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Research Article

Design and Development of a Model Smart Storage System

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ABSTRACT

Food security has become a global major problem, due to the rapid increase in population growth. This has necessity the development of an effective agricultural products' storage system, to alleviate the problem of food wastage. This study was embarked upon to develop a prototype of universal smart storage system for farm products, by using the internet of thing (IoT). The storage structure consists of four principal constituents which were; the power source, storage chamber, central processing system, and peripheral component interconnect (PCI) heater and PCI fan. The developed model was tested at a pre-set temperature and relative humidity of 32°C and 62% RH respectively. The results revealed that the developed system had an efficiency of 85%. Though, the smart model had a failure rate of 15%, this smart prototype is a major breakthrough in the production of automated storage system for agricultural products.

Keywords: *Automation, Environmental conditions, Food security, Smart system, Storage structure*

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INTRODUCTION

Food insecurity is rising daily mostly due to decrease in food production and increase in human population. Apart from increase in food production, appropriate storage and processing conditions, may help to alleviate the problem of food wastage. Ekruyota and Uguru (2021a) reported that food wastage, probably caused by poor storage and handling conditions, is one of the major causes of food insecurity. This is because more than 30% of the crops produced globally, are susceptible to rapid deterioration, due to poor harvesting, transportation and storage operation. Nigeria is losing billions of Dollars annually due to food waste, resulting from inadequate storage structures, and scandals in crops processing (Ijabo *et al.*, 2019).

Soft tissue fruits and vegetable are highly prone to mechanical damage – which is one of the major causes of food wastage, when harvested and/or handled with inappropriate machines and methods (Ekruyota *et al.*, 2021). Likewise, Golf (2019) stated that adequate storage facilities, which modern equipment to monitor the interior environmental condition are necessary to combat the menace of food insecurity. Some of the vital factors inside storage houses which are regularly monitored, in order to increase the shelf-life of the stored products are; carbon oxides, humidity, water vapour, volatile gases, and temperature. Citing Hagstrum and Subramanyam (2006), the interior of a standard storage structure should be designed to preserve the quality and quantity of the stored agricultural product; hence, the heat of respiration of agricultural products is an important parameter to be considered during the development of any storage system.

Remarkably, results from the shortage of human power to accomplish the task of massive food production, automation of agricultural business is gaining foothold. Most of these automated systems uses artificial intelligence (AI) to provide food security, through substantial food production and protection (Bezboruah and Bora 2020; Idama *et al.*, 2021). Internet of things (IoT) is of the techniques used for the automation of agricultural activities (smart farming). It incorporates hardware (devices), software, and other relevant technologies, with the aim of monitoring the farm operations through the internet. Designing a functioning smart agriculture operation required adequate knowledge of the intended crop engineering properties, prevailing environmental conditions, and the farming system (method) employed (Nwanze and Uguru, 2020; Ekruyota and Uguru, 2021b).

Mabrouk *et al.* (2017) reported that poor monitoring techniques are contributing greatly to the quality deterioration of crops stored inside storage structures. Mabrouk *et al.* (2017) listed the advantages of an automated farm operation as, extraordinary proficiency of sensing errors, reduced human health risks, and an elaborate structure; while design complexity and high cost of corrective maintenance, are some of the delimitation of smart systems. Though several researchers have designed or developed smart systems for various crops storage (Onibonoje *et al.*, 2019; Zhao et al., 2014; Ekuewa *et al.*, 2022), there is still serious necessity to develop universal smart machine, that can handle to storage if various agricultural crops. Therefore, the main purpose of this research work is to design and developed a prototype of smart storage structure for different crops, where the temperature and humidity can be regulated.

MATERIALS and METHODS

The prototyping methodology, as explained by Boehmer (2015) and shown in Figure 1, was adopted for this research work, to develop a prototype of an automated storage structure.

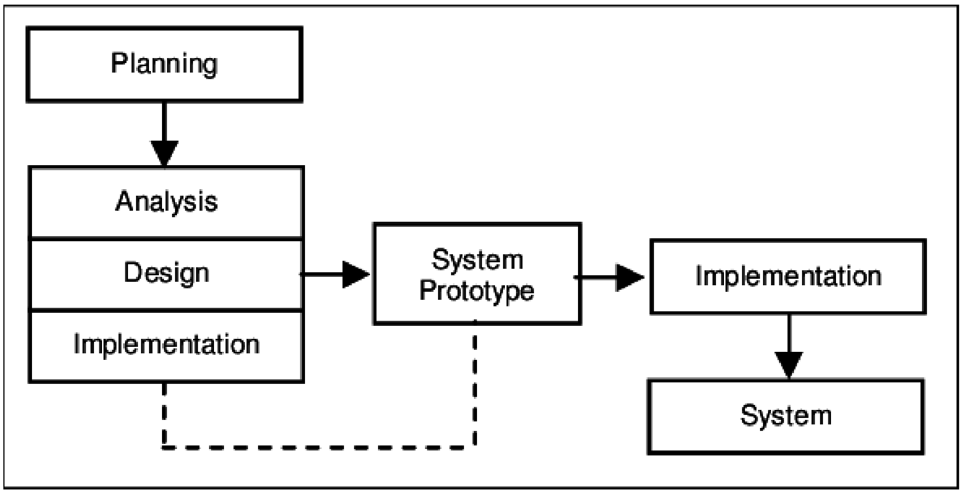

Figure 1. *Prototyping methodology (Boehmer, 2015).*

System Analysis

The automated storage structure has four main components, which are:

I. the power source,
II. the storage chamber,
III. the central processing system that consists of the relays, sensors and microcontroller, and
IV. peripheral component interconnect (PCI) heater and PCI fan.

The smart system performance rating (efficiency) was calculated with Equation 1.

$$PR = \frac{observed\ output}{expected\ output} \times 100 \qquad (1)$$

Where PR = system performance rating.

The failure rate of the system was calculated through Equation 2.

$$Failure\ rate = 100 - PR \qquad (2)$$

System Description

Figure 2 shows that the system comprises of an arduino microcontroller that acts at the brainbox. The arduino device receives information from the environmental sensors (temperature and humidity sensors), and send them to the main station through the GSM module. Additionally, the PCI heater and fan will switch on if the temperature and humidity exceeded the pre-set values.

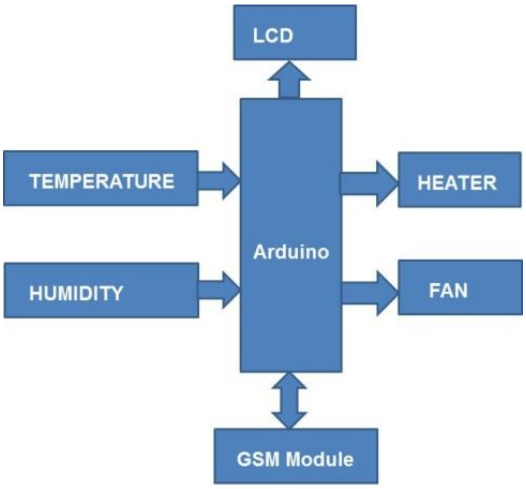

Figure 2. *System design architecture.*

Component Specification

The components were used for the building of the prototype with their specification are presented in Table 1.

Table 1. *The smart system components.*

S/No	Component	Specification
1	NodeMCU	Model ESP8266
2	Arduino uno Microcontroller	Arduino Mega 2560
3	Relay module	5 V
4	Humidity sensor	5V DC SL module
5	Gas sensor	CCS811 module sensor
6	Temperature sensor	DHT11 sensor
7	Jumper Wire	
8	Liquid crystal display (LCD)	16x2 LCD screen
9	Wi – fi module	ESP8266 01S
10	Bread board	
11	Storage chamber	Capacity of 0.2 m^2, and made from aluminum sheet
12	Heater	100°C, sensitivity of ± 0.1°C
13	Fan	SL-PCI-02_SML, DC 12 V, speed 2500 rpm

Development of the Internet of Things (IoT) System

The language use for the design was the C++ language, while the framework was the arduino IDE and blynk App. The blynk application (App) for Android was used to develop the GUI Interface, while the arduino IDE was used to build instruction for the board (Jenkins and Kurasaki, 2018). The blynk app is compatible with numerous IoT applications. Blynk app has effective pins that emulate the Arduino pins, which are used to transfer information between itself and the Arduino.

Furthermore, a Wi-Fi module (powered by 3V DC dry cell) which is an extremely integrated chip was used link the smart storage system to the web (internet), to facilitate the communication with the mobile app distantly. All the system hard ware (fan and heater) were powered by a 12 V battery; while the PIC heater and fan were switch “OFF” and “ON” through the help of the relay modules. Humidity and

temperature sensors are sensitive devices, which were incorporated into smart system to monitor the temperature and humidity level inside the storage system.
The graphical user interface (GUI) used in selecting commands in this system is presented in Figure 3. On the System dashboard is the Switch "ON" and "OFF" buttons, which allows the user to switch on the heater and fan from anywhere, provided there is internet network.

Figure 3. *System dashboard design.*

Testing of the Smart Storage System

The storage system was test run at the research center of the Delta State University of Science and Technology, Ozoro, Nigeria. The internal temperature and humidity of the system were pre-set at 32°C and 62% RH respectively. It took the system about 3 h to attain this pre-set state. Few potatoes tubers were put inside the storage chamber, and the system was allowed to run a period of 20 hours.

RESULTS AND DISCUSSION

The results obtained through the testing of the automated storage chamber are presented in Table 2. It was noted that the heating system automatically switched on when the temperature inside the storage chamber fell below 32°C; but when the temperature rose above 32°C due to heat of respiration of the stored material, the heater was switched on. Table 2 depicted that the heating system operated for 13 h, during the 20 h during which the system was test-run. Nevertheless, as presented in Table 2, the smart storage structure has efficiency of 85%. These results are similar to earlier observations made by Mabrouk *et al.* (2017), who recorded approximately 90% success in a design smart storage system. Similarly, Karim *et al.* (2018) reported about 91% success in using IoT to monitor the temperature and humidity inside storage chamber.

Table 2. *The environmental conditions measurement.*

Time (h)	Humidity (%)	Temperature (°C)	Heater	Fan
0	75	35	OFF	ON
1	71	38	OFF	ON
2	68	33	OFF	ON
3	72	34	OFF	ON
4	57	30	ON	ON
5	59	31	ON	ON
6	63	29	ON	ON
7	65	28	ON	ON
8	54	31	OFF	OFF
9	50	30	OFF	OFF
10	51	25	ON	OFF
11	52	24	ON	OFF
12	60	23	ON	ON
13	61	24	ON	ON
14	63	25	ON	ON
15	62	20	ON	ON
16	67	25	ON	ON
17	62	27	ON	ON
18	55	29	ON	OFF
19	49	33	OFF	OFF
20	51	32	OFF	OFF

Based on the programmed temperature (32°C) and humidity of 62%, it was noted that the system operated at the right temperature setting in 17 occasions.

Efficiency of the system based on the heater performance = $\frac{17}{10} \times 100 = 85\%$.

Failure rating of the system based on the heater performance = 100 – 85 = 15%.

It was observed that the humidity sensor failed in some cases, as the humidity increases with increased in the chamber temperature. This could be linked to transmission speed of the sensors used for the prototype construction.

CONCLUSION

The research was carried out to develop a model smart storage structure. Heat and humidity sensors were incorporated into the storage structure, to effectively monitor the temperature and relative humidity inside the storage system. These two parameters are crucial factors to be considered during the design and development of any storage structure for agricultural products. The system was tested with potato tubers, and results obtained revealed that based on temperature regulation, the smart system has 85% accuracy. Although, 15% failure rate was recorded, this smart prototype is a major breakthrough in the production of smart storage system for agricultural products.

DECLARATION OF COMPETING INTEREST

We hereby declare that we have no conflict of interests.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Ovuakporaye Godwin Ekruyota data analysis and review of the original draft,
Omokaro Idama designed the research and writing the original draft.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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