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Drug Storage System based on Fuzzy Logic and the Internet of Things

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ABSTRACT:

Health-related issues are a top priority for anyone in the world, and if there is any issue related to health, then solutions should be found as soon as possible. Medicine is one of the most important causes of recovery, so storing medicines of the highest possible quality is necessary. Storing medicines is very important for the hospital because they are used for hormones, viruses, and ointments, which are of great value to the hospital's sustainability and must always be preserved. This study designed and implemented a system to continuously control and monitor sensitive atmospheric information for drug storage, such as temperature, humidity, and light exposure. The system starts by reading the environment sensors around the drug store by the microcontroller. Then the microcontroller passes the data to the fuzzy logic. Mamdani-type fuzzy control is implemented to control and monitor devices that are used on fuzzy rules. The system has the ability to send an alarm when any of the temperature and humidity-related parameters are higher or lower than normal. The data collected using this system is sent via two methods: the first is the website platform, and the second is GSM notification. Drug storage is designed and implemented using a microcontroller and IoT sensors. During the system analysis phase, the SWOT method was utilized to obtain user perspectives and preferences, which were then incorporated into the system output specifications for the development phase. This approach helped to identify the necessary system requirements. During the implementation phase of the system and to measure the capabilities of the system, the technique of measuring the system usability scale was used, with the contribution of 22 users of the system, and the percentage recorded as general satisfaction with the system was 91%. The new system improves the overall quality of drug storage, reduces the risk of drug deterioration to patients' health, and reduces the incidence of adverse events associated with drug mismanagement.
KEYWORDS: Fuzzy Logic System, Temperature Control System, Humidity Control System, Global System for Mobile Communication, System Usability Scale.

1. INTRODUCTION

Storage of medicines is a very important asset of the hospital because there are medicines used for hormones, viruses, and ointments which are very valuable for the sustainability of the hospital, so the weather conditions for storing medicines should always be monitored in real-time (Biryukov et al., 2020). One of the important factors to watch is the humidity and temperature of the store because high temperatures and extreme humidity affect the drugs (Fletcher et al., 2013). The normal range for storing medicines is between 10 and 25 degrees Celsius, and the normal range for relative humidity is between 30% and 60% (Sihombing et al., 2018). The effects of low moisture static charge accumulation are one of the main effects of low relative humidity levels below 30%, and static charge accumulation can cause drugs to dry out, negatively affecting the solubility process of the solutions used in production (Wang et al., 2020). Products absorb too much moisture in the atmosphere when the humidity levels are high, this may be equally harmful as being in low humidity. The strength and usefulness of some products can be compromised by excessive humidity, which can cause product deterioration or indeed toxicity. Mites, fungi, mold, bacteria, and viruses can flourish in environments with relative humidity values of 55% or more (Zare & Mehrabi, 2019).

The many chemicals included in medications interact with the body to prevent disease and malfunction when they are combined into a pill, liquid, or another form. Although these substances work once, they enter the human body. They are often not chemically stable enough to survive for extended periods of time, even under ideal circumstances. Additionally, high temperatures impact the stability of medications. Medicines start to degrade at extremely hot temperatures. Then, contaminants develop that reduce a drug's effectiveness in curing a patient. Additionally, contaminants may possibly be harmful to the person using the drug. Medical proteins also break down in extremely low temperatures. For instance, vaccinations and insulin that are kept frozen throughout storage lose their potency and may not be used (Pradhan et al., 2021).

Utilizing the Internet of Things (IoT) is one system-based strategy that is utilized to regulate and keep track of the humidity and temperature of medicine storage. This is the concept that data transmission via a network can be accomplished by an item without the requirement for human-to-human or human-to-computer interaction. IoT-based tools to keep an eye on drug storage, gas, light, humidity, and temperature data may be automatically monitored utilizing sensors and microcontrollers linked to local and internet networks. IoT devices can manage the humidity and temperature, allowing the drug storage humidity and temperature to be maintained within a specified range. Fuzzy logic, which makes mapping the input space to the output space easy, is among the greatest methods for managing a microcontroller-based system. Fuzzy logic is simple to comprehend, adaptable, tolerant of incorrect data, being capable to directly develop and use expert expertise without training, able cooperate with traditional control techniques, and is based on the concept of natural language. The basis for fuzzy logic architecture is the microcontroller that controls the air conditioner and fans to regulate the temperature and employ the dry mode to reduce storage humidity (Ahamed et al., 2016; Prakash et al., 2019) The primary goal of this paper is to protect medicines in drug storage by utilizing microcontroller and fuzzy logic to manage temperature and humidity.

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2. RELATED WORKS

In this section, a literature review is provided on previous research related to the proposed work. The focus is on the contributions of multiple researchers in the area of IoT and Fuzzy Logic Systems (FLS).

The Internet of Things (IoT) has made it feasible and uncomplicated to design a smart management system. This smart management system enables individuals to supervise, regulate, and handle the system without any wastage. The management of water is a crucial matter, and the proposed method is an IoT system integrated with a fuzzy controller-based system for managing the water level in the storage tank at the Rumaila power plant, located in the southern region of Iraq. The existing system, consisting of two electric motor pumps, is responsible for supplying untreated water from the river to the storage tank for later use in reverse osmosis (R.O.). However, this system is manual and lacks an efficient monitoring and control system. This research paper presents two control systems, namely the classic PID and fuzzy logic, and a comparison between them. The fuzzy control system is initially simulated using MATLAB and later developed using a Sugeno-based fuzzy algorithm within the Programmable Logic Console (PLC) environment. The Modbus protocol is used to connect the PLC with the Object Process Control (OPC) server, while the sensors are directly connected to the Kayenne platform. The IoT system is built using OPC and MQTT to publish and subscribe data from the PLC and cloud. The wireless communication between the sensors and router is facilitated by the Node MCU-ESP8266 (Ali et al., 2020).

The advancement of Internet of Things (IoT) technology has allowed for the seamless connectivity and data exchange between smart devices and sensors, resulting in the need for robust data analysis and storage platforms like cloud and fog computing. The healthcare industry has shown significant interest in IoT as it has the potential to improve patient safety, staff satisfaction, and operational efficiency. This survey aims to examine the latest IoT components, applications, and market trends in healthcare and review the current development of IoT and cloud computing-based healthcare applications since 2015. The paper also explores the use of promising technologies like cloud computing, big data, wearables, and ambient assisted living in healthcare and evaluates the IoT and e-health regulations and policies worldwide. Additionally, the paper conducts an extensive analysis of IoT privacy and security issues, including potential threats and attack types from a healthcare perspective. The study concludes by discussing previous security models and providing insights into trends, challenges, and opportunities for the future development of IoT-based healthcare (Dang et al., 2019).

The study proposes a server room's layout humidity and temperature regulating mechanism utilizing fuzzy logic and a using a Wemos D1 microcontroller as a remote device with an infrared transmitter to regulate the in the Air Conditioner's settings and temperature to regulate the temperature and humidity of the server room. With computation testing results applying MATLAB, fuzzy logic built on a microcontroller has been effectively developed and embedded into the microcontroller for regulation of the humidity and temperature of a server room. The mean output deviation AC Mode Set became 0.01225 and the mean output deviation of the AC Temperature Set became 0.03500. Additionally, system is intended to be capable of monitoring data that is humidity, power voltage and temperature online by using internet sites and sending out warning signals early on via social media (Purwanto et al., 2018).

Field irrigation in conventional agricultural systems uses a lot of energy. A smart irrigation system is suggested by this study which employs the Global System for Mobile Communication (GSM) to help farmers irrigate their fields. A confirmation indication is sent by the system on the work's state, including the area’s temperature, the soil's humidity level, and the motor's condition in relation to the primary power source or solar energy. Fuzzy logic controllers are used in calculating input parameters (e.g., humidity, temperature, and soil moisture) and generating motor status outputs. When rain is available, the system turns off the motor to save energy and prevents the crop-using panels from receiving constant rain. Drip irrigation, manual flooding, and the proposed system are all compared. The comparison results demonstrate that the proposed smart irrigation system conserves both water and power (Krishnan et al., 2020).

PharmDE is an expert system that assesses the risk of drug-excipient incompatibility using knowledge. To store incompatibility data, PharmDE first created a knowledge database with 532 datasets from 228 publications. Then, based on information, research, and discoveries, 60 drug-excipient interaction limitations were developed. Therefore, due to an organic mix of database searching and rule-based incompatibility risk prediction, the PharmDE drug-excipient incompatibility database now comprises 532 data items related to 200 medicines and 123 excipients. IST yielded 163 collected data items (30.6%); whereas, thermal technical implementation provided 127 data items (23.9%), combining the two equipment analysis methods produced 97 data items (18.2%), and other procedures such as in vivo testing and dissolution testing generated 145 data items (27.3%) (Wang et al., 2021).

Internet of things-based irrigation system that uses fuzzy logic to minimize the watering frequency and boost crop output rate. A Mamdani fuzzy controller joins data from the environment like temperature sensors and soil sensors, after which applies fuzzy rules to regulate the flow of water from the water pump and deliver water just at the appropriate time and frequency. This may be built and programmed using MATLAB. Fuzzy logic and IoT technologies were combined to develop an intelligent irrigation solution for conserving water and improving irrigation control in high-water-stress areas. Using trapezoidal and triangle element functions depends on Mamdani fuzzification, the produced fuzzy controller efficiently calculates the irrigation time and duration for a certain crop. The fumigation control application kept the soil wet above a predetermined level with smooth changes, avoiding device weariness and saving water and power. The gadget was also tracked in real-time using a massive ZigBee wireless network (Alomar & Alazzam, 2018).

3. METHODOLOGY

Using Mega2560 microcontroller and fuzzy logic system, the creation of a new system for regulating humidity and temperature of drug storage will be discussed (Kravchenko et al., 2020). As shown in Figure (1), the system's operational structure for drug storage system. In this paper, the FLS technique was relied on to control the decision-making process to keep the drug storage temperature and humidity within the required range for storage using an air conditioner and a fan depending on data that are received from the sensors. The microcontroller obtains data from sensors such as voltage, humidity, temperature, smoke, and light. It then sends this temperature, humidity, gas, and light values to the website over the network automatically, which are monitored by all authorized users using their devices (computers and smartphones). To regulate the humidity and temperature of drug storage, humidity and temperature were read from sensors by the system as precise input for fuzzification then an inference system (fuzzy rule bases) was used to process the fuzzy input from the fuzzification, then, to manage the temperature and humidity, fuzzy output was processed using defuzzification to generate proper result, so that the humidity and temperature are controlled by the air conditioner and fan (Fezari & Al Dahoud, 2019; Wang, 2014). The system circuit diagram in Figure (2) shows the connection between the devices and sensors of the microcontroller.

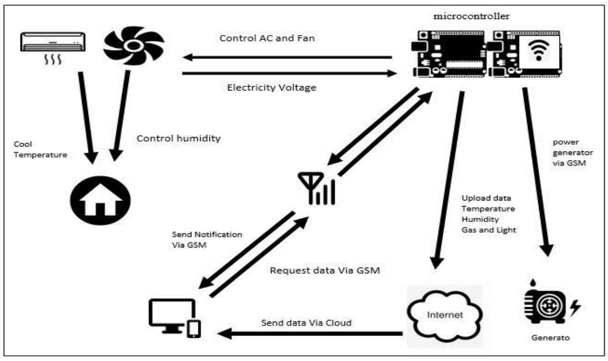

Figure 1. Describes a system that has been designed to monitor and control drug storage conditions

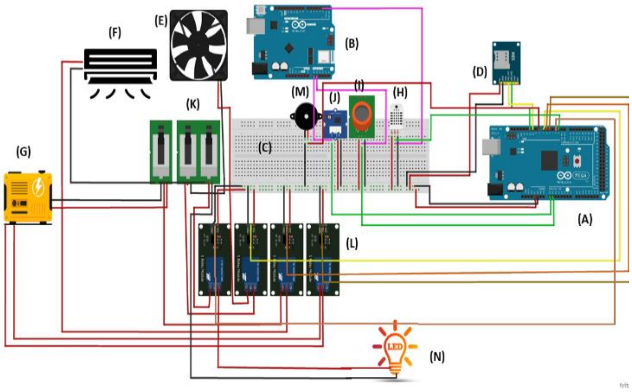

Figure 2. System Circuit Diagram.

A- Mega 2560 Rev3	B- Uno Wi-Fi	C- Breadboard
D- GSM800L	E- FAN	F- Air condition
G- power generator	H- DHT22	I- Gas Sensor (MQ2)
J- Light Sensor	K- Switch	L- Relay
M- Buzzer	N- System Light	

3.1 Fuzzy

Because of their ability to "train" and "learn" how to execute during a control task, FLS are considered a form of intelligent control system. FLS can include part of the knowledge of human specialists as logical inference rules. These controllers can then behave similarly to humans, for instance, by "deciding" what to do in different situations. The ability of fuzzy logic technologies to offer an approximate answer to an imprecisely described problem is its primary distinguishing feature, which the two-valued classical logic does not provide. Fuzzy logic is more human-like than classical logic (Ordila & Irawan, 2020). A FLS consists of three main parts: Fuzzifier (Fuzzification), Rules, Defuzzifier (Defuzzification).

3.2 Fuzzification

Through the use of a membership function, this section converts sensor-generated quantitative numerical data into qualitative linguistic variables. The three functions that are most commonly employed in the literature are the Gaussian, triangular and trapezoidal. Controlling temperature and humidity is the fuzzy process of transforming input into fuzzy form is called fuzzification. Fuzzification gives a membership degree. Figures (3) and (4) show that humidity and temperature are examples of fuzzy input membership degrees. AC and Fan are examples of fuzzy output membership degrees. For forms of membership function, we employ fuzzy trapezoidal (Mittal et al., 2020).

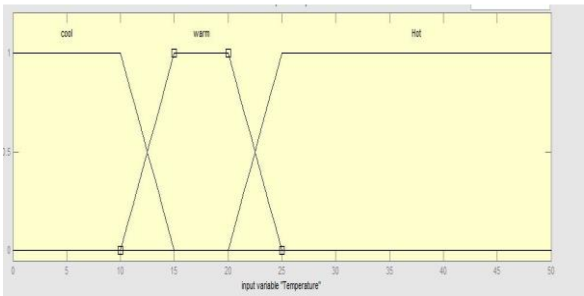

Figure 3. Displays the membership functions for the variable "temperature", which are categorized into three groups: "cool", "warm", and "hot"

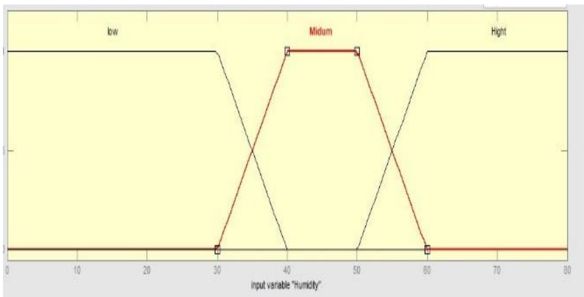

Figure 4. Displays the membership functions for the variable " Humidity ", which are categorized into three groups: " Low ", " Medium ", and " High "

3.3 Rule base

A group of different rules that connect the system's fuzzy input variables to its fuzzy outputs is generally referred to as inference rules. Such rules are shown as "IF-THEN" rules: IF condition 1 AND/OR condition 2 (and/or) THEN follow-up with the results (Villarrubia González et al., 2017). Table (1) and (2) show the fuzzy rules for the Fuzzy Logic system.

Table 1. fuzzy rules for temperature and humidity control system.

	IF (Humidity is High) and (Temperature is Cool) THEN (AC is OFF) and (FAN is ON)
	IF (Humidity is low) and (Temperature is cool) and THEN (AC is OFF) and (FAN is OFF)
	IF (Humidity is medium) and (Temperature is cool) THEN (AC is OFF) and (FAN is ON)
	IF (Humidity is low) and (Temperature is warm) THEN (AC is OFF) and (FAN is ON)
	IF (Humidity is medium) and (Temperature is warm) THEN (AC is ON) and (FAN is OFF)
	IF (Humidity is High) and (Temperature is warm) and THEN (AC is ON) and (FAN is OFF)
	IF (Humidity is low) and (Temperature is Hot) THEN (AC is ON) and (FAN is OFF)
	IF (Humidity is High) and (Temperature is Hot) THEN (AC is ON) and (FAN is ON)
	IF (Humidity is medium) and (Temperature is Hot) THEN (AC is ON) and (FAN is OFF)

Table 2. shows the matrix representation of the fuzzy rules for the Fuzzy Logic.

Temperature\ Humidity	LOW	MEDIUM	HIGH
COOL	AC-OFF\ FAN-OFF	AC-OFF\ FAN-ON	AC-OFF\ FAN-ON
WARM	AC-OFF\ FAN-ON	AC-ON\ FAN-OFF	AC-ON\ FAN-ON
HOT	AC-ON\ FAN-OFF	AC-ON\ FAN-OFF	AC-ON\ FAN-ON

3.4 Defuzzification

In this stage, the several instructions produced by the inference engine would be combined into a single output. The process of transforming a linguistic variable that is qualitative into numerical data that is quantitative can be accomplished through various methods. The two most widely used defuzzification techniques are mean of maximum (MOM) the center of gravity (COG). Figures (5) and (6) present degrees of fuzzy output membership, including Ac and Fan, forms of membership function, we employ fuzzy trapezium (Dewantoro et al., 2020).

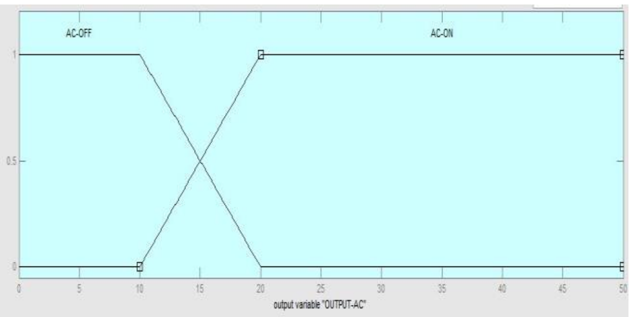

Figure 5. Displays the output membership functions for the air conditioner, which are categorized into two groups: "AC OFF" and "AC ON"

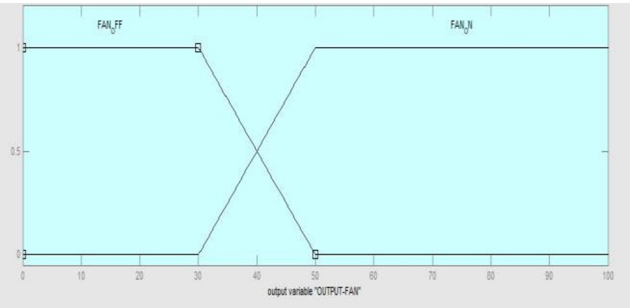

Figure 6. Display the output membership functions for the FAN, which are categorized into two groups: " FAN OFF" and " FAN ON"

3.5 Internet of Things

The Internet of Things (IoT) refers to a system in which a variety of mechanical and digital devices, as well as computers and other items, are interconnected and able to communicate with each other via a network, without requiring any form of interaction between humans or between humans and computers (Dewantoro et al., 2020; Silva et al., 2018).

3.6 Hardware specification details

Using the Arduino, the employed gadgets will determine the environment surrounding the pharmacy as well as the state of the pharmaceuticals and medications. The "Drug Store model" employs a variety of gadgets, and their specific features are outlined in Table 3. The sensors present in each gadget play a crucial role in collecting all the required information (Demircilioğlu et al., 2019; Koshti et al., 2016).

Table 3. hardware specification details.

Devices / Technology	USAGE	NAME	ATTRIBUTES
Sensor of temperature	Store temperature	DHT22 (AM2302)	Voltage- 3 to 6V DC Accuracy +/- 0.5ºC (at -40 to 80ºC)
Sensor of humidity	Store humidity	DHT22 (AM2302)	Voltage- 3 to 6V DC Accuracy +/- 0.5ºC (at -40 to 80ºC)
fire detection system	In order to avoid the possibility of a fire breaking out in the store.	MQ2 GAS	Voltage- 3.3~5 V Responsive time -15—s Size- 22×30mm
Light sensors	level of light	LDRLM 393	3.3V-5V
GSM	SMS text messages	SIM800L GSM/GPRS	3.4V to 4.4V
Relay	Normally Open, Normally Closed	Relay	voltage 5V
Microcontroller	Control all devices	Mega2560	Voltage 7 to 12V
Microcontroller	To upload data to the website	Uno Wifi	Voltage 7 to 12V

3.7 Software specification details

Software specification is important to analyze the data. Table (4) shows the software used in our model.

Table 4. shows the software used in the system.

No.	Software used
1	Arduino IDE Version :1.8.16
2	Programming Language: C
3	Fuzzy Library: eFLL Library
4	Fuzzy Type: Mamdani
5	Aggregation: Max Defuzzification Centroid
6	Membership function Type: Trapmf
7	Defuzzification centroid

4. RESULT AND DISCUSSION

The drug storage environment must be under control twenty-four hours a day, and it is not humanly possible to do so cheaply or reliably. Drug is very important for patient safety, so more papers are needed in this area. Temperature, humidity and light values varied over a wide range. Medicines are very sensitive to the environment in which they are stored. Therefore, the development of FLS applied to the Internet of Things in the drug storage environment is necessary to reduce costs and obtain high reliability of use. The developed system also does several other things, such as sending a notification via GSM to the responsible person or turning on the power generator when necessary (Sugiyanti, 2019). Using the traditional method, air conditioners, fans, and other controls always have to be operated manually, which will consume a lot of electricity and also shorten the life of the appliances. To solve these problems, a FLS has been developed on a microcontroller to be used in all control devices more effectively and efficiently to increase their lifespan and consume less energy. A FLS has preserved the drug storage atmospheric condition. If the drug storage temperature exceeds the normal range, the fuzzy logic will activate a fan to lower the temperature and bring it back within the normal range, and if the temperature is too high, the air conditioning system will be activated by the fuzzy logic in order to bring the temperature back down to the normal range. in the drug storage environment. Fuzzy logic also turns off the air conditioner and fan. The system activates the fan to remove the moisture from the air when the humidity is higher than normal range, to keep the humidity and temperature within the allowed range.

As demonstrated in Table (6), the designed system, which made use of the FLS, produced very good standard deviation results. It is evident from the experiment results that fuzzy logic provides very good solutions. The microcontroller requires an average response time of 10 seconds in generating corresponding output signals upon detecting any anomalies or variations in input variables. In this paper, the SUS questions are utilized. A total of 10 questions made up the questionnaire's content, The 5 odd numbers are positive and 5 are negative (even numbers). The same individuals who took the first exam also took part in this one at the Department of Pharmacy and Drug Storage. During the SUS testing phase (20 days), from (3/10/2022) to (23/10/2022). This questionnaire's primary objective is to assess the Drug Storage System's usability while taking into account the satisfaction, efficiency, and effectiveness of the System Users (Sabri et al., 2017). The test's outcomes are presented in Table (5).

Table 5. SUS Score by the participants (N=22).

Participant	SUS score	Participant	SUS score
User1	92.5%	User12	92.5%
User2	92.5%	User13	90%
User3	87.5%	User14	92.5%
User4	97.5%	User15	90%
User5	90%	User16	92.5%
User6	97.5%	User17	90%
User7	92.5%	User18	92.5%
User8	92.5%	User19	92.5%
User9	72.5%	User20	95%
User10	95%	User21	90%
User11	92.5%	User22	95%
SUS Total Score	91.71		

In this test of usability, 22 users took part in the system's testing. The minimum and highest SUS scores are 72% and 97.5%, respectively. Consequently, the overall SUS score is 91.71%, demonstrating that Fuzzy Logic Drug Storage (FLDS) complies with the requirements of the SUS. According to the findings presented in the paper, the FLDS has a high level of overall satisfaction. Again, several crucial conclusions may be drawn based on the findings. Users would prefer to utilize this system regularly, as evidenced by the (Q1) score of 4.90. Additionally, the users felt the system to be overly complicated, as shown by the score (1.27) for (Q2); this might be both a poor score and a positive outcome. Additionally, a score of (4.68) for (Q3) indicates that users found the system to be user-friendly. Therefore, the users would require the assistance of a technical expert to utilize this system by (Q4) score, which is (1.36). The users felt the different operations in this system were effectively integrated, as evidenced by the (Q5) score of (4.63). The score of (1.40) in (Q6) means that users believed this system to have too many inconsistencies. Additionally, the users believe that the majority of individuals would pick up to using this system fast, as seen by the (Q7) score of (4.68). According to (Q8), a score of (1.68) means that the system is difficult to operate. The users felt extremely confident using the system (FLDS), based on the (Q9) score of (4.72). This is a successful outcome and a high score. The last query, (Q10), received a score of (1.27), implying that a lot of users had to learn before they could utilize this system. The results are shown in Figure (7) (Abdulrazaq & Mustafa, 2017).

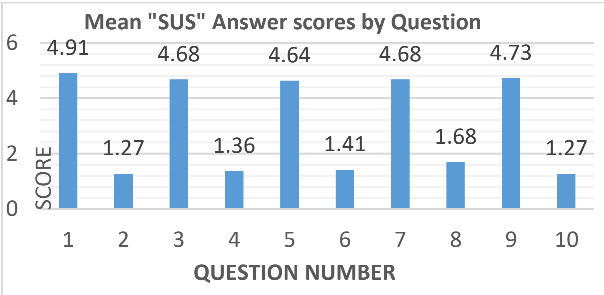

Figure 7. Mean survey result (N=22).

Table 6. The result of the fuzzy logic controller using Arduino microcontroller variation of humidity and Temperature Sensors

Temperature	Humidity	Temperature	Humidity	Temperature	Humidity
24	52	24	52	24	53
23	52	24	52	24	53
23	52	24	52	24	53
24	52	24	52	24	53
24	52	24	52	24	53
24	52	24	52	24	53
24	52	24	52	24	53
24	52	24	52	24	53
24	52	24	52	24	53
23	52	24	52	23	53
24	52	24	52	24	53
24	52	24	52	24	53
24	52	23	53	24	53
24	52	24	53	24	53

5. CONCLUSION

The integrated system has been effectively utilized to monitor and control humidity, temperature, and light in drug storage facilities to maintain a comfortable temperature range of 10-25°C and a humidity range of 30%-60%. The study's findings indicate that a fuzzy logic-based microcontroller system for regulating temperature and humidity in drug storage has been successfully designed and implemented with an average standard deviation of AC temperature setting at 0.334318 and an average standard deviation of humidity set output fan at 0.4797. Additionally, upon detecting any anomalies or variations in input variables, it is expected that the microcontroller will generate the corresponding output signals within an average response time of 10 seconds. Moreover, the developed system allows for real-time monitoring and display of temperature, humidity, and voltage information via a website platform, thereby enabling early warning messages to be dispatched through GSM in the event of abnormalities, ensuring prompt action and effective control. According to the SWOT analysis, the conventional system's weakness lies in the absence of a sophisticated automated mechanism to monitor and control the atmosphere of drug storage. The system's primary strength lies in its capability to automatically monitor and control the atmosphere of the drug storage system, resulting in increased efficiency in medication and drug storage. Furthermore, the evaluation of the developed system through testing has revealed that the overall satisfaction rate with the current system was successful (91%) as determined by the respondent's assessment of the System Usability Scale (SUS). In future works to enhance the quality control of medicines, it is recommended to establish a unified system for both private and government drug stores to monitor and track medications from their origin, along the transportation process, and until they arrive at the drug stores. This would allow the Ministry of Health to exercise better control over the quality of medicines.

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