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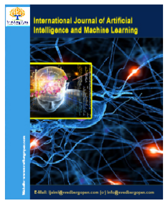

Research Paper **Open Access**

Development of a Smart Grain Storage Silo Using the Internet of Things (IoT) Technology

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Abstract

Food security is the aspiration of every nation. To achieve this, particularly in Developing Countries, there is a need to reduce wastage by storing staple foods grains beyond their production seasons. Longer storage requires human presence, monitoring and control of the storage environment which may be laborious, demanding and sometimes outrightly unsafe. Therefore, the needs to employ automation and artificial intelligence become necessary to control this storage environment. This study developed an automated, intelligent silo bin that controls the storage environment of the system for the small-scale rural farmers, of which over 70% of their population still depend on agriculture, using Internet of Things (IoT). The developed system consists of three units interfaced together. These units are the pro-type 2-ton (2,000 kg) silo structure, the embedded system (made up of the microcontroller, sensors and relays). The system is integrated to an IoT system (made up of mobile application (BLYNK), Wi-Fi module and ultrasonic atomizer) and the air blowing system (consisting of blower fan and heater). The developed smart system was tested and the test run results showed that it successfully monitors and controls storage air temperature, humidity, air pressure, grain moisture, insect infestation and CO_2 levels, the key parameters for long term storability of grains. The coding process could be set to suit different grains and storage conditions required for their effective storage. Although the silo bin structure used for testing was for a particular proto-type, it can be geometrically scaled for many silo structures.

Keywords: *Smart silo, IoT, Artificial intelligence, Embedded system, Ultrasonic atomizer, Controlled environment*

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1. Introduction

According to USAID Report (2022), food security is the ability to sustain a healthy and productive life style through meeting dietary needs with physical and economic access to sufficient food, where a family does not

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live in fear of hunger. The phenomenon of food insecurity is predominant in developing countries. As at the year 2020, it was reported that about 800 million people, go to bed hungry every night globally. Out of this figure, about 690 million including 144 million children are in the developing countries where agriculture accounts for 40% GDP, and 54% of the population depend on agriculture for sustenance. 70% of the rural populace are smallholder farmers who depend on agriculture to make a living and feed their families and as impoverished as they appear, they still contribute over 50% of the calorific requirement of the population in the developing world. However, associated with a very heavy cost of consuming 75% of the current fresh water utilization and contributing about 30% of GHG in addition to being responsible for over one million biodiversity losses. So, in order to feed a population that is expected to grow to 9 billion people by 2050, the world will have to double its current food production (especially staple food). Hence, there is the need to increase staple food production at less total cost and store excess production towards food security.

The world most common staple foods are cereal grains and tubers. Out of about 50,000 edible plants on earth only 15 provide 90% of the world energy intake. Rice, maize and wheat constituent 2/3 of this while others; millet, sorghum, potatoes, cassava and yams accounts for 33% (Resource Library, 2022). Shahbandeh (2022) produce a statistical report on the status of global cereal grain production from 2009 – 2021. The report shows that about 2.2 billion metric tons of grains were produced worldwide with maize contributing about 1.05 billion metric tons. There is, therefore, the need to continue to develop a more efficient storage structures for these staple foods. According to Hagstrum and Subramanyam (2006), Storage structures are design to protect grain from birds, rodents, fungi, mites, insects and weather conditions. There are numerous challenges faced by farmer during storage of agricultural product. Although, silos are the most commonly used commercial grains storage structures for bulk grain storage, there is still the need to control the storage environment for optimum storage life. To achieve this, there will be need for an automatic artificial control and monitor this storage environment with no direct human input.

Artificial Intelligence is intelligence exhibit by a machine. In a more explicit sense it is the development of computer systems that has the ability to perform tasks that usually require human intelligence (Saleh, 2019; Bezboruah and Bora, 2020, Audu and Aremu, 2021). Automation is a technical term usually associated with artificial intelligence. IBM Automation guide (2022) define automation as a technique or technology that is transferred to a machine that enables the machine to perform a task without or with minimum human interference. Automation could be classified into four categories: basic, integration, process and artificial intelligence automations. This study deals with artificial intelligence automation of a silo bin and this automation process make the silo smart. Various researchers had previously developed smart storage devices for different storage grains to solve specific storage problems.

Baranwal and Pateriya (2016) developed an IoT (Internet of Things) smart wireless security system that can identify rodents, alert farmer and repel rodents in store grain storage. This system consists of raspberry pi micro-controller, cameras and sound sensors working on PTC's ThingWorx's IoT platform and python program. Evaluation of the system shows 84.8% successful test cases on rodent control. Mabrouka *et al.* (2017) proposed an efficient and new solution to control and monitoring grain stored in silos using ultrasonic sensor and servo motor to scan the surface of the stored grain. The result of the scan is then sending through GSM modules to a LCD display. The study is of the opinion that the system will eliminate fraudulent quality in wheat quality assessment. Dal-uyen *et al.* (2019) developed an automated silo bin environmental control system. Parameter monitored and controlled were temperature, relative humidity and moisture content. Arduino microcontroller and sensors were hardware used. Evaluation was carried out using 100 kg capacity small-scale metal silo containing rice. The control system was used to switch on/off the heater and fans of the bin to control its inner environment to maintain the grain moisture at 14%. Hence, this confirms the acceptable of the device. Onibonoje *et al*. (2019) developed a dispensed low-power, low-value but however powerful wi-fi tracking gadget for monitoring stored bulk grains. Evaluation results show the gadget performed most advantageous trade-offs which amongst are insurance efficiency, decreased electricity consumption, decreased cost, real-time monitoring, and longer node life. The gadget is suitable for small and medium-scale farmers and marketers. Furtadoa *et al*. (2020) developed a low-cost automated drying system for drying stored cocoa beans. The system consists of Esp8266-12E microcontroller with wi-fi internet modules that is connected to a relay, humidity and temperature sensors. PLX-DAQVR and Data Silo software were used to collect data and activate the heating on/off. Test results shows effective drying of the stored cocoa beans. Basciftci *et al*. (2021) developed an IOT system to monitor and control cereal storage in silos bins. The system consists of NodeMCU micro-controller, temperature and humidity sensors. Then, through wi-fi silo monitoring data are send to web server to computers and mobile phone. The system was used to monitor and regulate the environment of stored cereal grains. Ekuewa *et al*. (2022) developed a smart security and monitoring device for stored maize in silo. The system uses Arduino micro-controller via internet to store data in the cloud. Then, receive and analyze the data using cloud mobile app. Test result shows that there's a moderate distinction among the Temperature and Humidity acquired from the device and the most reliable Temperature (18-27 ºC) and Humidity (62-70%) required for maize storage. This makes it a higher technique whilst as compared with the traditional technique of storing maize.

This study developed a proto-type of a smart grain storage silo bin with self-regulating and storage environmental monitoring system using the Arduino microprocessor controller technology with python base code. It incorporates the monitoring of temperature, moisture content of grain, humidity, carbon dioxide level, pressure of the bin and insect infestation level. Embedded into the coding control system is the safe threshold for each of the six monitored parameters. Whenever any of these parameters exceed the set safe range as predetermined, the system automatically triggers a control measure to bring back the grain environment to the safe threshold without any human interference or input required, hence the smartness. It measures, take decisions, and activate control measure required for safe storage condition.

2. Materials and Methods

2.1. Smart Grain Silo Storage Structure and Configuration

There are three main components of the smart silo that was interfaced together. The main silo structure itself fabricated with 1.5 mm sheet metal, the stand-alone solar power supply and the embedded system (made up of the microcontroller, sensors, relays integrated with drying system that comprise of the heater, blower fan) and automatic fumigant spray embedded with the controller. The three interfaced parts and configuration are shown in Figure 1.

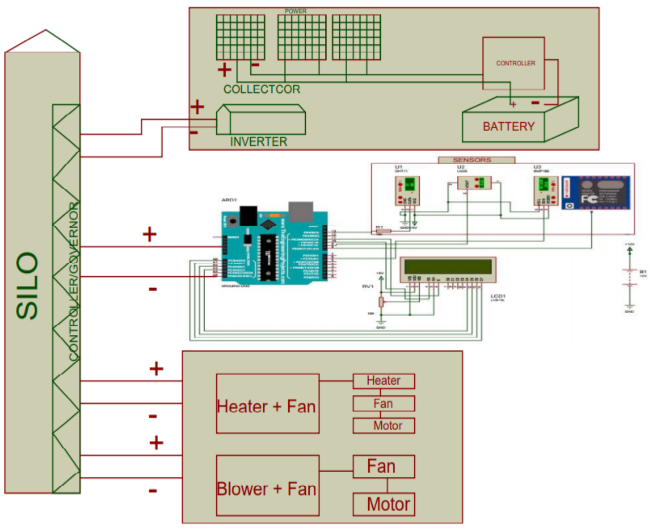

Figure 1: Smart Silo Storage Components and Configuration

2.2. Design and Construction of Proto-Type Grain Silo Bin

The silo grain bin is 2-tons (2,000 kg) capacity with a peak height of 0.51 m. The design dimensions are displayed in the supplementary material in Figure S1 and S2. The pipe design for better aeration is shown in Figure 2. However, only one fan blower was used since it is more economically efficient. The heater was fixed with the fan blower to allow heat through convection in cases where sensor temperature reading is less than the specified temperature range set by the code controller.

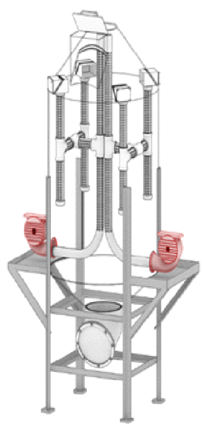

Figure 2: Grain Silo Pipe Design for Better Aeration

2.3. Design and Selection of the Embedded (Automated Artificial Intelligence) System

2.3.1. Micro Controller (Arduino)

Arduino Mega 2560 microcontroller board with the a Tmega2560 microprocessor was selected for the project due to its large number of digital pins (since the project need pins for four sensors, a wi-fi module, relays, and an LCD screen). It consists of a reset button, 4 hardware serial ports, an In-Circuit Serial Programming (ICSP) header, 16 analogue inputs, a USB link, power jack and 54 digital pins for input and output. Its power pins are capable of 5 V and 3.3 V (Figure 3). The board can be powered using an external battery adapter, a battery as well as plugging it into a device (like a laptop) with the USB cable (Arduino, 2015). The board programming codes Integrated Development Environment (IDE) are displayed in Figure S3 in the supplementary material.

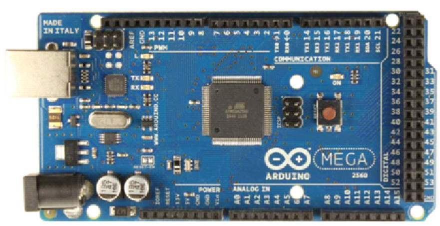

Figure 3: Arduino Mega 2560

2.3.2. Temperature and Humidity Sensor

A simple and cost effective DHT11 sensor module was selected for temperature and humidity measurements. It makes use of a capacitive sensor and a thermistor for measurements and sends data through its signal pins (Greiner, 2019). DHT11 also consists of an integrated circuit that measures, processes, and converts the measured value into digital form. It measures temperature values ranging from 0 to 50°C with a ±2°C precision and humidity ranges from 20 to 80%, with ±5% accuracy. According to Elprocus (2020a) its sampling rate is 1 Hz which means that it gives one reading every second with 3 to 5 V operating voltage and 2.5 mA maximal current. The Arduino receives data from the DHT11 through a single signal cable. Power was provided through the separated 5 V and ground pins. A 10 kΩ pull-up resistor was necessary to ensure that the default signal level remains high. There are two variants of the sensor, one with three pins and another with four pins as shown Figure 4. The one used for the study was the one with three pins having a 10 kΩ resistor mounted on the printed circuit board of the sensor.

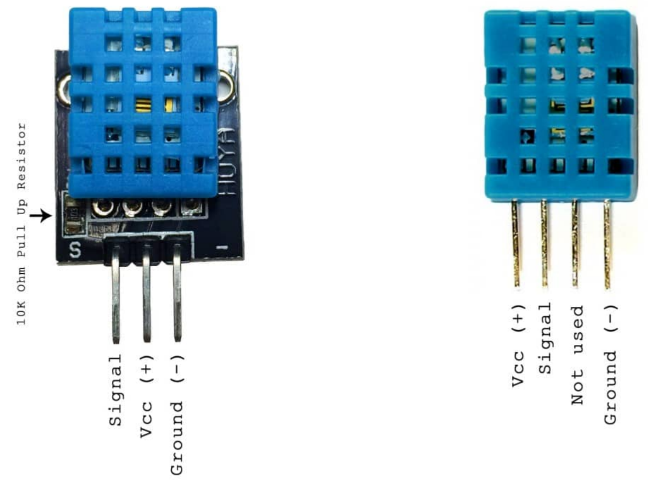

Figure 4: A Typical Three and Four Pin DHT11 Sensor (Circuit Basics, 2015a)

2.3.3. Pressure Sensor

The pressure sensor selected was the BMP180 sensor. It is a small sensor with high precision for calculating atmospheric (or barometric) pressure. Also, the BMP180 sensor can be used to measure altitude as well as give temperature readings. The sensor comes either with five pins or four pins depending on specifications. BMP180 five pined sensor used in the study is displayed in Figure 5. The Serial Data Pin (SDA) and Serial Clock Pin (SCL) were connected to the Arduino's I2C pins which were pins 20 and 21 respectively on the Arduino mega board. The BMP180 pressure sensor can give pressure readings ranging from 300 to 1100 hPA (1 hectopascal = 100 Pa) with 0.12 hPa accuracy.

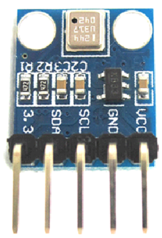

Figure 5: BMP180 Five Pined Pressure Sensor

2.3.4. Carbon dioxide (CO_2) Sensor

A digital and low-powered gas CCS811 module sensor was selected (Figure 6). It consists of a gas detector with metal oxide for detecting a wide range of Volatile Organic Compounds (VOCs) for observation and monitoring of air quality and an Analogue to Digital Converter (ADC) and Inter-Integrated Circuit (I2C) interface provided by the microcontroller. It is mainly designed to be used for indoor systems. CCS811 module sensor sense TVOCs ranging from 0 – 32,768 ppb (parts per billion) and estimated concentration of carbon dioxide ranging from 400 – 29,206 ppm (parts per million). It works with 30 mA current supplied with a 1.8 V to 3.3 V DC voltage. It has eight pins:

i. VCC: used to power the module with 3.3 V pin of the Arduino
ii. GND: connected to the ground pin of the Arduino
iii. SCL: Serial Clock Line helps in I2¬C communication by providing clock pulse
iv. SDA: Serial Data Address uses I2C communication for data transfer
v. WAK: Wake pin
vi. INT: Interrupt pin
vii. RST: Reset pin
viii. ADD: helps in the selection of addresses

Only four of these pins were connected to the Arduino board. The VCC and GND pins were connected to the respective 3.3 V and GND pins of the Arduino mega as well as the SDA and SCL pins to pins 20 and 21 of the Arduino mega respectively.

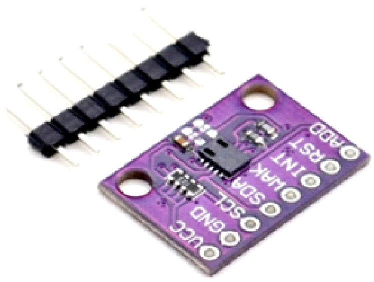

Figure 6: CCS811 CJMCU-811 Gas Sensor

2.3.4 . Acoustic Sensor

KY-037 module acoustic sensor was selected (Figure 7). It comprises of a sound-detecting capacitance microphone and a circuit that amplifies the signal as well as a variable resistor and potentiometer for controlling it sensitivity. According to David (2021) its operating voltage is 3.3 V to 5 V with detection frequencies ranging from 50 Hz to 20 kHz with sensitivity ranging from 44 dB to 66 dB. The choice of the acoustic sensor was based on recommendations on studies carried out on acoustic detection of insects on stored grains. These studies were done by Fleurat-Lessard *et al.* (2006), Hagstrum *et al.* (2012), Kiobia *et al*. (2015) and Hinckley (2018). The pins configuration for connecting to the arduino board is shown in figure S4 in the supplementary material.

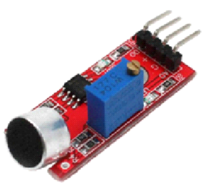

Figure 7: KY-037 Acoustic Sensor (ElectroPeak, 2019)

2.3.5. Liquid Crystal Display (LCD) Screen

The 16x2 LCD screen was selected. It is cost effectiveness, ease of programming, relatively low power consumption and custom display functions. Figure S5 in the supplementary material shows the pin out configuration and functions of the 16x2 LCD screen. The pin outs of the16x2 LCD screen are shown in Figure 8. There are two types of registers used by the LCD, the data register and the command register. Data registers allows the LCD to process data and the command register allows the screen to process instructions and commands (Elprocus, 2020b).

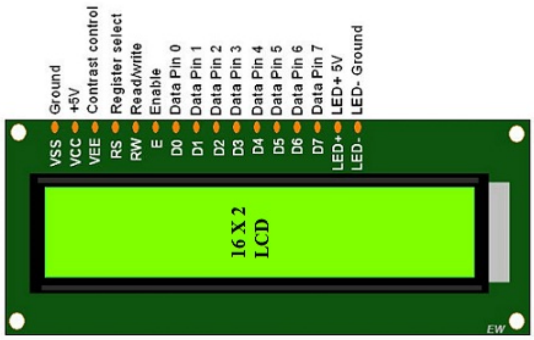

Figure 8: Pin Out of a 16x2 LCD Screen

2.3.6. Jumper Wires

Jumper wires are basically wires with pins for connection on both ends that can be used to link or attach two points without the use of solder. They are readily adaptable with breadboards since they have pin connectors to connect to the pinholes of the breadboard and the female jumper wires with pin holes can connect with other components. This allows easy testing and changing of circuits. There are three types of jumper wires based on the ends of the wires which are the male-to-female, female-to-female and female-to-male jumper wires. The male connectors have protruding pins while the female parts have pin holes (Hemmings, 2018). Jumper wires are displayed in Figure S6 in the supplementary material.

2.3.7. Relays

A 5 V relay was selected for automatic switch on and off devices like fan and heater whose voltage is greater than 120-240 V using the arduino board. The relay can be triggered by the arduino when an event occurs; it can also be triggered at set periods of time (and not from a sensor) based on how the Arduino is programmed. The terminals and pins of a 5 V relay are shown in Figure 9. The configuration of a 5 V relay terminals when it is open or close is displayed in Figure S7 in the supplementary material.

Figure 9: 5V Relay Pin Out (Circuit Basics, 2015b)

2.4. Design and Selection of the Internet of Things System

2.4.1. The Mobile Application (BLYNK)

The mobile application selected for the IoT system was “Blynk”. The Blynk application is a third-party mobile cloud application. It can be used as a Platform as a Service (PSAS) as well as Software as a Service (SAAS) to provide cloud services. It can readily interface with IoT devices and applications that is, it has the capability to monitor and read sensor data, control hardware remotely, store data and other applications. The Blynk configuration consists of the Blynk application, the servers and the libraries. The application was used to design the mobile application's graphics with the use of widgets to create an interactive user interface. The server was used to store data from the hardware and the mobile application for communication between both components. The libraries were used to process commands and signals for supported hardware like Arduino boards. Blynk application consists of virtual pins which imitate the Arduino pins which was used communicate with the Arduino. These virtual pins allow the Arduino to receive user input from the application. Sensor data from the Arduino was displayed on the application using widgets. The application connects to the hardware using a unique means of identification called the authorization token which will also be needed to share the application after the design is completed. The blynk architecture is shown in Figure 10.

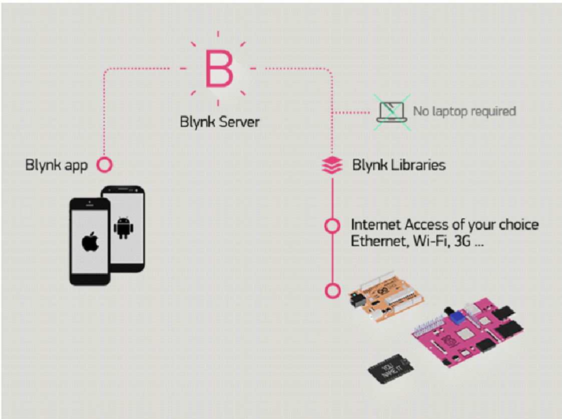

Figure 10: Blynk Architecture (Blynk, 2020)

The ESP8266 Wi-Fi module (Figure 11) selected and used to connect the smart silo to the internet in order to communicate with the mobile application remotely. The module was powered by 3 V maximum as anything greater than this will damage the module permanently. The ESP8266 consists of eight pins (Figure 11). The RX and TX pins were used for communication and the VCC and ground pins was used to power the module. It also has an LED to indicate power. More details about the pins and connections of the ESP8266 are shown in Table S1 in the supplementary material (Components101, 2018a).

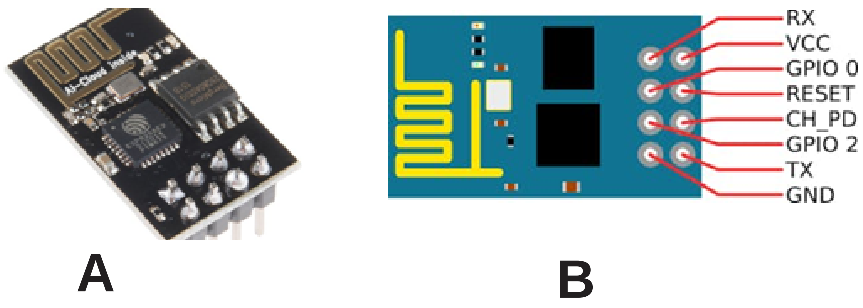

Figure 11: A is ESP8266 Wi-fi module; and B is the Module Pin Out

2.4.2. Bread Board

A breadboard was selected to connect the Arduino pin, 5 or 3.3 V pin is to the positive rail while the ground pin was connected to the negative rail to power the breadboard. This is to allow the IoT system to be tested after design to avoid wrong soldering. Figure S8 in the supplementary material display a bread board.

2.4.3. Ultrasonic Atomizer Module

A 16 mm 110 kHz ultrasonic humidifier or atomizer module was selected for spraying fumigant in cases of infestation (Figure 12). Once the silo operator receives a notification of possible infestation through the blynk mobile application, the operator then has the option to switch on the atomizer to spray fumigant. The module works by transferring energy to the fumigant by vibrating at a high frequency thereby forming uniformly sized fine droplets or mist (Hareendran, 2019). It has just two wires for power (that is, positive and ground wires) and it is powered by 5 V. It was connected to one of the 5 V relays which will be triggered by the Arduino Mega board.

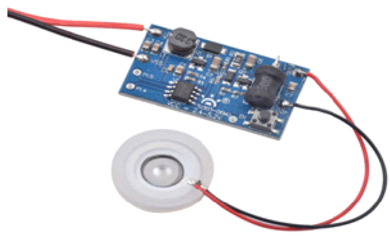

Figure 12: 16 mm 110 kHz Ultrasonic Atomizer Module

2.5. Assembly and Operation of Embedded (Automated Artificial Intelligence) System

The assemble drawing of the embedded (automated artificial intelligence) system is shown in Figure 13. The operation of the embedded (automated artificial intelligence) system starts with the powering of the arduino mega board by solar battery. Then the arduino board triggers 2-channel relay modules to switch the fan, heating element and spray bottle. The 16x2 LCD pins 15 and 16 then power the LCD backlight. Pin 15 was connected to 5 V or a potentiometer (to adjust brightness) and pin 16 was connected to ground. During the overall operation of the silo's smart system, a breadboard power supply module was used to interface with the

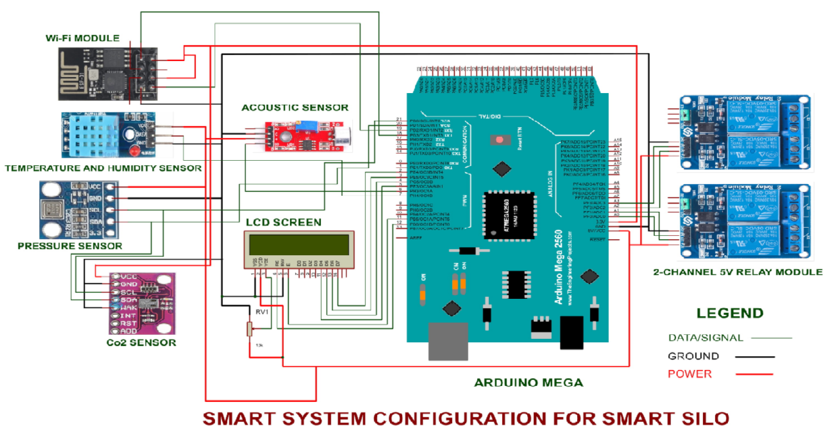

Figure 13: Assembled Drawing of Embedded (Automated Artificial Intelligence) System

bread board to power the relays and ultrasonic atomizer. The breadboard power supply module provides both 5 V and 3.3 V output from 6.5 – 12 V DC maximum input voltage (which also has a 5 V power supply USB port that was used to power the Arduino Mega). It was also provided 700 mA output current and has an on and off switch. A 9 V 1A AC to DC adapter was used to power the breadboard power supply. LCD results from sensors are displayed in Figure S9 in the supplementary material. Figure 14 shows the physically complete assembling of the automated artificial intelligence unit or system.

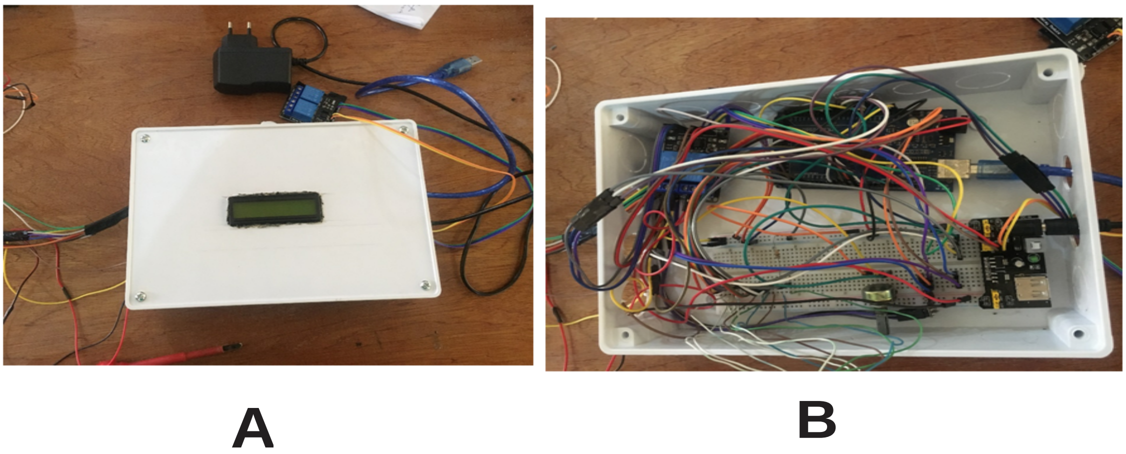

Figure 14: Assembled Pictures of Embedded (Automated Artificial Intelligence) System. A is the External Features, B is the Internal Features

2.6. Assembly and operation of the Internet of Things System

The IoT system was powered by the arduino board using the ESP8266 wi-fi module to activate the blynk cloud base mobile application with internet wi-fi. Data from temperature and humidity sensor, pressure sensor, CO_2 gas sensor and acoustic sensors are transferred and continuously updated to the blynk mobile application to

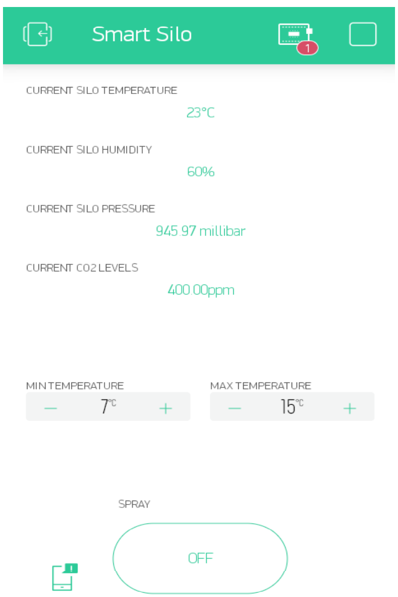

Figure 15: Mobile Application User Interfaces

be viewed by the silo operator. Alarm from the acoustic sensor sends to the blynk mobile application triggers the relay for ultrasonic atomizer module to spray and fumigate the silo bin. Readings outside the set thresholds set for moisture content, temperature, humidity, CO_2 and pressure sensors create alarms that trigger the relays to operate the fans and heater or fan alone into operations that normalizes the situation. When normalization is achieved which is indicated by the readings getting back into the threshold range, all the actions initiated (fan, heater, spray) are terminated and reset for the next alarm. Figure 15 shows schematics for the blynk mobile application user interface.

2.7. Operational Principle of the Combine System

The entire operational principle is explained using the code flowchart deployed for the Arduino coding process. This flow chart is displayed in Figure S10 in the supplementary material.

2.8. Developed Smart Grain Storage Silo Bin Test Run

Twenty hours test run of the developed smart grain storage silo was carried out without load, at the agricultural engineering laboratory in Landmark University, Nigeria. The test run started with the powering of Arduino, then, the code initialized and connected to the Wi-Fi network as specified in the code which in turn connects to the Blynk servers. This process took about one minute. The LCD screen was powered on immediately but sensor values were not displayed on the LCD until after the Arduino had connected to the Blynk servers through the internet. This process was monitored using the serial monitor on the Arduino Integrated Development Environment (IDE). Once the silo was online, a notification was displayed on the mobile application.

For the purpose of the test run, the fan and heater were programmed to come on line when the bin temperature is between the ranges of 20 °C – 40 °C. Also, the ultrasonic humidifier or atomizer was programmed to activate when the bin CO_2 content reaches between the ranges 0.5 – 1 ppm.

3. Results and Discussion

The results obtained for the 20 h test run of the developed smart grain storage silo without any stored grain in it is displayed in Table 1. At the beginning of the test run the smart silo displayed initial temperature and humidity of 20 °C and 45% respectively. The air pressure and CO_2 inside the smart silo were 1053.85 millibar and 1.02 ppm respectively. The fan blower and heater were set to activate automatically. This setting was not based on any grain storage condition but just to test the effectiveness and sensitivity of the developed system. The response of the temperature and humidity inside the silo during test run is shown in Figure 16.

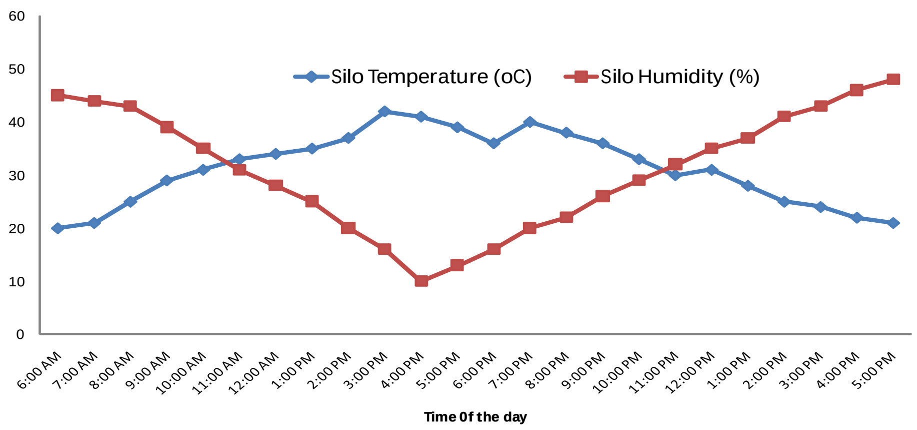

Figure 16: Smart Silo Inside Air Temperature And Humidity During Test Run

Table 1: Test Runs Result of the Developed Smart Grain Storage Silo Bin Without Stored Grain

S. No.	Time (h)	Silo Temperature (oC)	Silo Humidity (%)	Silo Pressure (Millibar)	Silo CO2 Level (ppm)	Status of Blower Fan and Heater	Status of Fumigation Prayer
1.	6 am	20	45	1053.85	1.02	on	on
2.	7 am	21	44	1040.20	1.00	on	on
3.	8 am	25	43	1037.56	0.94	on	on
4.	9 am	29	39	1023.83	0.73	on	on
5.	10 am	31	35	1020.62	0.60	on	on
6.	11 am	33	31	1011.21	0.41	on	off
7.	12 am	34	28	1009.96	0.26	on	off
8.	1 pm	35	25	972.43	0.17	on	off
9.	2 pm	37	20	925.56	0.02	on	off
10.	3 pm	42	16	926.78	0.02	off	off
11.	4 pm	41	10	928.45	0.03	off	off
12.	5 pm	39	13	937.42	0.03	off	off
13.	6 pm	36	16	961.61	0.04	off	off
14.	7 pm	40	20	978.05	0.04	off	off
15.	8 pm	38	22	979.83	0.04	off	off
16.	9 pm	36	26	986.98	0.05	off	off
17.	10 pm	33	29	992.22	0.05	off	off
18.	11 pm	30	32	998.71	0.05	off	off
19.	12 pm	31	35	1003.86	0.05	off	off
20.	1 pm	28	37	1009.95	0.06	off	off
21.	2 pm	25	41	1014.04	0.06	off	off
22.	3 pm	24	43	1019.62	0.06	off	off
23.	4 pm	22	46	1022.85	0.06	off	off
24.	5 pm	21	48	1031.89	0.1	off	off

Figure 16 illustrate that the air temperature inside the smart silo continue to rise as the test run progresses with time. This is caused by the blower fan and heater blowing hot air into the silo bin. The air temperature the silo then starts to gradually reduce after it reaches 40 ^{o}C. This occurs because the fan blow and heater were programmed to set off when the air temperature inside the silo reaches 40^{o}C. The remaining test run showed a gradual and fluctuating reduction in air temperature inside the silo. This phenomenon occurs due to external influence of temperature on the environment within the silo structure. Also, the air humidity inside the silo begins to reduce as the air temperature increases. This reduction of humidity is cause by the hot air generated by the blowing fan and heater. Low humidity cause further dryness to stored grains by reducing its moisture content. This discourages microbial growth and reduces spoilage in grain storage.

The developed system was able to reduce the air humidity to 10%, before the fan blower and heater automatically stopped when the air temperature reaches 40 °C. After this, the air humidity inside the silo begins to gradually increase throughout the remaining part of the test run. This increase is caused by the external atmospheric condition during the test run. This showed that the developed smart system can effectively control the storage temperature and humidity inside the silo bin.

Another storage air condition that was control was air pressure. The behavior of the air pressure inside the smart silo bin is shown in Figure 17. The smart silo inside air pressure begins to reduce from its initial air pressure of 1053.85 to 925.56 over the test period. This reduction was caused by the introduction of hot air by the fan blower and heater into the silo.

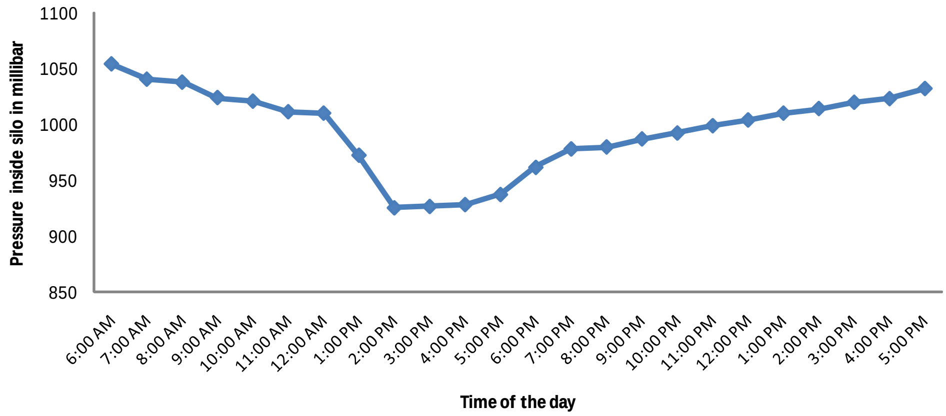

Figure 17: Air Pressure Inside The Smart Silo During Test Run

When the fan and heat automatically stopped when the air temperature reaches 40 °C as programmed, the air pressure in the smart silo began to rise again. Controlling of air pressure in the silo bin is crucial in maintaining the stability of the silo bin structure. This attribute will effectively prevent the compressive cave-in or side collapse of the silo caused by pressure reduction associated with moisture exchange between the grain and the silo air present in the pore spaces of the grain when the grain is too dry, a condition that is common in commercial grain silo systems. This also shows that, the developed smart silo can automatically control it storage environment.

Another important storage condition that is being controlled is the CO_2 content in the storage air. The behavior of CO_2 level inside the silo bin is displayed in Figure 18. It shows that the CO_2 level inside the smart silo bin begins to reduce from the start of the test run from 1.02 to 0.02 ppm. This attribute would reduce the build-up of CO_2 that may be the consequence of activities of insects, fungi or the grain respiration resulting to an increased soundness of the grain condition over an elongated period of storage. The Arduino board was also programmed to alert the installed relay to turn on the ultrasonic humidifier or atomizer module to spray or fumigate the silo bin during the fungal infestation detectable by the vibration frequency range of insect activities. During the test run, the Arduino was programmed to activate the spraying when the level of the main frequency of vibration gets to 1,000 Hz generated by a small pocket concrete vibrator with a frequency of 0 Hz to 2000 Hz. The actual time the atomizer module switched on and off was shown in Table 1. After the fan was automatically switch off the CO_2 content of the air inside the silo begins to rise again. This rise was caused by gradual exchange of air between the silo and its environment. This test shows that the developed system can control insects and fungal level of stored grain by controlling the CO_2 content of the silo and monitoring the vibration levels.

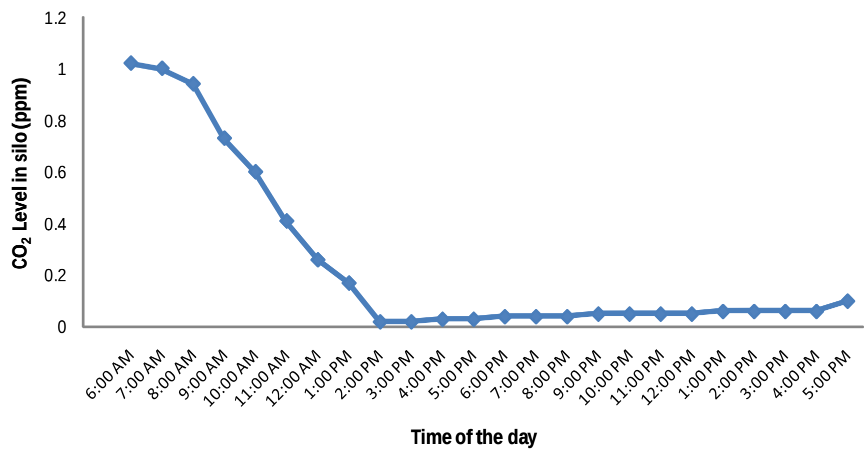

Figure 18: CO_2 Level Inside the Smart Silo During Test Run

4. Conclusion

An automated intelligent silo bin grain storage system using IoT was developed and tested. This smart system was test and shown to be able to successfully control storage air temperature, humidity, air pressure, insect and CO_2 levels within the storage bin. These parameters are keys to long time storability of grains and must be controlled to suit different grains required specifications and storage conditions. Although, the developed smart silo was a proto-type, the size can be scaled to produce equivalently result.

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Supplemetary Material

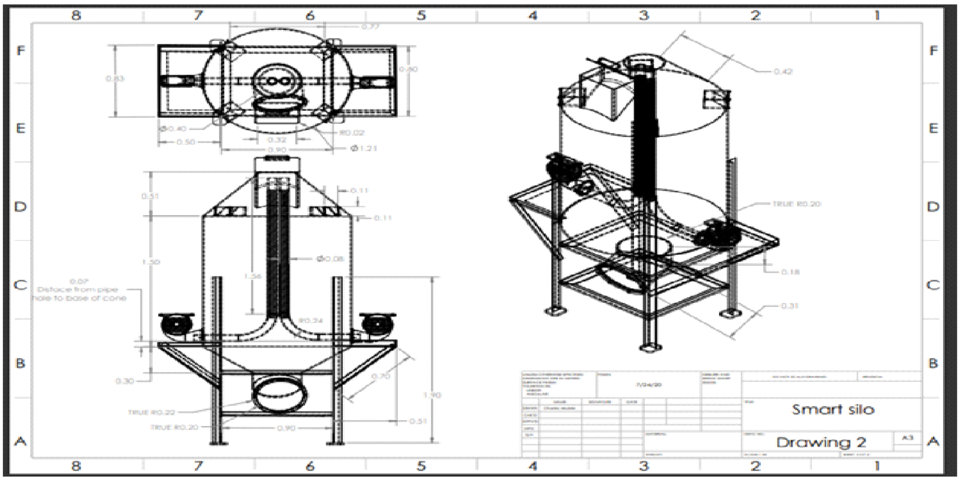

Figure S1: Design Drawing of the Internal Structure of the Grain Silo Proto-Type

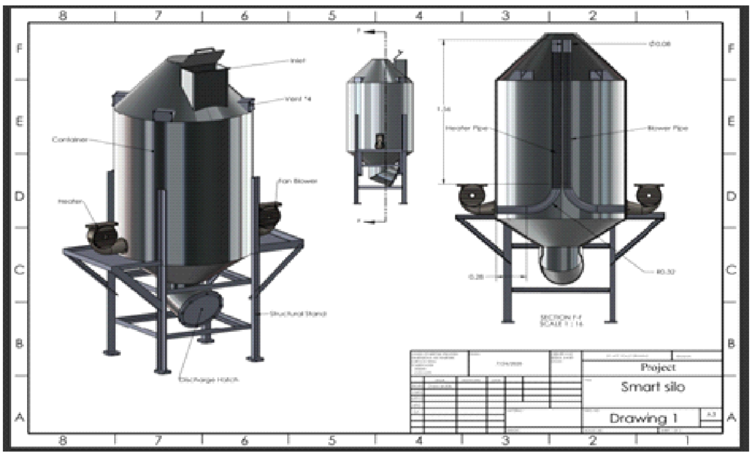

Figure S2: 3D Model Design Drawing of the External Structure of the Grain Silo Proto-type

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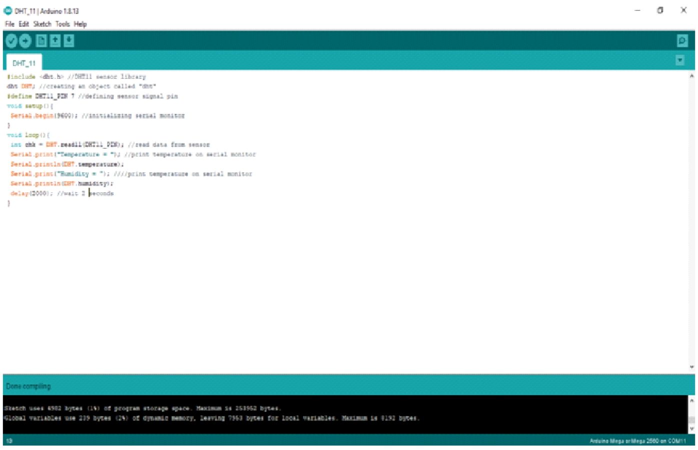

Figure S3: Arduino IDE (Integrated Development Environment)

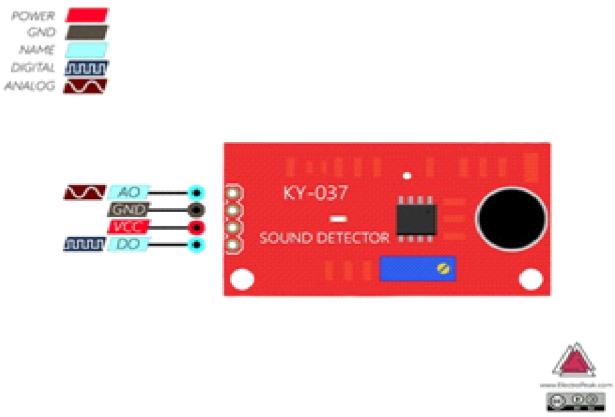

Figure S4: Pins configuration of KY-037 Acoustic Sensor

Pin number	Pin Name	Pin Description/Function
1	Vss = Ground	Connect this to your system ground or reference
2	Vdd (Logic power)	Logic voltage to drive LCD, this could be 5V or 3.3V. 5V is best for colder temperatures.
3	V_E	Contrast adjust to lighten or darken the character with respect to the background. This is a variable between max logic power and ground.
4	RS = Register Select	Connect this to your microprocessor to shift between Command and the data register
5	RW = Read/Write	Used to read or write data between the LCD and the microprocessor. This can be tied to ground if you only plan to write data.
6	Enable	0 or 1 to communicate with the microprocessor
7	DB0	DB is Data Bit from 0 to 7
8	DB1	These are connected to the microcontroller to send/receive up to 8 bits of data at a time. It is possible to only use four data bits if you have limited I/Os. (In/Outs)
9	DB2	
10	DB3	
11	DB4	
12	DB5	
13	DB6	
14	DB7	
15	LED +	This is the power for the LED and is independent of the LCD voltage. About 50% of the LCDs have pin 15 as positive and 16 negative, the other 50% are reversed. LEDs are DC(Direct Current) and have polarity.
16	LED -	

Figure S5: Pin Configuration and Functions of a Standard 16x2 LCD Screen

Supplemetary Material (Cont.)

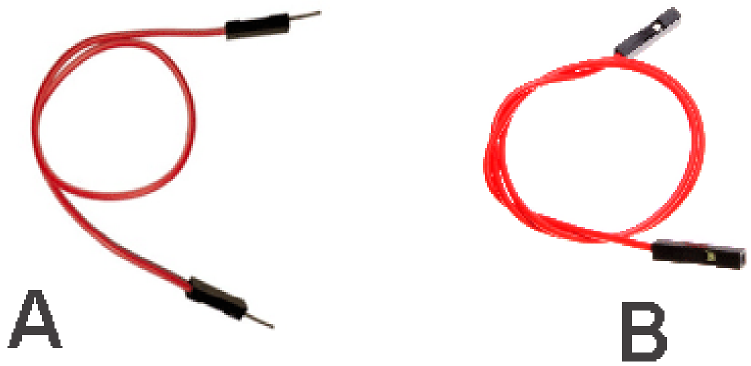

Figure S6: A is Male Jumper Wire While B is Female Jumper Wire

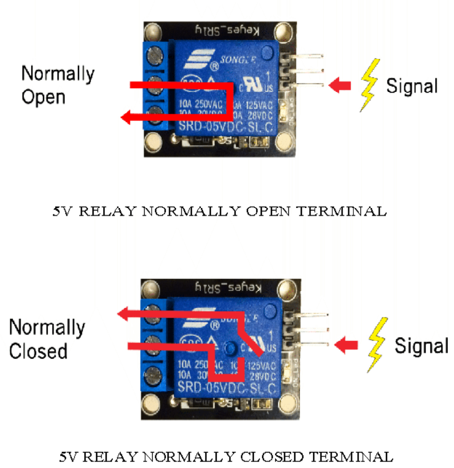

Figure S7: The Configuration of a 5 V Relay Terminals When it is Open or Close

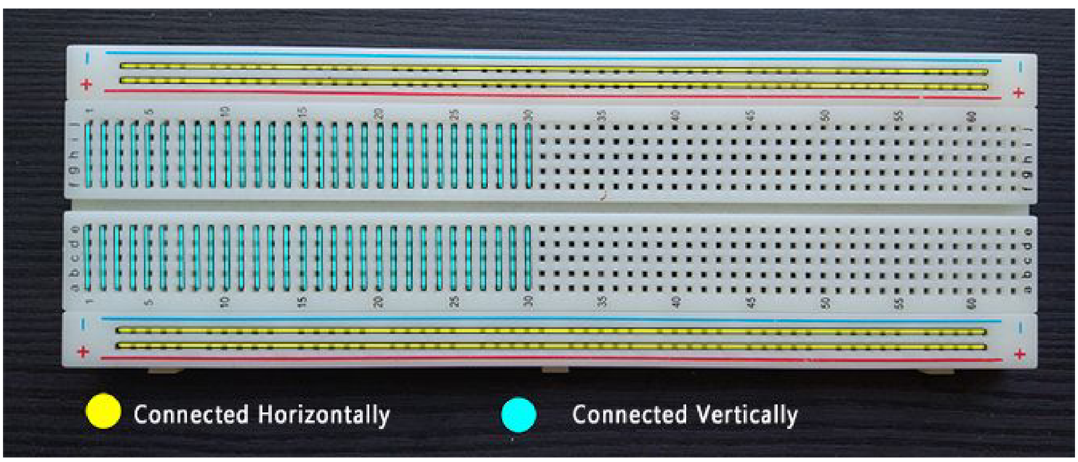

Figure S8: Bread Board

Supplemetary Material (Cont.)

Figure S9: LCD Screen Displaying Sensor Values

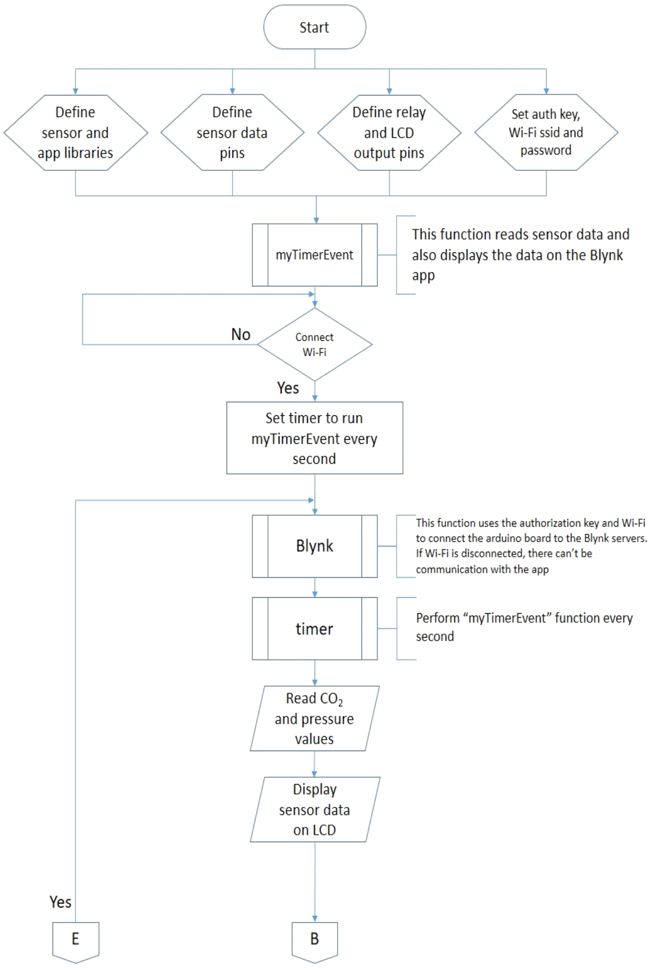

Figure S10: The Code Flowchart Used for the Arduino

Supplemetary Material (Cont.)

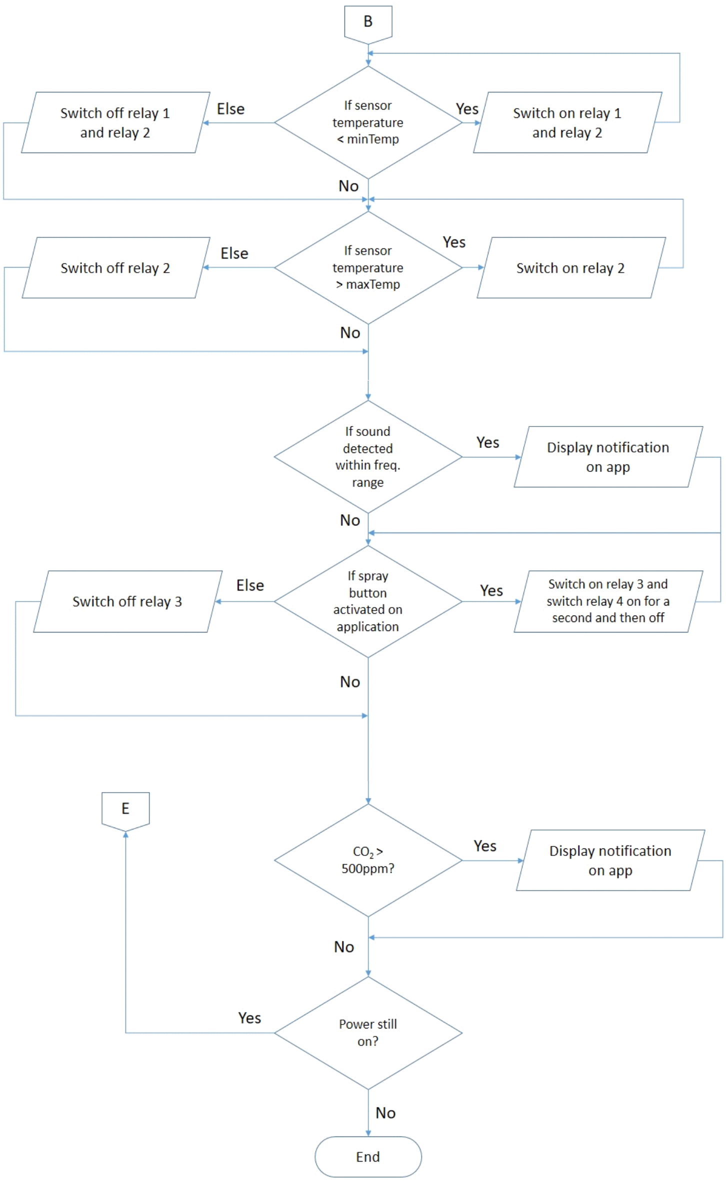

Figure S10 (Cont.)

Table S1: ESP8266 Wi-Fi Module Pins and Connections		
S. No.	**Name of Pin**	**Connections**
1	Ground pin	This is connected to the ground pin of the Arduino board
2	TX or GPIO-1 pin	It is connected to the RX pin of the Arduino board and can also act as an input/output pin generally
3	GPIO-2 pin	This is a general input/output pin
4	CH_PD or CH_EN or Enable pin	It is also connected to the 3.3V pin of the Arduino along with the VCC pin to receive power
5	GPIO-0 or Flash pin	This is a general input/output pin
6	Reset pin	It can be used to reset the Wi-Fi module
7	RX or GPIO-3 pin	This is a general input/output pin
8	VCC	This is the positive power pin connected to the 3.3V pin of the Arduino

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