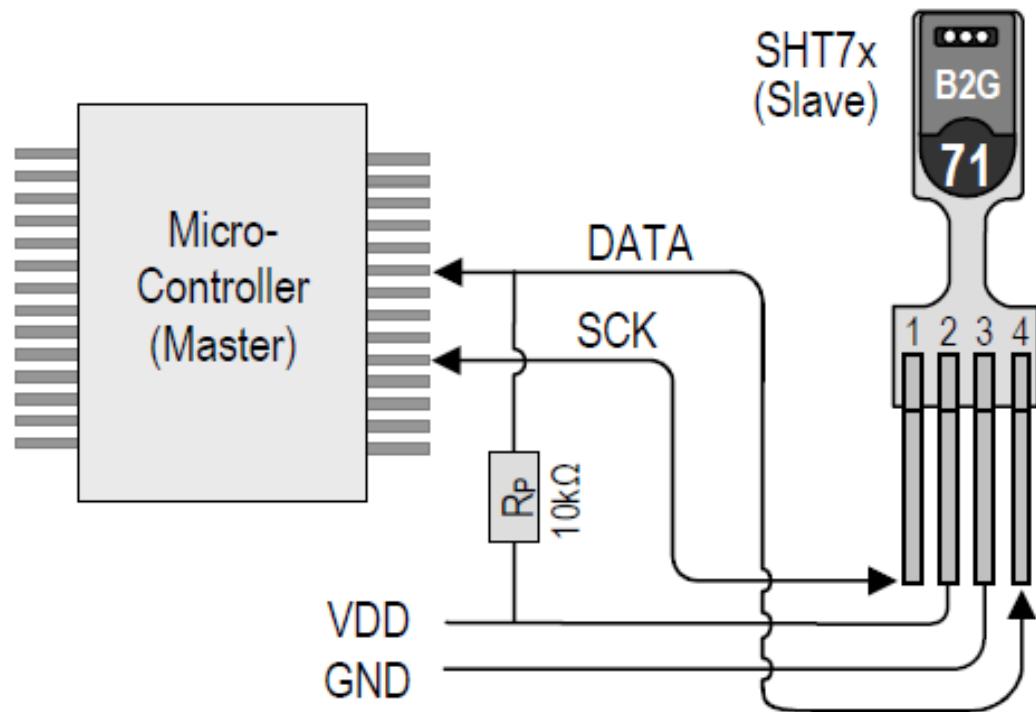


Figure 12. SHT75 Interfacing Diagram [27]

This digital sensor contains a capacitive sensor to measure relative humidity, a band gap sensor to measure the temperature, 14 bit A/D converter and serial interface circuit. All of these components are packed onto a single chip. Figure 12 shows the interfacing diagram with the main controller board. Pin 1 and 4 for clock and data transfer, respectively. The

data pin is bidirectional in which request and response are sent and received. Pin 2 is for connecting a positive power supply and pin 3 is for connecting ground.

This sensor is factory calibrated. Its response time is 55 millisecond, power consumption is $80 \mu\text{W}$ and has an operating range of 0 to 100% and -40 to $125 \text{ }^\circ\text{C}$ for relative humidity and temperature, respectively. Figures 13 and 14 show the maximal accuracy of temperature and relative humidity.

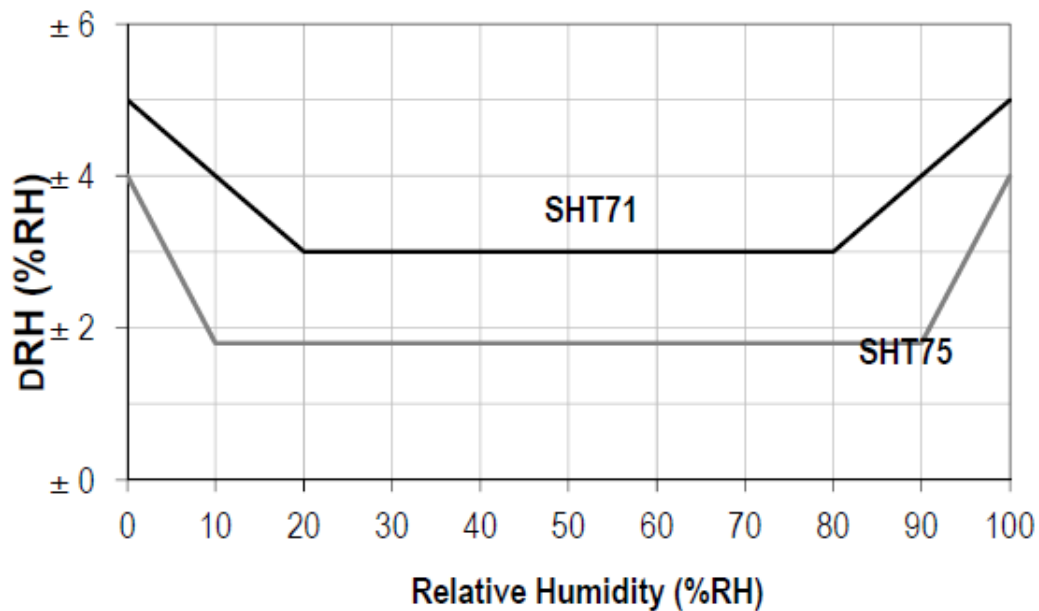


Figure 13. Maximal Accuracy Limit for Relative Humidity at 20 °C [27]

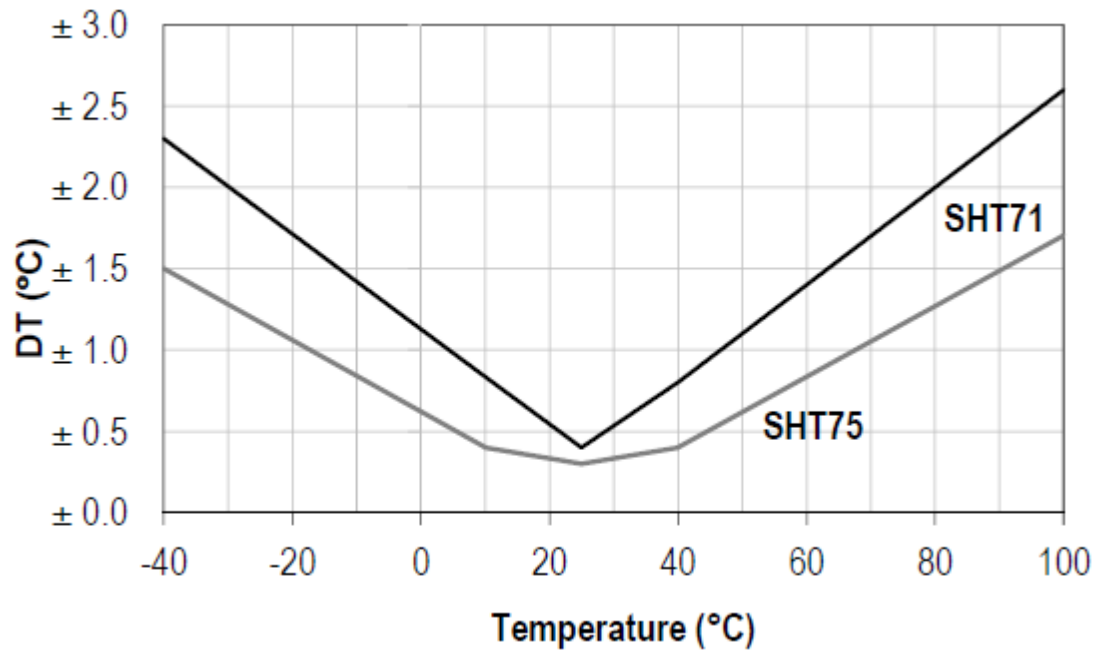


Figure 14. Maximal Accuracy Limit for Temperature [27]

For the relative humidity the error is ± 2 in the range of 10% to 90% and for the temperature the error is less than ± 1 °C in the range of -20 to 70 °C. The sensor and the microcontroller communicate through a 2-wire serial interface. This interface is not compatible with Inter-Integrated Circuit (I²C) communication. Because sensor SHT 75 does not support the addressing option; therefore, in this design a common clock line is used but a separate data line is used for each sensor (see Figure 16 below).

Serial Clock Input (SCK) is used to synchronize the communication between the microcontroller and the sensor. Data lines are pulled high by default by using pull-up resistors and the microcontroller or the sensor should pull down to change the level to low.

A logic level should be changed after a falling edge in SCK and it is valid after a rising edge of the SCK. This is how command is passed to the sensor by the microcontroller and data is passed to the microcontroller by the sensor. Figure 15 bellow show the overall view of the measuring sequence. Initially the command is send first and then the system waits for the data. Once the data is ready, the sensor pulls down the data line. After that, 12 bits of data can be read. Command bit patterns “00011” and “00101” are send to measure temperature and relative humidity, respectively.

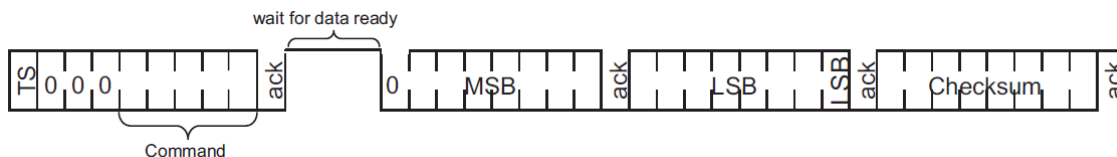


Figure 15. Measuring Sequence [27]

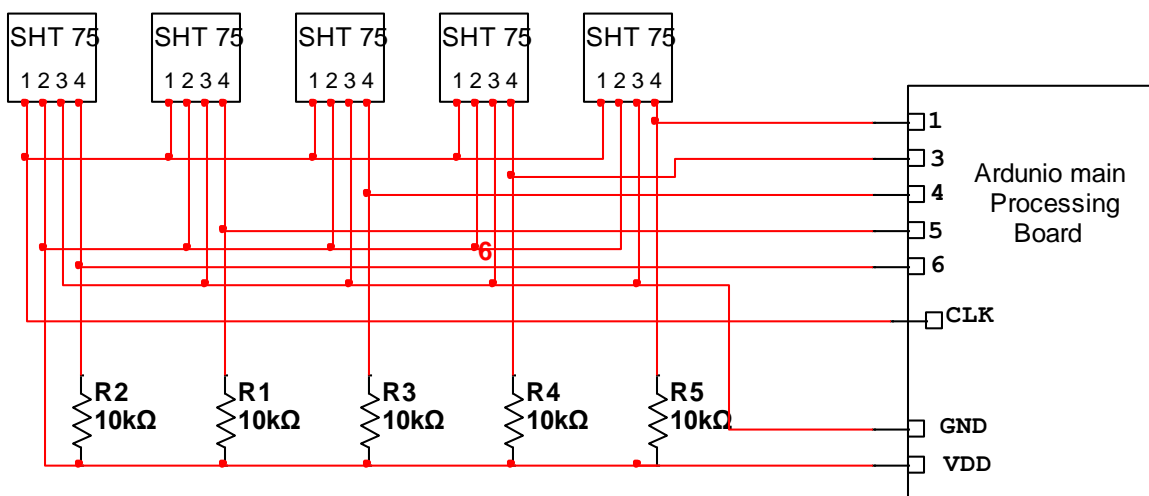


Figure 16. Circuit that Shows Connection Between Sensor and Processing Board

Figure 16 shows how all the sensors are connected to the main processor board. Pin 1 is the clock input of the sensor. All sensors clock inputs are connected together and this common clock input receives the clock signal from the main processor board. This clock signal is created by a program running in the processor. Each sensor output is pulled up using a 10 K ohm resistor. This pull-up resistor is required as the data line should be high by default and the microcontroller or sensor needs to pull down in order to change data. As shown in Figure 17, one of the sensors is placed in the sealed container in which the experiment is being carried out. A special USB airproof coupler is used to make a connection to the outside. As shown in Figure 18 humidity maintaining solution is poured onto the bottom of the box and then a solid plastic egg crate lighting panel (3/8" thick, 1/2" x 1/2" grid) is placed on top of it. On top of this plastic crate nylon mesh bags containing seeds are placed and the box is closed. Plastic screws on the box ensure an air-tight enclosure.

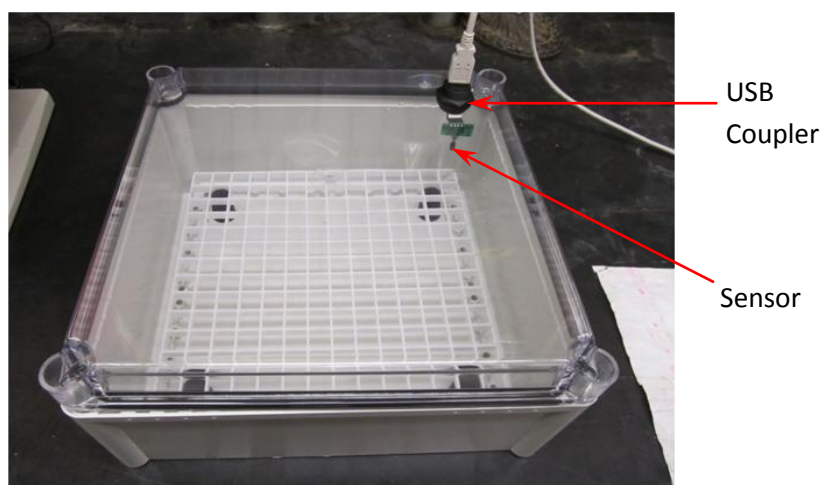


Figure 17. Sensors Connected Using a USB Air-Proof Coupler

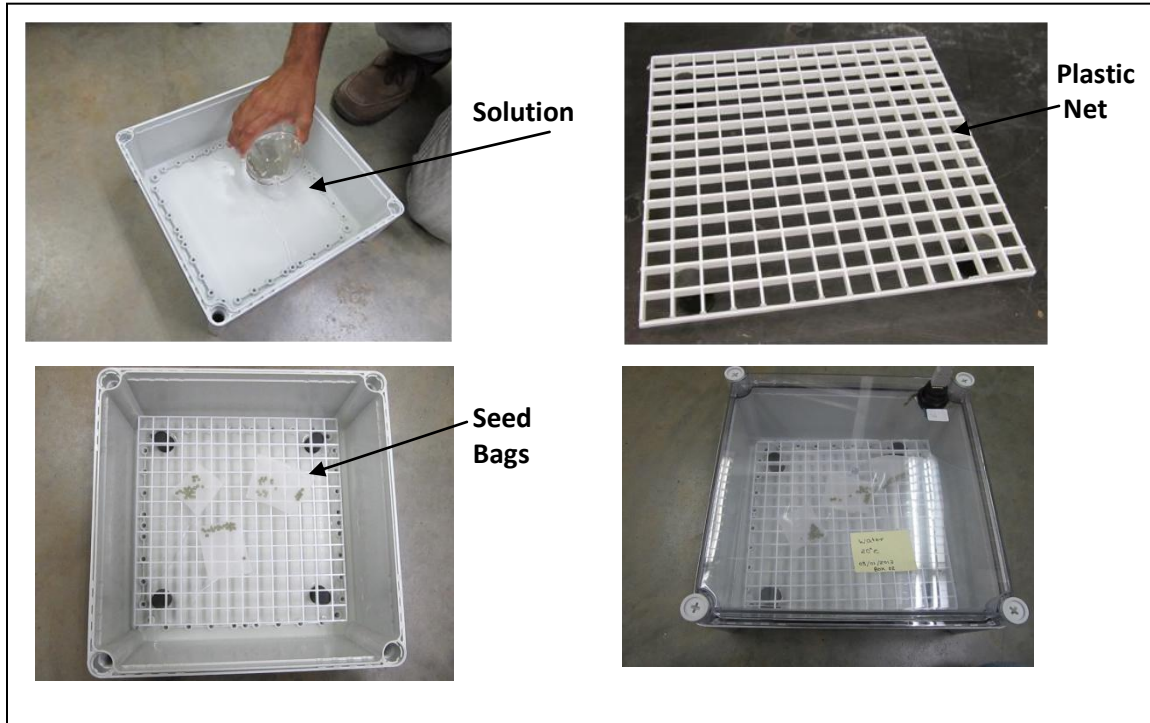


Figure 18. Setting up the Box for the Experiment

3.4 Creating Google Spread Sheet and form to log the Data

The system developed in this research is capable of both storing the data and plotting them in real time. To store the data Google drive is used. The developed system sends the data to the Google drive by submitting them in the Google form. Figure 19 shows the Google form created for the system.

The image shows a Google Form titled "Temperature/Humidity". Below the title, there is a text label "test1". The form contains six input fields arranged in three pairs. The first pair is labeled "Box_1_Temp(Celcius)" and "Box_1_RH %". The second pair is labeled "Box_2_Temp(Celcius)" and "Box_2_RH %". The third pair is labeled "Box_3_Temp(Celcius)" and "Box_3_RH%". At the bottom of the form is a "Submit" button.

Figure 19. Google Form Used to Enter Data

In order to create this form, a Google account is needed and then a person can login to the account. After the login, there will be a menu at the top of the screen named "Drive". Select that option and then click "Create". Then in the drop down menu select "spreadsheet". Figure 20 below shows the locations of the above tabs, they are circled. Once the spreadsheet is clicked, a new window will open in a new tab. This new window will display the spreadsheet. As shown Figure 21, click "Tool" and then select "Create Form," which allows the creation of the form as needed.

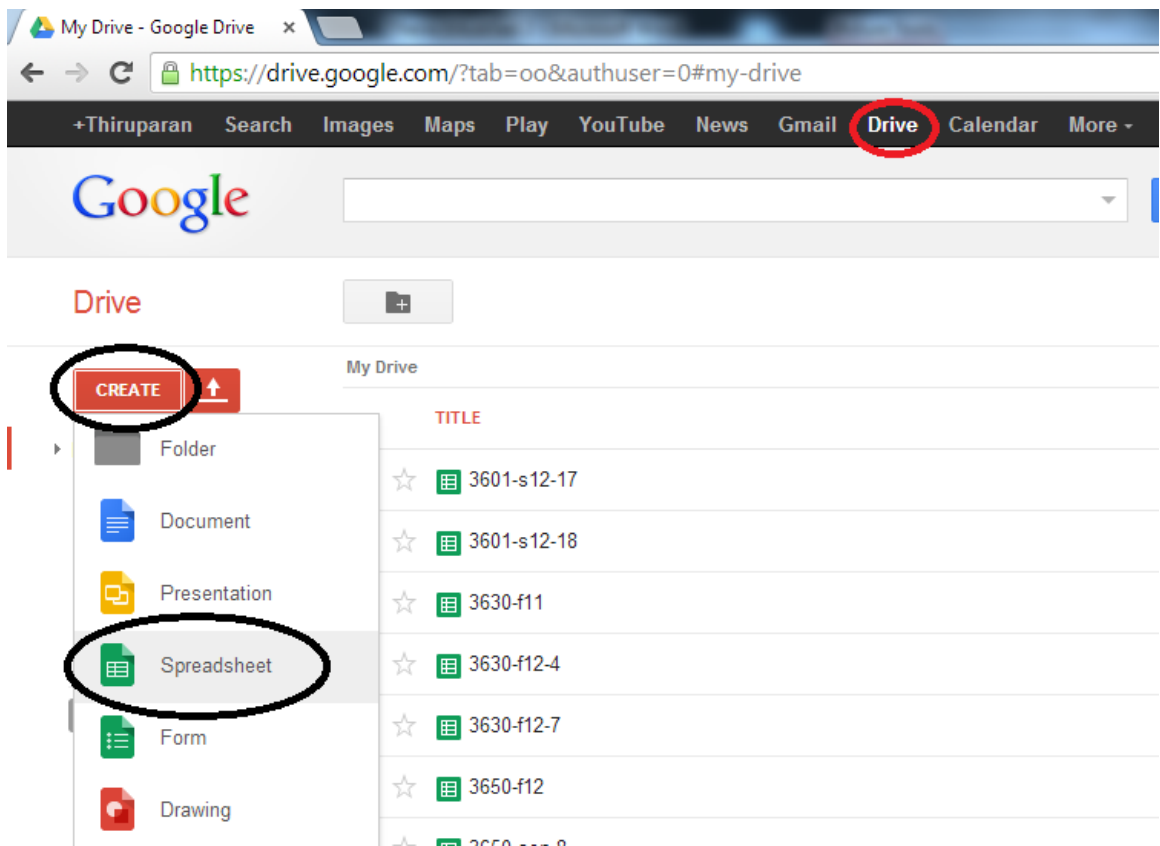


Figure 20. Tabs Associated with Creating Google Spreadsheet

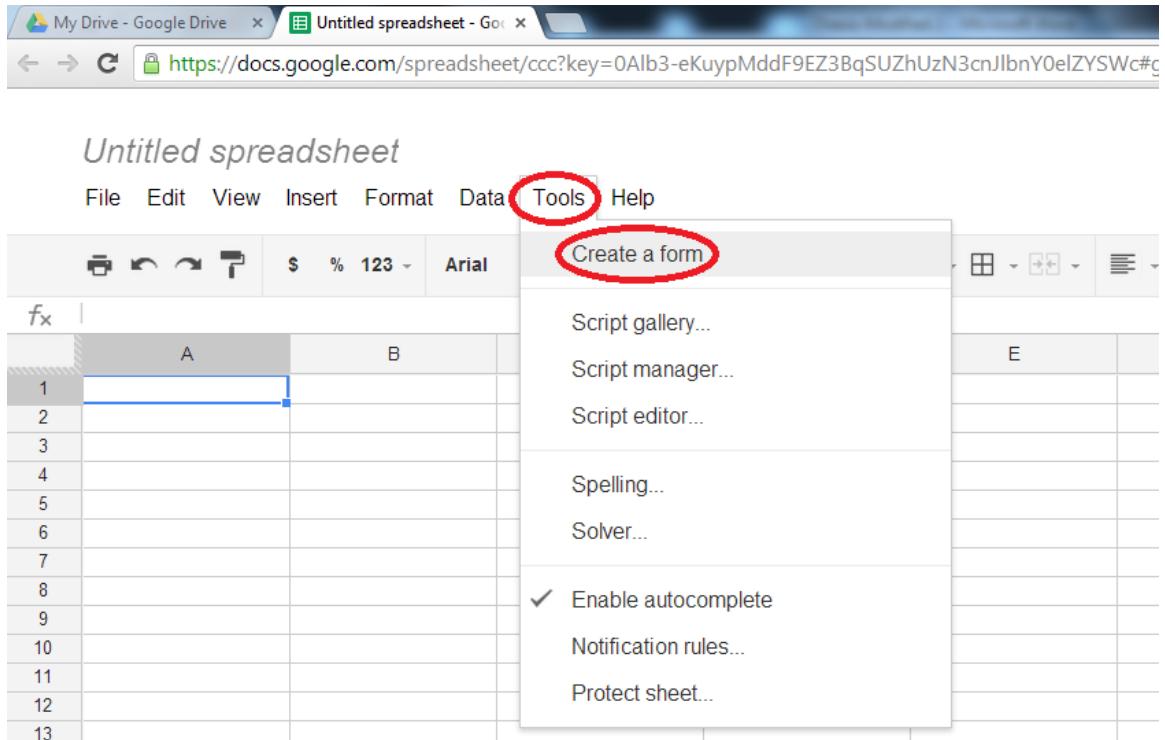


Figure 21. Tabs Associated with Creating Google Form

There are millions of Google spreadsheet created by users in the Google server. Each spreadsheet has unique key and it is identified by using this key. Figure 22 shows the spreadsheet created for the system and the URL of the spreadsheet. In the URL, the key can be found, which in this case is “0Alb3eKuyPMddGINaGRzdS0zUHNhaG8xdC0weGV6Umc.”

	A	B	C	D	E	F	G
1	Timestamp	Box_1_Temp(Celcius)	Box_1_RH%	Box_2_Temp(Celcius)	Box_2_RH%	Box_3_Temp(Celcius)	Box_3_RH%
2	5/10/2013 16:15:44	23.47	64.66709	29.68	94.59024	23.27	94.59024
3	5/10/2013 16:16:18	23.56	64.1284	29.66	94.64038	23.33	94.64038
4	5/10/2013 16:16:48	23.59	63.981	29.63	94.70922	23.34	94.70922
5	5/10/2013 16:17:19	23.57	64.035	29.44	94.77205	23.22	94.77205
6	5/10/2013 16:17:50	23.55	64.17733	29.14	94.78793	23.2	94.78793
7	5/10/2013 16:18:18	23.48	64.37332	28.78	94.8406	23.12	94.8406

Figure 22. Google Spreadsheet of the System

```

27 for="entry_0">Box_1_Temp(Celcius)
28 </label>
29 <label class="ss-q-help" for="entry_0"></label>
30 <input type="text" name="entry.0.single" value="" class="ss-q-short" id="entry_0"></div></div></div>
31 <br> <div class="errorbox-good">
32 <div class="ss-item ss-text"><div class="ss-form-entry"><label class="ss-q-title" for="entry_1">Box_1_RH %
33 </label>

```

Figure 23. Part of the HTML Code of Spreadsheet

Each text box that is created, a special name called entry name is given. The entry name of the text boxes can be found by looking at the HTML code of the spreadsheet. The entry name of the box normally looks like “entry.0.single” for the first text box and “entry.1.single” for the second text box and so on, but this should be confirmed by looking at the HTML code. Figure 23 shows the part of the HTML code of the form – i.e., “Box_1_Temp” that is named “entry.0.single”. By examining the code, each entry name is identified.

The main processor board sends data to the Google form, using a specific standard syntax URL. This URL contains the key of the form, entry name of the text box and the data.

This URL is passed to the wireless router through Wi-Fi shield and from there get routed to the Google form via campus WAN. The standard URL should be

<https://spreadsheets.google.com/formResponse?formkey=KEY &ifq&ENTRY NAME OF TEXT BOX =THE VALUE TO STORE &submit=Submit>. For this system, the developed key is “0Alb3-eKuypMddGINaGRzdS0zUHNhaG8xdC0weGV6Umc” and the entry name of the text box “Box_1_Temp” is “entry.0.single”. For example, to enter data 20 to text box “Box_1_Temp” the syntax will be:

“<https://spreadsheets.google.com/formResponse?formkey=0Alb3-eKuypMddGINaGRzdS0zUHNhaG8xdC0weGV6Umc &ifq&entry.0.single =20&submit=Submit>” .

The main processor will automatically grant the above URL string for each box.

3.5 Firmware for the Processing Board

Arduino Integrated Development Environment (IDE) is used for code editing, compiling and uploading programs. Firmware is written using Arduino programming language. This is the language created by Arduino open source community. It's a high level language similar to C++. One of the advantages of Arduino is that it is an open source platform.

As shown in the flowchart (Figure 24), once started, the system initializes all the variables and attempts to make connection with the Wi-Fi router. If connected, it will move to the next step and if it is not connected, it waits for 10 seconds and attempts to reconnect again. This is repeated until a connection to the Wi-Fi router is made. The name of the Wi-Fi network and password are hard coded into the system. After a successful connection to Wi-Fi connection is established, the main processor scans each sensor and records relative humidity and temperature values on the board. The main processor then creates the URL syntax using the box entry name and the data, and the system connects to the Google server. If it is not connected to the server, the processor waits for 10 seconds and tries to connect again. It keeps trying to connect until a connection is made to the Google server. Once it is connected to the Google server, it enters these values in the Google form using the syntax URL and then it disconnects from the server. Then, main processor waits for 15 seconds and measures the values again and transfers these values to the Google form. By default this Google form is connected to a Google spreadsheet, which contains a time stamp associated with each data point and the spreadsheet can be download into Microsoft Excel.

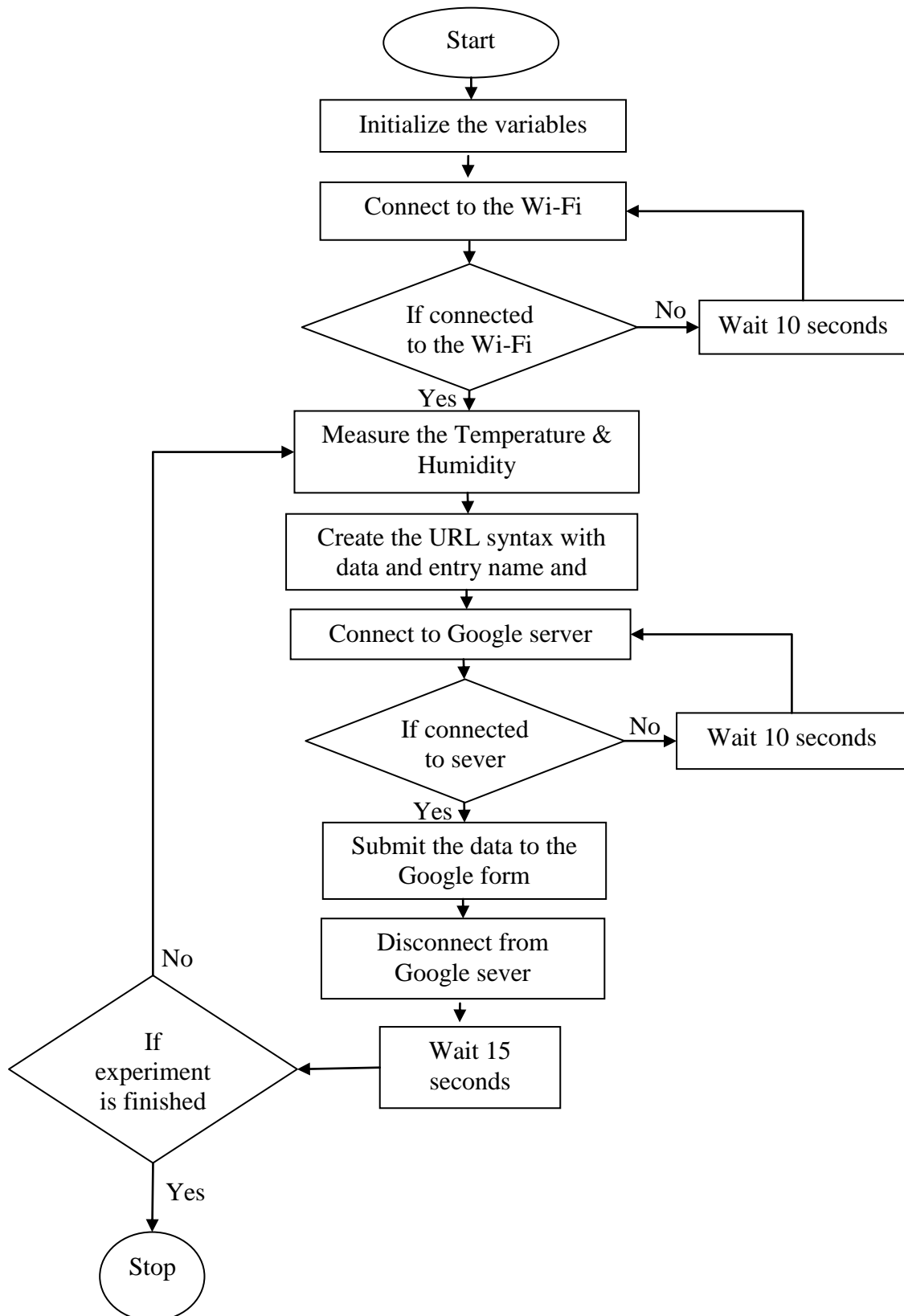


Figure 24. Flow Chart of the Firmware

3.6 Software for Real Time Plotting

Google Chart Tools are used to draw the graph. This is an open JavaScript library where we can define our own data sets and populate the graph. Since Google spreadsheet is used to store the data, Google query method is used to retrieve the datasets, and the arguments for that method are the URL of the spreadsheet and the range of the column to be populated as data.

To plot a graph using Google Application Programming interface (API), first the horizontal and vertical axes had to be created and then the method AreaChart was used to define the HTML division names for the graph. The draw method plots the graph by taking the real time data and the options as argument. Since this is a real time system, data in the Google spread sheet is keep updated every 3 seconds with new sensor values. To reflect this new data in the graph “TheSet interval” function is called with the update interval 3 seconds. This ensures the real time monitoring.

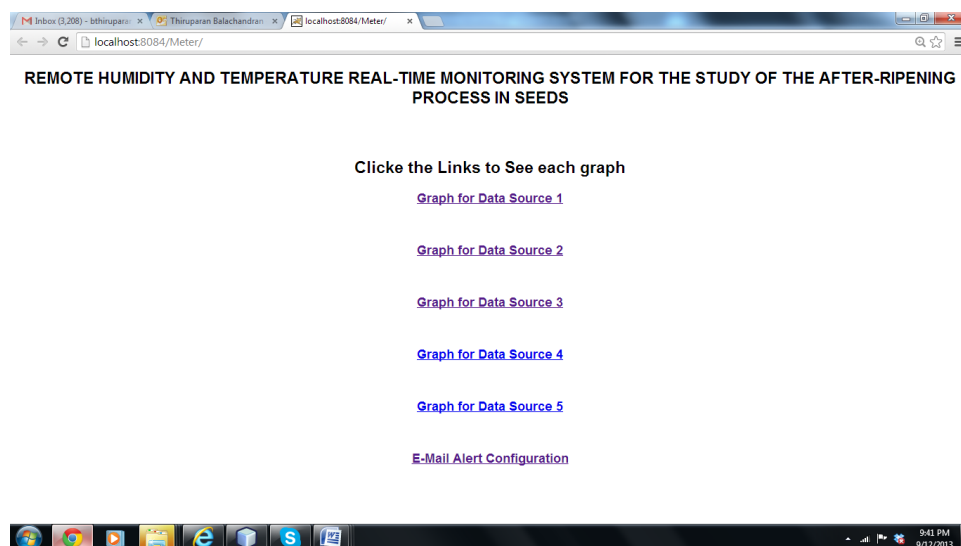


Figure 25. HTML Page to View the Data as a Graph

Figure 25 shows the HTML page created to view the data in real time as a graph by clicking the appropriate link. This enables a user to view data from any part of the world if an internet connection is available.

3.7 E-mail Alert of the System

Figure 26 below shows the screenshot of the E-mail Sender Application. This application is created using Java Mail Application Programming Interface (API) and Simple Mail Transfer Protocol (SMTP) to delivers the e-mail to the E-mail server. In this interface, the user can set the alert receiver and the upper and lower threshold values of each parameter. This application reads the latest data in the Google spreadsheet and checks whether it is a new value or an existing same value. If it is a new value, the program checks with the user threshold value to ensure the value is in the range. If the new value is not within the range, the program sends an e-mail alert to the user. This e-mail alert contains the seed box name, current temperature and relative humidity data, and the user threshold value. Figure 27 below show the screenshot of the sample alert e-mail.

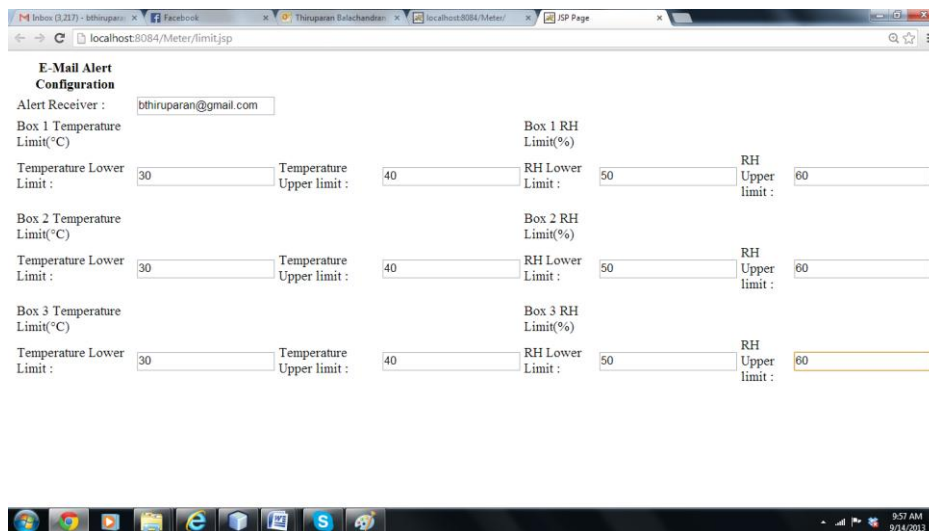


Figure 26. E-mail Alert Configuration Page

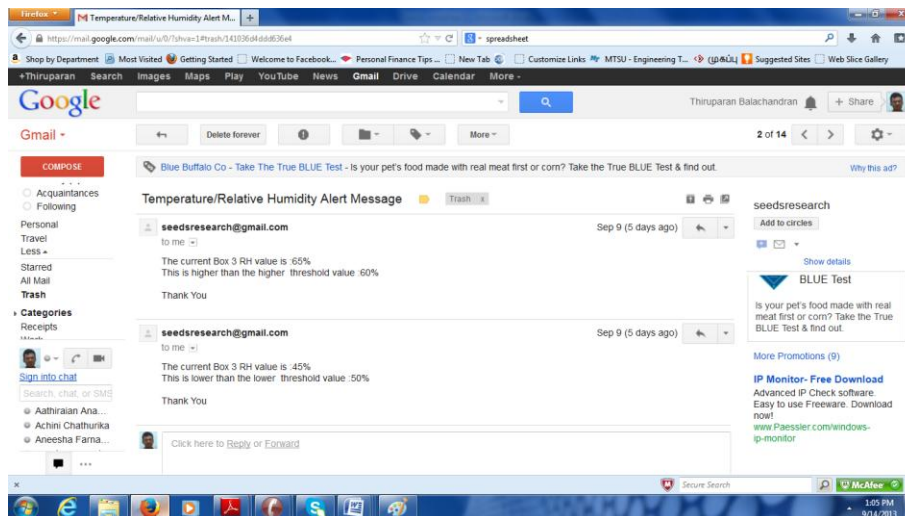


Figure 27. A Sample E-mail Received Through this System

3.8 The Complete System

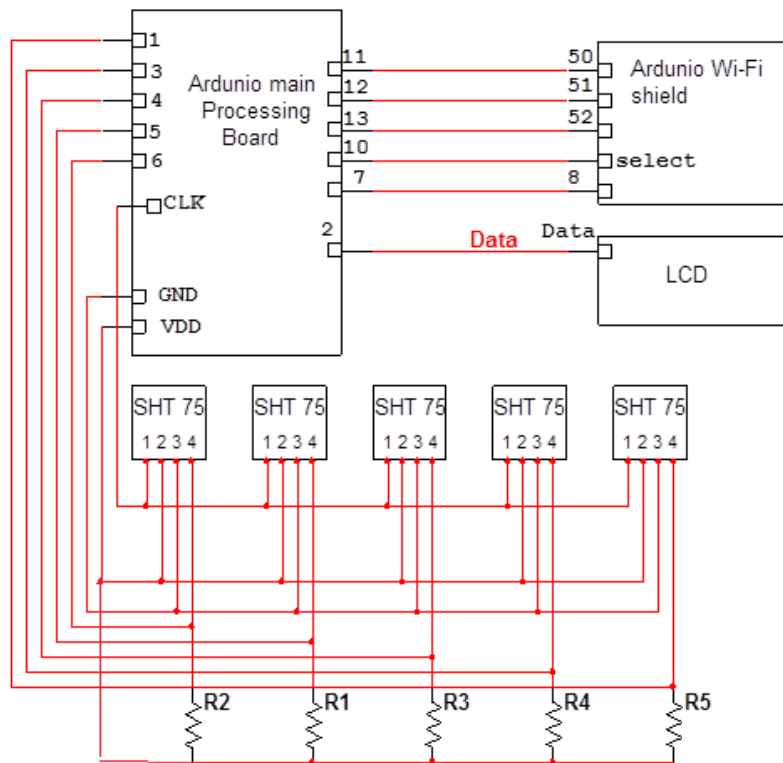


Figure 28. Complete Circuit of the System

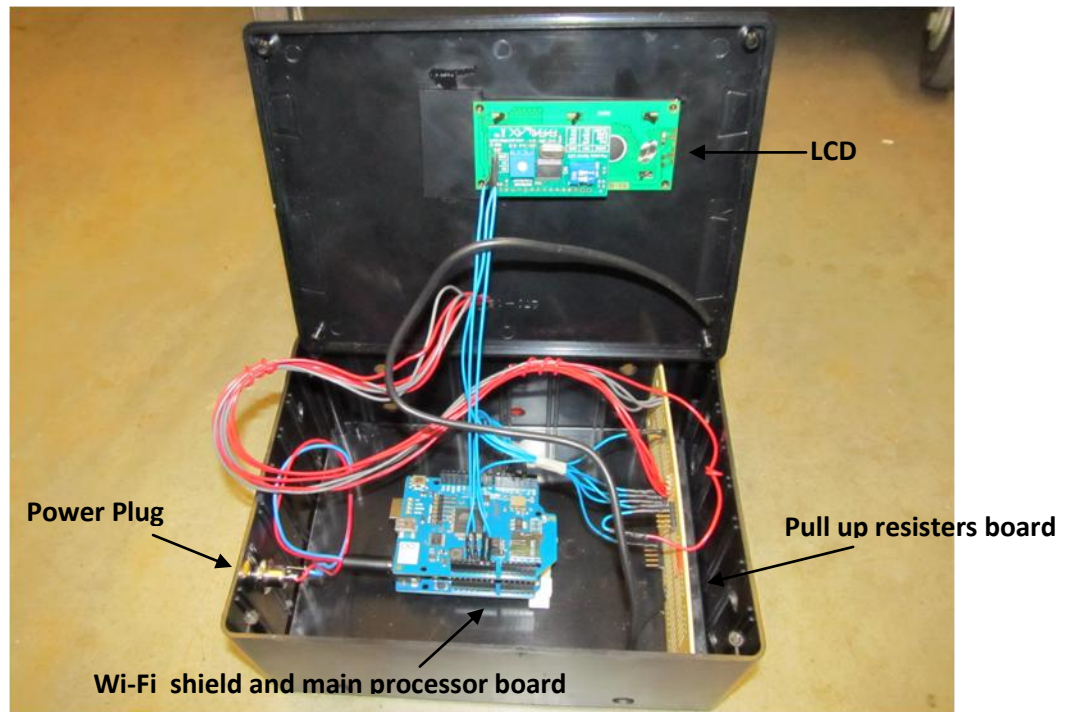


Figure 29. Inside the Case

Figure 28 shows the complete circuit of the system. Resistors R1 – R5 are 10K. Figure 29 shows how it is placed into the system enclosure. The main processor is placed in the bottom and the Wi-Fi shield is placed on top of it. The board containing pull up resistors for the sensors is placed on the side, the LCD is placed on the top side, and air holes for ventilation are made on each side in the bottom.



Figure 30. Setup of the Complete System

Figure 30 shows the setup of the complete system. To make user friendly connections between the sensors and the device USB ports are used. An LCD is added to the system to display the device states, which are shown in Figure 31. Once the system is turned on, the device initializes all variables and functions and attempt to connect to the Wi-Fi and display whether the connection is made. After the device connects to the Wi-Fi, it measures each box's relative humidity and temperature and sends the data to Google spreadsheet. There are 7 USB ports available; in the current design only five ports are used to connect five separate seed boxes. Switches are not used in the system, which automatically detects which USB ports are connected to the seed boxes and measures the temperature and relative humidity of each of the boxes.



Figure 31. LCD Display Showing States of the System

Troubleshooting information

Table 2. Troubleshooting Information

Issue	Fixes
No Display in LCD	Check the Power supply
Display in LCD is “Wi-Fi not Connected”	<ol style="list-style-type: none"> 1. Check Wi-Fi router 2. Unplug the power adapter of the Wi-Fi router and plug it after 30 seconds 3. Unplug the systems power supply and plug it after 30 seconds
Negative values for relative humidity	Check connection between the system and the seed box

Above Table 2 gives the details of the common issues and fixing steps. If the device is getting power there will be at least some display. In case of no display, then it might be a problem in the power supply. In this case check power supply and connections. If the display is “Wi-Fi not connected” it should to be some issues with Wi-Fi router. To fix this problem, follow the steps as described in the table. If the connection between sensor and the device is not good, device will display negative value for relative humidity. In this cause check the connecting USB cable. If the cable is damaged, replace with new cable. When cleaning the container, take care that sensor not to get wet.

Device specification

Main device dimension: 8 x 6 x 3 inches, Seed box dimension: 11 x 11 x 5 inches

Power: 9 - 12 V, Current: ~ 250 mA while sending data, 50 mA while in idle state

CHAPTER 4

RESULTS

The sensor system was tested in closed polyethylene electrical boxes with various relative humidity values. The box contained seeds to simulate an after-ripening or longevity experiment. Three different set of experiments were carried out.

The first set of experiments was conducted to study the controlling property of relative humidity of different concentrations of LiCl at 20 °C. A gradient in relative humidity was created across five containers. The containers were placed in a temperature and light controlled incubator set at constant 20 °C with a 14 hr photoperiod. Nine green gram (*Vigna radiata*) seeds, which are used in a variety of food dishes in many countries, were placed in each box.

The second set of experiments was carried out to study the effect of the photoperiod. In the incubator, fluorescent light was used simulate the photoperiod. Three different concentrations of LiCl were used and nine green gram seeds were placed in each box. Temperature was maintained constant at 20 °C. Photoperiod is being toggled to 14 hours of light and 10 hours of darkness continuously for two days.

In the third set of experiments, a constant amount of LiCl was used while the temperature was increased from 10 °C to 50 °C at 10 °C intervals. Each temperature was maintained for 24 hours. In this setup 14 hours of light and 10 hours of darkness is used.

During these experiments, it was observed that the system successfully updated the relative humidity and temperature of the boxes in the Google spreadsheet and the software plotted the graph in real time. Moreover the e-mail alert functionality of the system was also tested.

4.1 Relative Humidity Controlling Property of Different Concentrations of LiCl at 20 °C

To study the effect of LiCl on relative humidity, five different concentrations of LiCl were used. Five separate seed boxes were used for this purpose. These solutions were poured onto the bottom of each box. Nine grams of green seeds (*Vigna radiata*) were also placed in each box. Figure 32 shows the different amounts of LiCl and the expected relative humidity at 20 °C. These boxes were placed in the incubator for 24 hours. The photoperiod was also set to 24 hours. Figures 32-35 below shows the real-time graphs of relative humidity and temperature of each boxes. These graphs are obtained using the software developed in this research.

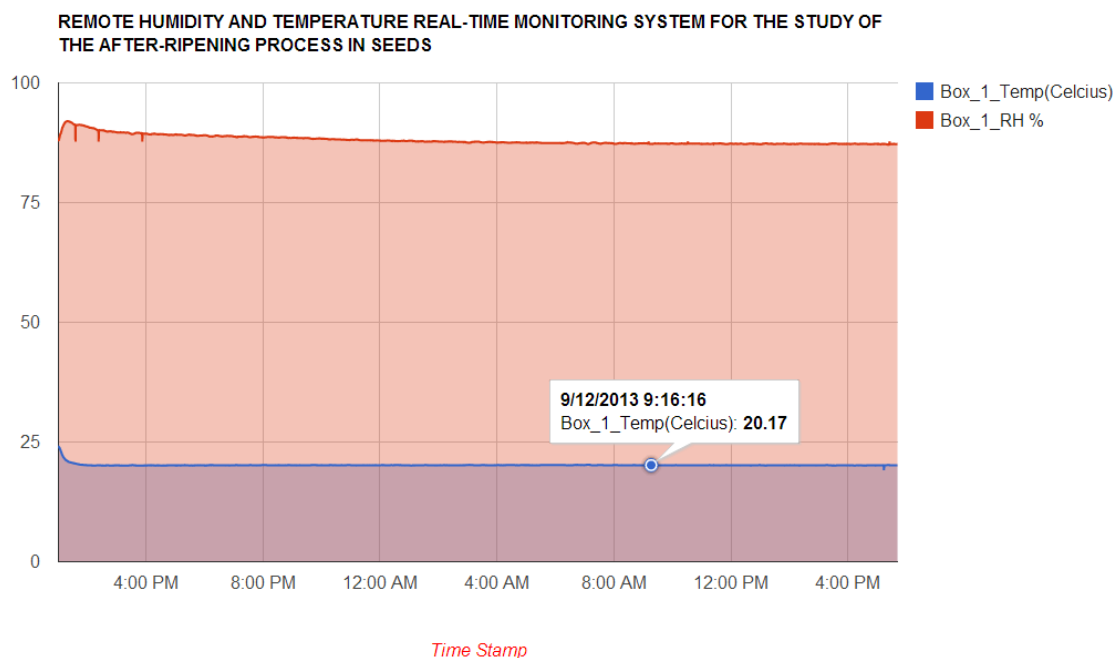


Figure 32. Relative Humidity and Temperature Measurements in Box 1 Using 26 g LiCl +200 ml Water Solution

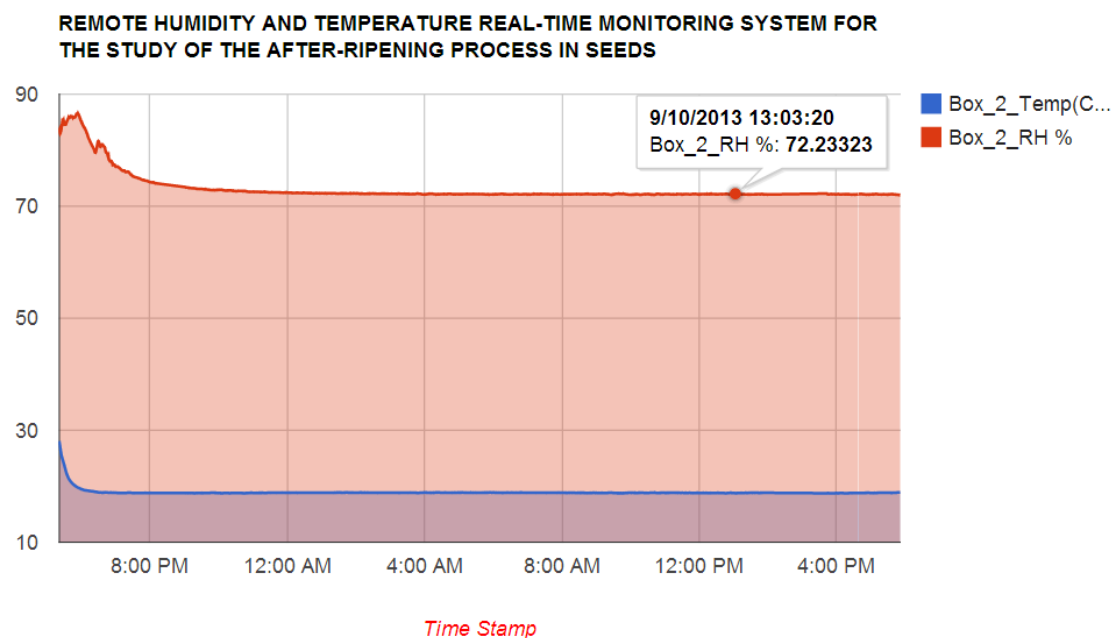


Figure 33. Relative Humidity and Temperature Measurements in Box 2 Using 50 g LiCl +200 ml Water Solution

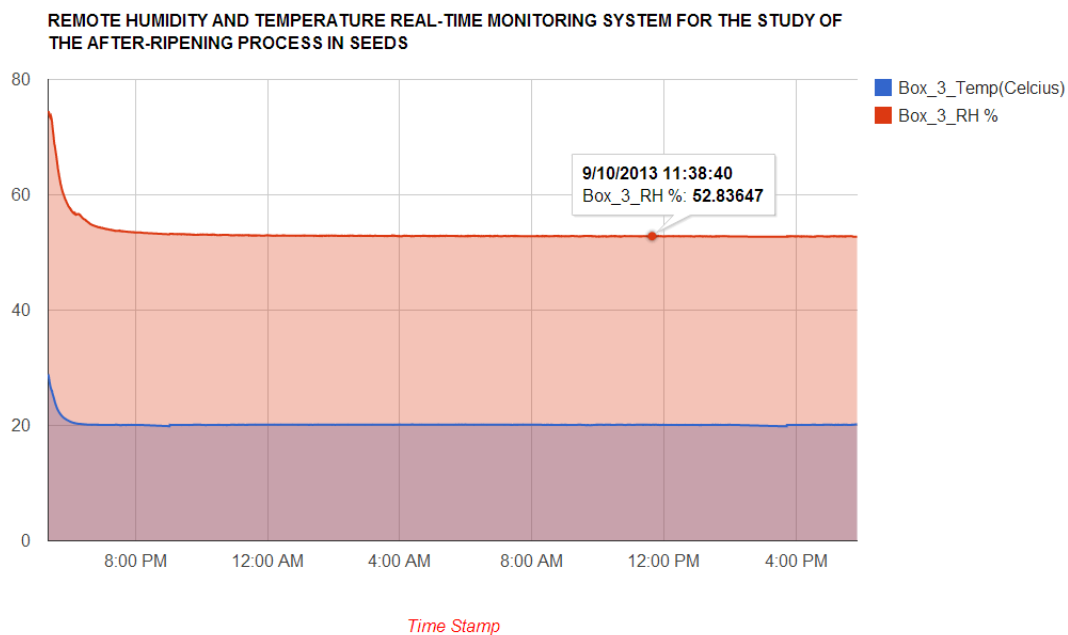


Figure 34 . Relative Humidity and Temperature Measurements in Box 3 Using 74 g LiCl + 200 ml Water Solution

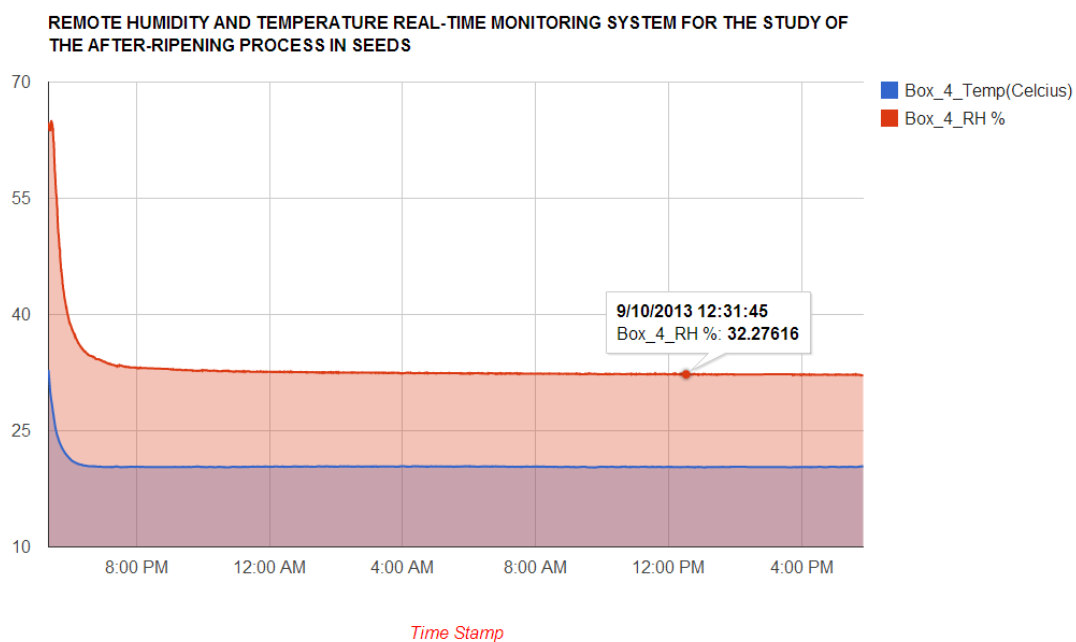


Figure 35 . Relative Humidity and Temperature Measurements in Box 4 Using 104 g LiCl +200 ml Water Solution

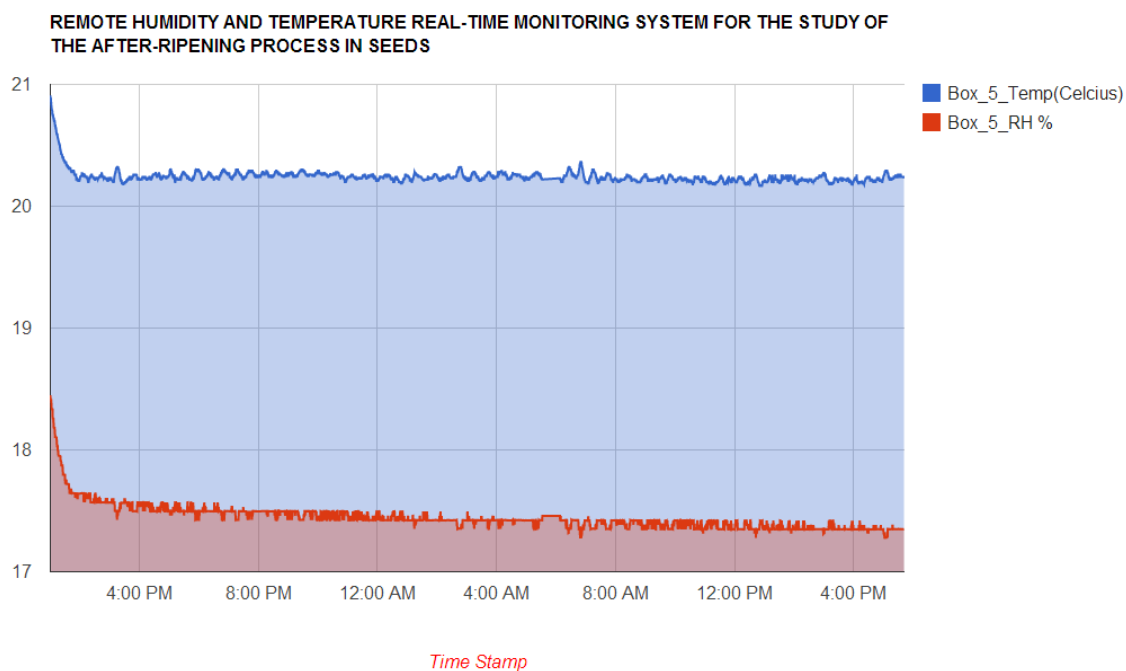


Figure 36. Relative Humidity and Temperature Measurements in Box 1 Using 147 g LiCl +200 ml Water Solution

Table 3 below shows the expected and experimental results. The experimental results were approximately the same as the expected results. Average deviation of the relative humidity is between 2.23 to 2.70%. This accuracy is recommended for seed experiments. As the concentration of LiCl increased, the relative humidity of the boxes varied with minimum temperature change of 0.50 °C. The temperature change of 0.50 °C may be attributed to the placement of seeds boxes in different rows in addition to the use of heating and cooling fans on the roofs of the incubator.

Table 3: Different Concentration of LiCl and the Resulted Relative Humidity

Box Number	Amount of LiCl in 200 ml of distilled water (g)	Average temperature inside the box (°C)	Expected Relative Humidity (%)	Achieved average relative humidity (%)	Deviation
1	26	20.10	85	87.16	+2.16
2	50	20.54	70	72.23	+2.23
3	74	20.34	50	52.70	+2.70
4	104	20.08	30	32.27	+2.27
5	147	20.16	15	17.50	+2.50

4.2 Effect of the Photoperiod and Dark Period

Three different concentrations of LiCl and nine grams of green seeds were placed in each box. A constant temperature was maintained at 20 °C. The photoperiod was toggled between 14 hours of photoperiod and 10 hours of dark period continuously for two days. Different relative humidity levels of 50, 70, and 35 % were maintained in three separate seed boxes.

4.2.1 Maintaining 50% Relative Humidity

Box 1 was set with a 74 g LiCl in 200 ml water.. This solution was expected to maintain 50 % RH in the box [18]. Figure 37 below shows the real-time plot of the relative humidity and temperature in this box.

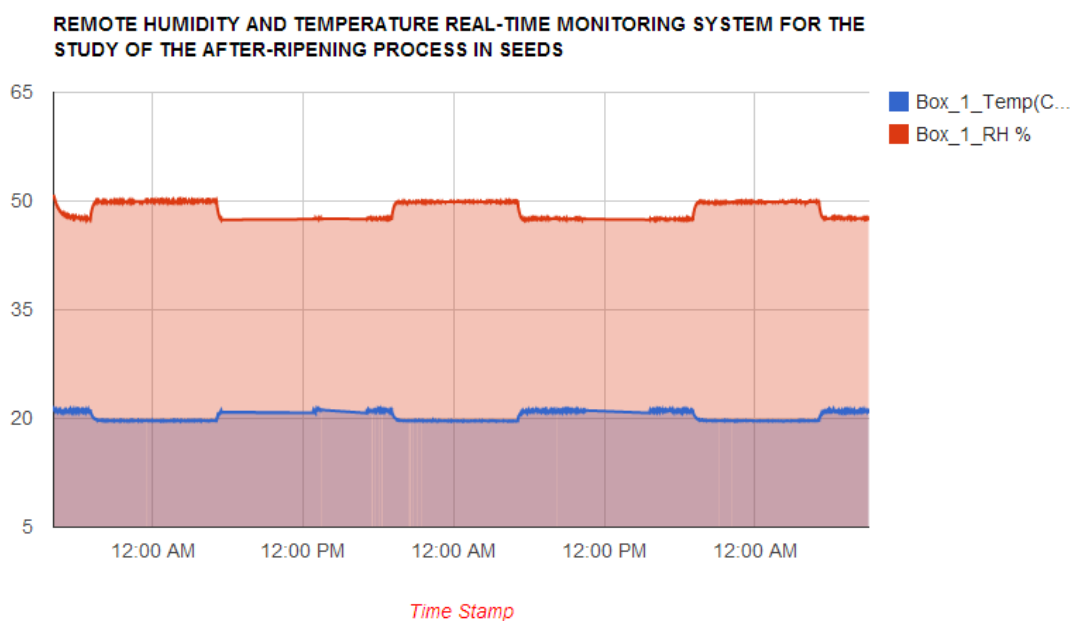


Figure 37. Relative Humidity and Temperature Measurements in Box Using 75 g LiCl +200 ml Water Solution

Figure 37 can be used to get an exact reading of what by pointing the mouse on plot line.

This system is also capable of downloading the data into a Microsoft Excel sheet.

Furthermore, data analysis could be done using the downloaded data. As seen in Figure 37, there is a small fluctuation in temperature and relative humidity.

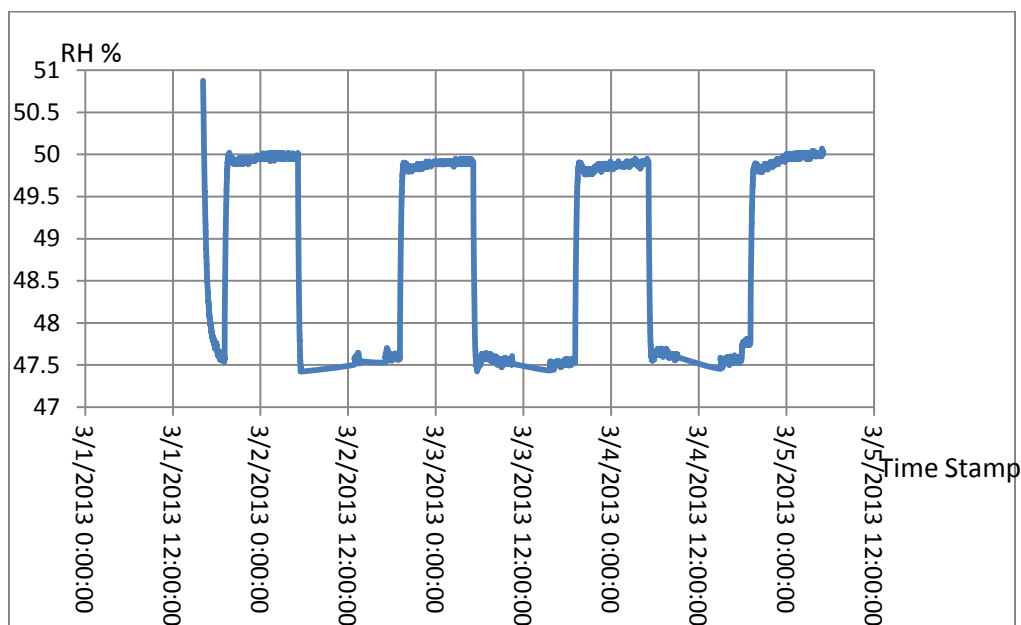


Figure 38. Relative Humidity Measurement of the Box Using 75 g LiCl + 200 ml Water Solution

Figure 38 shows the pattern fluctuation in the relative humidity. Once the LiCl solution reached equilibrium, the major change in relative humidity occurred during the transition from dark-period to photoperiod. The average relative humidity during the dark-period and photoperiod were 47.42% and 50.02%, respectively.

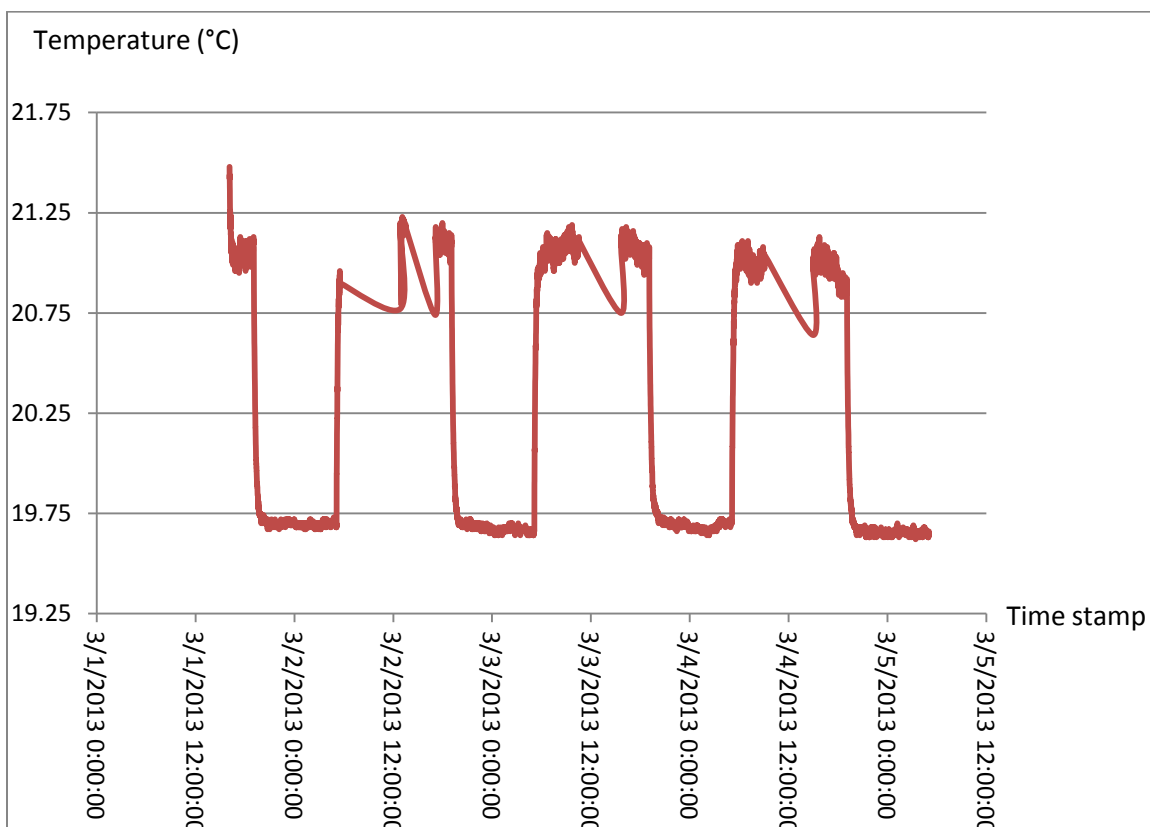


Figure 39. Temperature Measurement of the Box Using 75 g LiCl + 200 ml Water Solution

Figure 39 shows the fluctuation in temperature with time. The major temperature change occurred during the transition from dark-period to photoperiod resembling the change that occurred with relative humidity. The average temperatures during dark-period and photoperiod were 19.72 °C and 21.23 °C, respectively, with an increase of 1.39 °C during the transition.

The major point that can be derived from this is that the sensor placed inside the box is not affected by light. Fluorescent lights are used in the incubator to implement the photoperiod. Thermal radiation from fluorescent lights is the main cause for the major

fluctuation in the temperature of the seed box. The temperature controlling feedback system of the incubator is not detecting these changes and adjusting it accordingly. This same temperature fluctuation is observed not only inside the seed box but also inside the incubator. Therefore, there is no apparent relationship between the temperature fluctuation and chemical (LiCl). Since relative humidity is also dependent on the temperature, the relative humidity fluctuation is attributed to temperature fluctuation.

In this seed box, the temperature is maintained at approximately 19.70 °C and the relative humidity is maintained at 49.92%. Relative humidity is expected to be at 50%. Fluctuations are less than 0.5 % and 1.19 °C for relative humidity and temperature, respectively. These small fluctuations do not have an impact on seed experiment.

4.2.2 Maintaining 70% Relative Humidity

In the second box, a solution of 50 grams of LiCl in 200 ml water was used. This solution was expected to maintain the relative humidity at 70% for a temperature of 20 °C [12]. Figure 40 shows the real-time plot of the software for temperature and relative humidity.

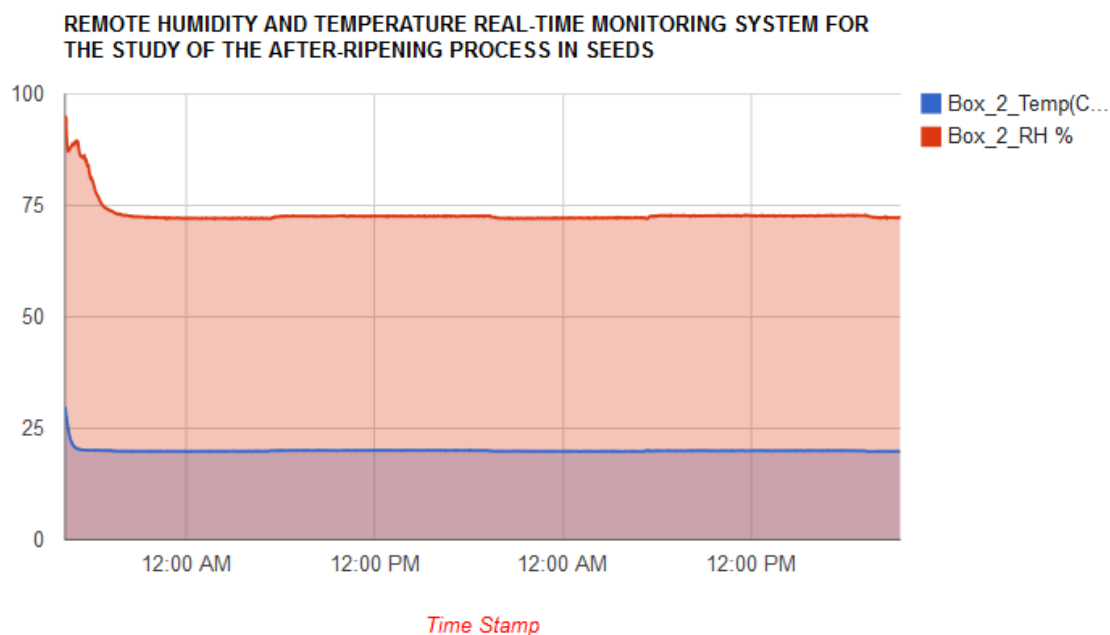


Figure 40. Temperature and Relative Humidity Measurement of the Box Using 50 g LiCl + 200 ml Water Solution

By using the downloaded data, further analysis was done. Figure 41 shows the fluctuation pattern with relative humidity.

In this seed box also, a major change in relative humidity happened during the transition from the dark-period to the photoperiod. Average relative humidity during dark-period and photoperiod were 72.64% and 72.21%, respectively.

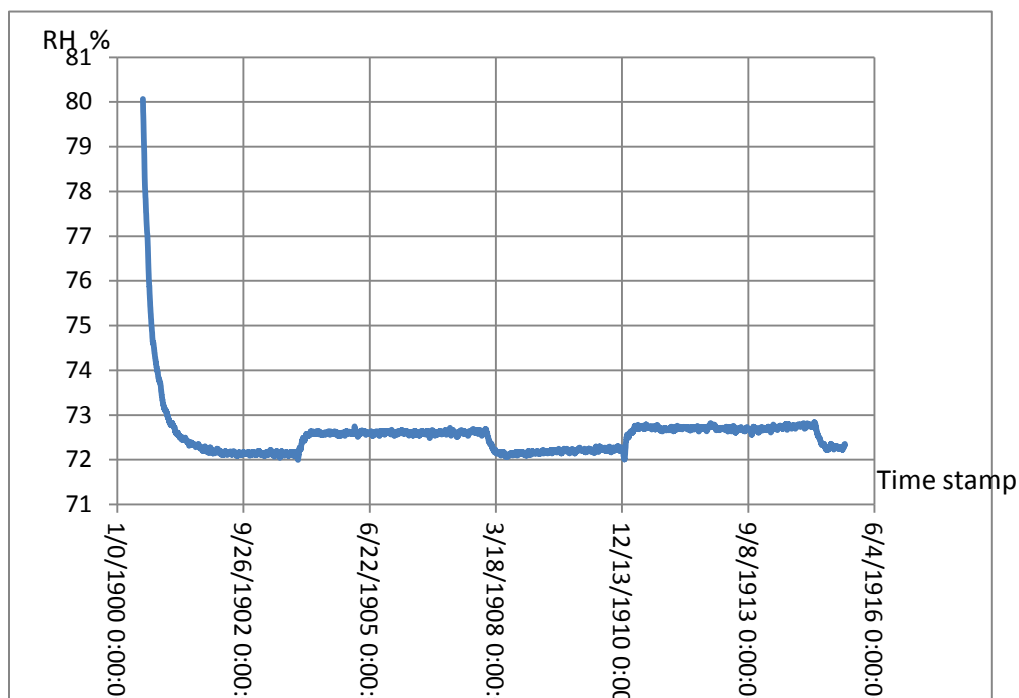


Figure 41. Relative Humidity Measurement of the Box with 50 g LiCl + 200 ml Water Solution

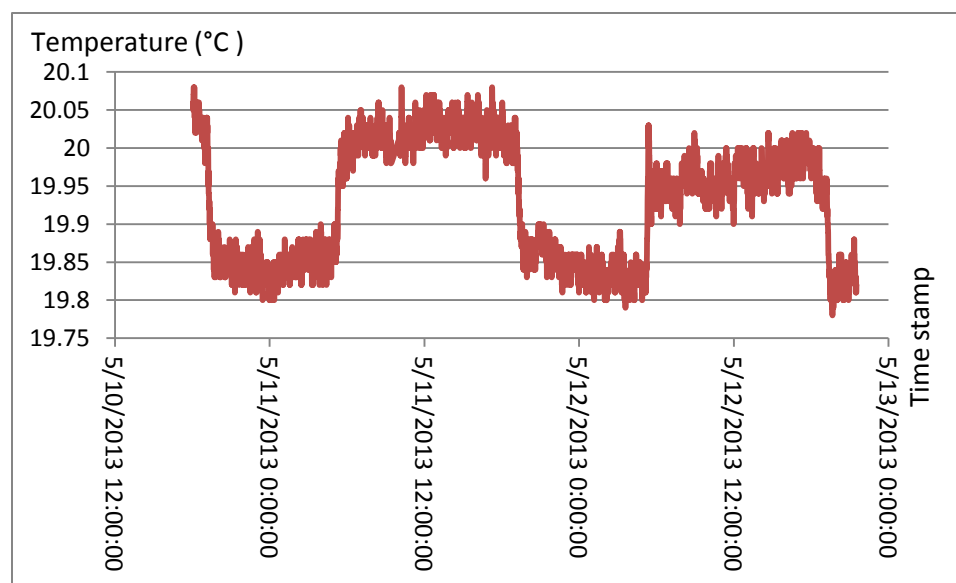


Figure 42. Temperature Measurement of the Box with 50 g LiCl + 200 ml Water Solution

Figure 42 above shows the temperature in this box. We can see same fluctuation pattern in this seed box as in the seed box 1. Average temperature during dark-period and photoperiod were 19.84 °C and 20.00 °C, respectively. There was an increase of 0.16 °C during the transition. Overall, the average temperature and the relative humidity in the box were 19.93 °C and 72.55 %, respectively. However, the average relative humidity was expected to be 70 % in this box.

4.2.3 Maintaining 35 % Relative Humidity

This box was set with a 100 g LiCl in 200 ml water. This solution was expected to maintain 35 % RH in the box at 20 °C [12].

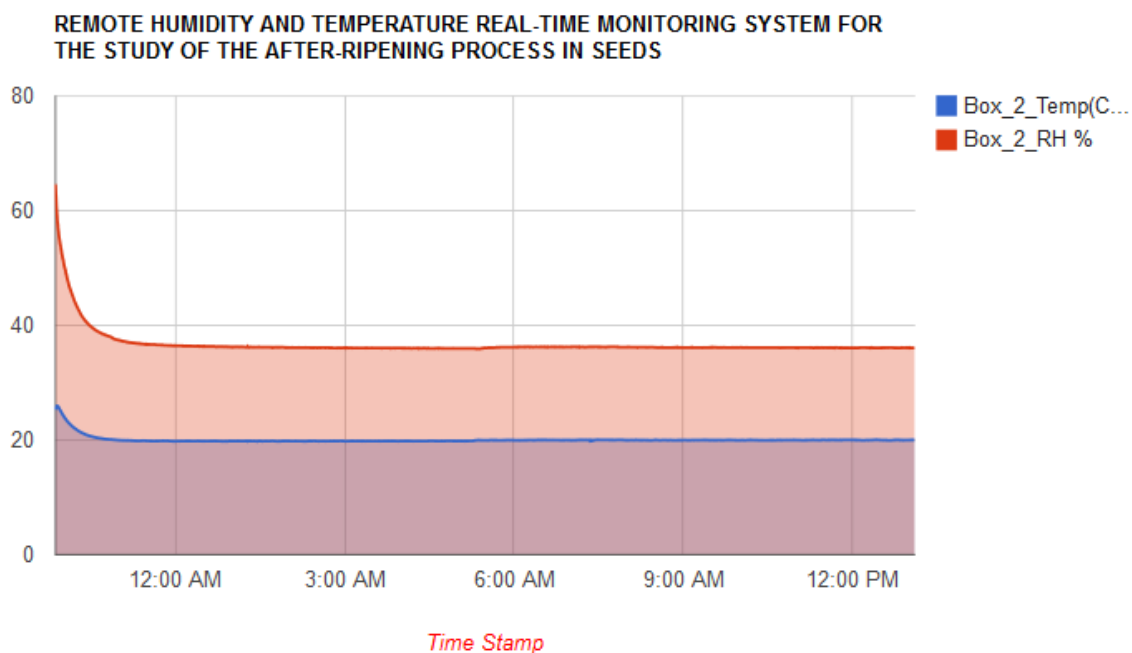


Figure 43. Temperature and Relative Humidity Measurement of the Box Using 100 g LiCl + 200 ml Water Solution

Figure 43 above shows the real-time plot provided by the system. Figures 44 and 45 show the relative humidity and temperature pattern in separate graphs.

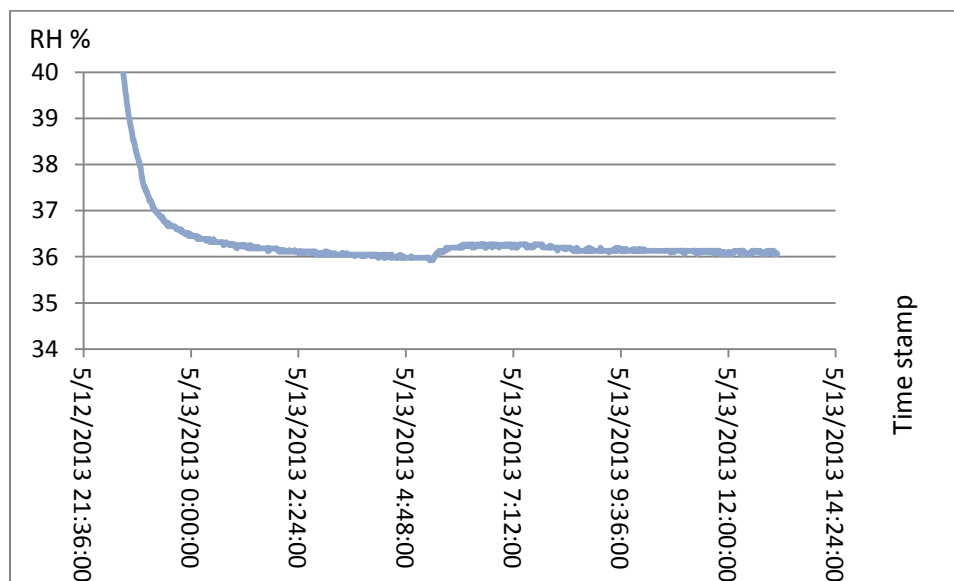


Figure 44. Relative Humidity Measurement of the Box Using 100 g LiCl + 200 ml Water Solution

Once the equilibrium was reached the relative humidity in this box was 36.09 %.

However, the relative humidity was expected to be 35 %. Furthermore, in this seed box also major change in relative humidity occurred during the transition from dark to photoperiod.

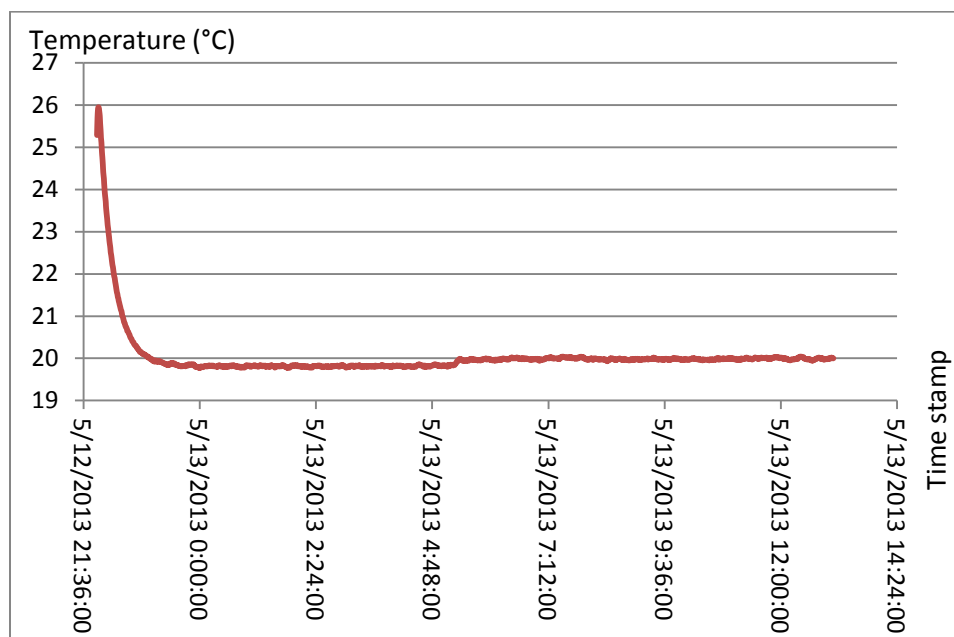


Figure 45. Temperature of the Box Using 100 g LiCl + 200 ml Water Solution

Figure 45 shows the temperature of the box. After equilibrium average temperature reached 19.91°C . Similar fluctuations were observed in this box as compared to the previous boxes.

4.3 Maintaining 100 % relative humidity

If a closed environment is in contact with pure water, it is expected to maintain 100% RH. This case was examined in this research by using 200 ml of pure distilled water.

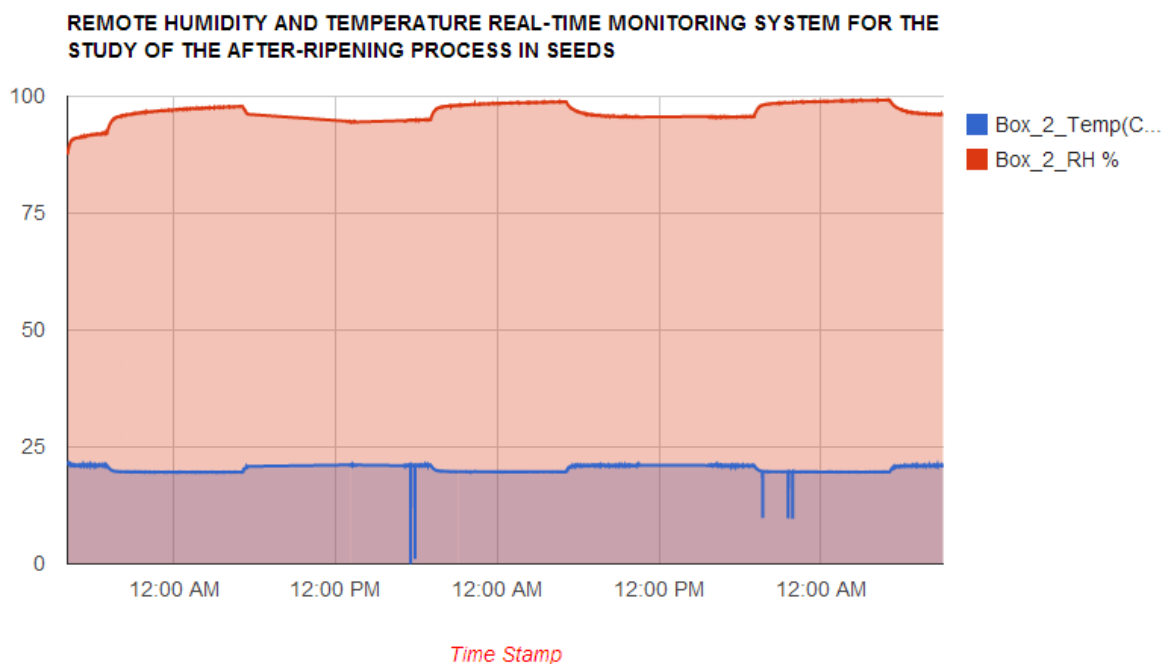


Figure 46. Relative Humidity and Temperature Measurements in the Box Which Had Distilled Water Only.

Figure 46 shows the graph provided by the system developed in this research. Fluctuation pattern of relative humidity and temperature are plotted in separate graphs (Figures 47 and 48). These graphs are plotted based on the downloaded data from the system.

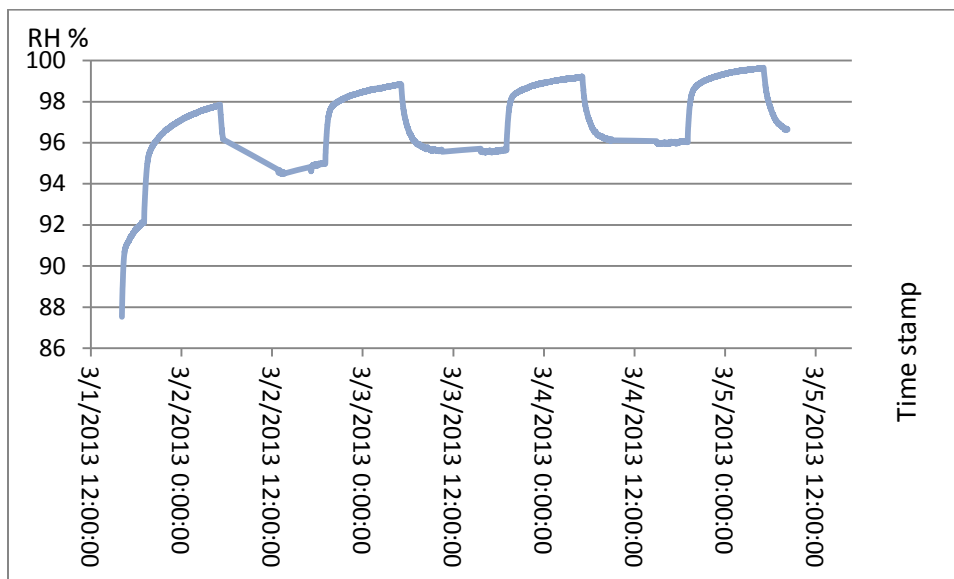


Figure 47. Relative Temperature of the Box with 200 ml Distilled Water Only

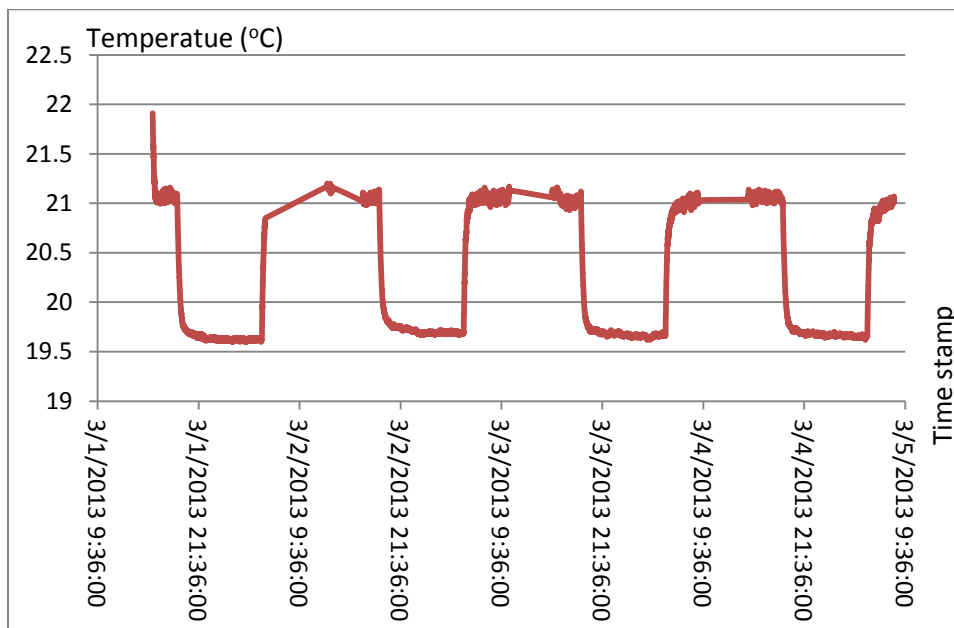


Figure 48. Temperature Measurement of the Box with 200 ml Distilled Water Only

After equilibrium, the average humidity reached 97.80 %. The time taken to achieve equilibrium was higher in this box compared to the other seed boxes. The average temperature in this box was 20.19 °C. However, the fluctuation pattern was same as in the other boxes.

4.4 Behavior of the Control Seed Box

A seed box without any solution was used as the control box. This box contains only seeds and was closed air-tight and placed in the same incubator along with other boxes.

Figure 49 shows the behavior of temperature and relative humidity in this box.

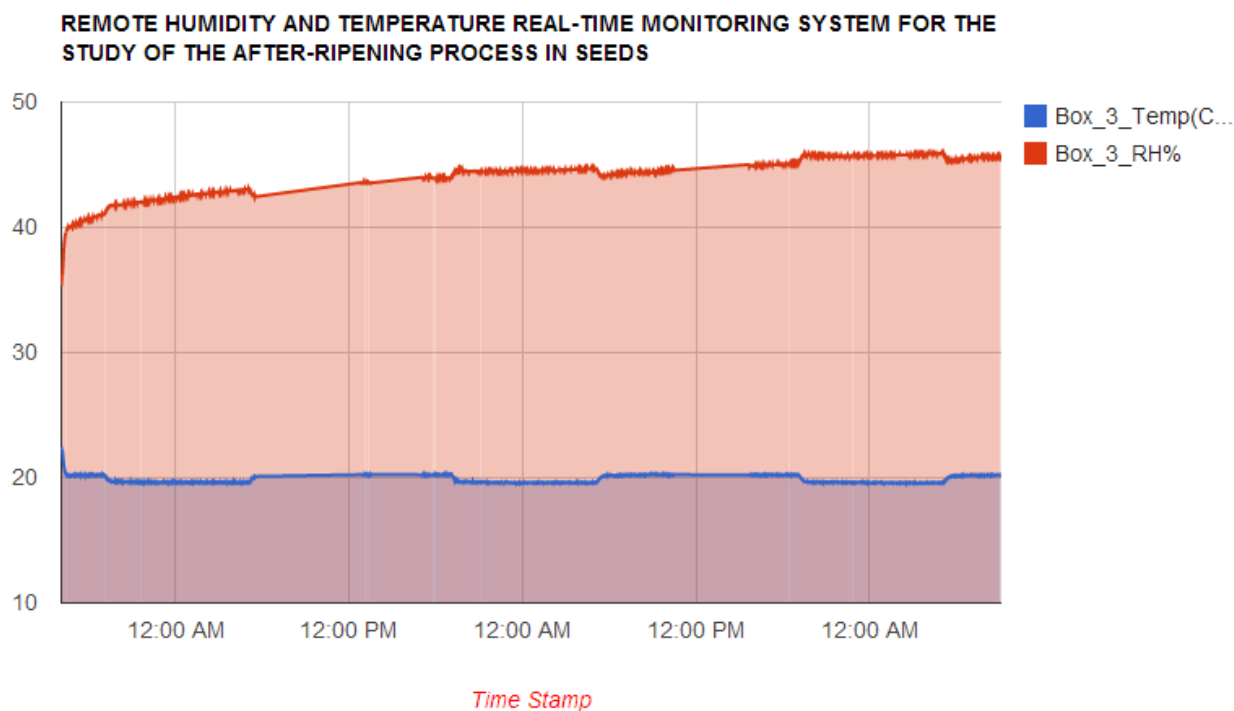


Figure 49. Relative Humidity and Temperature Measurements in Control Box

In this control box also, a major fluctuation was observed during the transition from the dark period to photoperiod. Arguably, this observation suggests that the major fluctuation is not due to the presence of any solutions. Average temperature was 21.90 °C. It was observed that the relative humidity kept on increasing from 34.30% to 47.11 %. This can be attributed to the evaporation in seeds. However, the fluctuation of less than 1 °C in seed boxes could be accounted for the orientation of the seeds boxes in the incubator. In all boxes, major fluctuations occurred during the transition from dark period to photo period. The observations clearly show that the LiCl controlled the relative humidity as expected.

4.5 Behavior of the Relative Humidity at a Constant Concentration of LiCl at Different Temperatures

To study the effect of the temperature on the relative humidity, a constant LiCl concentration was maintained with 147 g LiCl in 200 mL distilled water with nine grams of green seeds. Temperature was increased from 10 °C to 50 °C with a 10 °C interval. Each temperature was maintained for 24 hours.

Figure 50 below shows the real-time plot of this seed box.

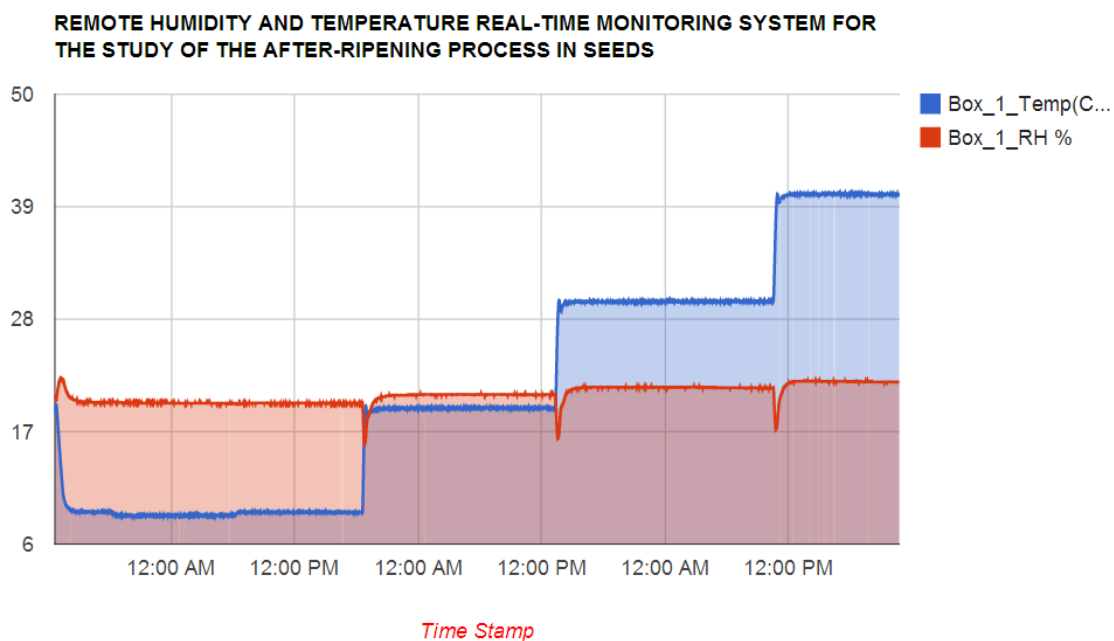


Figure 50. Behavior of the Relative Humidity While Changing the Temperature

Table 4. Temperature and Resulted Relative Humidity

Temperature (°C)	Relative Humidity (%)
10	19.80
20	20.64
30	21.36
40	21.85
50	22.16

Table 4 shows the resulted relative humidity at each temperature. As the temperature increased the relative humidity also increased. But this increase is very small. Here LiCl concentration is quite high. LiCl solution is dominating than the temperature in

maintaining the Relative humidity. During this experiment, an E-mail alert function of the system was also tested. It was observed that the system sends an e-mail alert whenever values go beyond the threshold values. For the testing purpose temperature threshold values 10, 20, 30 and 40 °C are used. For relative humidity 15,30,50 and 70% is used.

CHAPTER 5

SUMMARY AND CONCLUSIONS

It was demonstrated that a relatively inexpensive system can be designed and built for the purpose of seed research (See the Appendix A for the cost details). This system is very useful for the real-time measurement and monitoring of the relative humidity and temperature in a closed environment. It can be used to compare the capabilities of different chemical solutions, provides an easy and reliable method for monitoring the study of after-ripening and longevity, and is user-friendly and is easy to setup without much effort. The user can set up different experiments and check the relative humidity and temperature of each box remotely in real time, and data can be downloaded into Microsoft Excel for further data analysis. Since this system uses Google spreadsheet, the user does not need to buy a server space for implementation.

During the evaluation period, the system adequately monitored the relative humidity and temperature of the five containers. Moreover, the relative humidity and temperature in the containers were maintained (with little variations) over the test period. The variation observed in these two parameters was due to the slight heating/cooling of the incubator to maintain the desired temperature. Changes in light also cause small fluctuation in temperature. This is due to thermal radiation from the lighting source (fluorescent light). This fluctuation in the temperature leads the relative humidity to fluctuate. Thus, this system also could detect very fine variations in these parameters, which could lead to

better understanding of the environments inside containers and incubators and their role in seed dormancy break and longevity.

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Appendix A: Materials used

Components	Numbers of pieces	Price of each(\$)	Total(\$)	Source
Seed box Product code: PC 2828 13 T	5	92.50	462.50	http://www.fibox.com/
USB coupler	5	5.00	25.00	http://www.usbfirewire.com/
USB cable male to male	5	4.00	20.00	http://www.usbfirewire.com/
Sensor (SHT 75)	5	41.00	41.00	http://www.sensirion.com
Arduinio UNO	1	16.50	16.50	http://www.arduino.cc/
Wi-Fi Shield	1	85.00	85.00	http://www.arduino.cc/
Resistors, wires, etc		20.00	20.00	http://www.radioshack.com
Total cost			670.00	