Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Classification of Temperature and Humidity in Green Open Spaces by Implementing Internet of Things (IoT) using Mamdani Fuzzy Logic

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ARTICLE INFO

Article history:
Received 8 December 2023
Received in revised form 22 May 2024
Accepted 15 June 2024
Available online 31 July 2025

Keywords:
Green open spaces; Internet of Things; sensor; Mamdani fuzzy logic

ABSTRACT

The condition of green open spaces plays a pivotal role in influencing the comfort and well-being of users engaged in various activities within these environments. Hydrological and microclimate factors, particularly temperature and humidity, hold significant sway over the ecological balance in these areas. This study addresses the need for a tool to assess air temperature and humidity, facilitating public access to critical environmental data that impacts the psychological well-being of living organisms. In pursuit of this objective, a comprehensive monitoring system harnessing the power of the IoT was developed. This system integrates DHT22 and MQ-9 sensors to monitor temperature, humidity, and CO2 gas levels within multiple green open spaces. Data from these sensors is transmitted to a central database with minimal time delays: 2 seconds from the sensors to the server, 1 second from the server to the application, and 3 seconds from the hardware to the application. Impressively, this data transmission achieved a 100% success rate. To assess the comfort levels of these green open spaces, the system employs fuzzy Mamdani logic. It processes data obtained from the DHT22 sensor, using predefined temperature and humidity value thresholds. This innovative monitoring system provides valuable insights into the environmental conditions of green open spaces, contributing to the enhancement of the overall quality and suitability of these areas for various activities.

1. Introduction

Green open spaces are essential components of urban landscapes, providing respite and recreational opportunities for residents and visitors alike [1]. The quality of these spaces profoundly affects the comfort and well-being of individuals engaged in various activities within them. Critical factors such as hydrological balance and microclimate conditions, specifically air temperature and

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https://doi.org/10.37934/araset.49.2.205217

humidity, exert a profound influence on the ecological equilibrium within these environments [2-4]. Recognizing the significance of these environmental parameters and the need to empower the public with data relevant to their well-being, this study endeavours to design and implement an innovative monitoring system [5-7].

The role of greenery within open urban spaces, often referred to as the city's "green lung," involves an ongoing process of recycling between carbon dioxide (CO_2) and oxygen (O_2) gases through photosynthesis, primarily occurring within leaves [8]. This system of managing green spaces essentially serves as a form of natural ventilation within the urban environment. Moreover, green open spaces offer a myriad of functions beyond this, including aesthetic enhancements that provide valuable opportunities for both active and passive public recreation. These benefits are realized through the implementation of a green corridor system, serving as a spatial control mechanism within the urban green space framework [9,10]. Fuzzy Logic, a mathematical concept rooted in the theory of fuzzy sets, proves to be a suitable method for translating input data into meaningful output within various applications, including urban planning [11-14].

Numerous scholarly discussions in the field of Environmental Monitoring have explored the application of Fuzzy Logic. For instance, Fişne *et al.,* [15] employed a fuzzy logic approach to predict peak particle velocity (PPV) by considering parameters such as the distance from the blast face to the vibration monitoring point and the charge weight per delay. Their findings revealed a strong correlation, with a higher correlation coefficient (0.96) for the fuzzy model compared to a regression model (0.82). Muhammetoglu and Yardimci [16] innovatively applied fuzzy logic to assess groundwater pollution levels beneath agricultural fields, particularly those subject to intensive agricultural activities involving excessive fertilizer application. Pivovarova *et al.,* [17] introduced an expert information system designed to evaluate environmental risks, especially when dealing with complex and uncertain source data. Robles Algarín *et al.,* [18] presented a cost-effective system for monitoring and remotely controlling a greenhouse using fuzzy logic. Their system offered seamless access to configuring, monitoring, and controlling climatic conditions within the greenhouse. Su *et al.,* [19] proposed both average and adaptive fuzzy logic algorithms for temperature computation in monitored areas. These methods are renowned for their simplicity, accuracy, and outperforming the standard Mamdani fuzzy logic approach. Brulin *et al.,* [20] devised a computer vision-based posture recognition technique for home monitoring of the elderly. Prior to posture analysis, their approach utilized fuzzy logic for human detection. Malmir *et al.,* [21] delineated suitable urban development sites in Ahwaz County, employing a comprehensive set of biophysical and socioeconomic criteria. These criteria, comprising 27 sub-criteria, were initially derived through a literature review and expert interviews. Azaza *et al.,* [22,23] made a notable contribution by integrating key parameters governing the climate within a greenhouse. Their approach, founded on fuzzy logic, aimed to create an optimal micro-climate conducive to plant growth while simultaneously conserving energy and water resources. In summary, these studies collectively underscore the versatility and efficacy of fuzzy logic in addressing various facets of Environmental Monitoring, from assessing ground pollution to optimizing greenhouse conditions and beyond. However, integrates multiple sensors (DHT22 and MQ-9) to comprehensively monitor environmental factors, including temperature, humidity, and CO gas levels are still challenge of this work. This comprehensive approach allows for a more nuanced assessment of green open space conditions.

The main contribution of this study is to create a tool capable of detecting and disseminating real-time information regarding the temperature and humidity of the air within green open spaces. The primary aim is to enable individuals to access crucial data related to environmental conditions, ultimately impacting the psychological and physiological comfort of living organisms within these areas. Achieving this objective necessitates the development of a robust monitoring system that seamlessly integrates IoT technologies.

2. Methodology

2.1 Data Collection

In this study, we strategically placed DHT22 and MQ-9 sensors within selected green open spaces to capture real-time data on temperature, humidity, and CO2 gas levels. Additionally, we implemented a data transmission system to send sensor readings to a central database. The data transmission time delay was configured as follows: 2 seconds for data transfer from sensors to the server, 1 second from the server to the application, and 3 seconds from the hardware to the application.

2.2 Fuzzy Mamdani Logic Implementation

In this section, we will develop membership functions for temperature and humidity values, guided by predefined comfort level thresholds. Additionally, we construct a comprehensive fuzzy rule base for processing sensor data using Mamdani logic. Finally, implement the inference engine to assess the comfort level of green open spaces based on the established fuzzy logic rules

2.3 Implementation of the Monitoring System

The monitoring system for air temperature and humidity in green open spaces, based on fuzzy logic Mamdani and IoT, operates through a multi-component process. It begins with the utilization of the DHT22 sensor, which captures both air temperature and humidity data. This data is then processed by the Arduino Uno microcontroller, integrated into the system for program execution. Additionally, Mq series sensors serve as gas detectors, specifically for monitoring CO2 gas levels within green open spaces. The collected data is systematically stored in a dedicated database. Finally, the results of temperature and humidity detection are visualized in real-time through a web application, offering a user-friendly interface for accessing and interpreting the environmental data. The design process of this research can be seen in Figure 1.

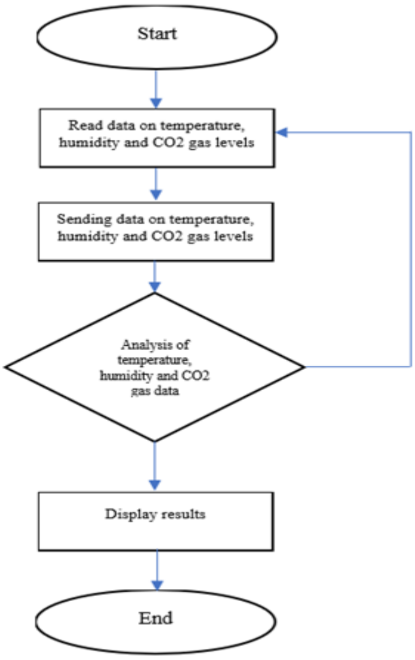


Fig. 1. Flowchart of this work

3. Results and Discussion

3.1 Modelling Fuzzy Mamdani

Automation for regulating air comfort is managed by the Arduino controller. In this context, the controller employs the Mamdani fuzzy method as a decision-making system for assessing air comfort, considering input values of temperature and humidity. The knowledge base within this system encompasses decision criteria and corresponding fuzzy sets. These criteria are categorized into linguistic variables, defining air comfort based on the following parameters:

i. Temperature: Cold, Moderate, Hot
ii. Humidity: Moist, Dry

The overall range of discussion that elucidates the determination of air comfort, considering various criteria and values, is presented in Table 1.

Table 1
Fuzzy universe set

Variable	Fuzzy universe set
Temperature	15-40
Humidity	0-100

The temperature configuration is determined by the temperature sensor's readings, which fall within the range of 15 to 40 degrees. This temperature variable comprises three distinct categories: cold, moderate, and hot. You can find the temperature variable categories in Table 2.

Table 2
Fuzzy temperature function

Fuzzy Temperature Function	Value Range
Cold	15-21
Medium	20-27
Hot	25-40

We can write fuzzy temperature function as follows:

$$\mu_{cold}[x]\begin{Bmatrix} 0.5, & 0 \leq 20 \\ \frac{21-x}{21-20} & 20 \leq x \leq 21 \\ 0 & x \geq 21 \end{Bmatrix} \tag{1}$$

$$\mu_{medium}[x]\begin{Bmatrix} 0, & x \leq 20, x \geq 27 \\ \frac{x-20}{25-20} & 20 \leq x \leq 25 \\ \frac{27-x}{27-25} & 25 \leq x \leq 27 \end{Bmatrix} \tag{2}$$

$$\mu_{hot}[x]\begin{Bmatrix} 0, & x \leq 25 \\ \frac{x-20}{25-20} & 25 \leq x \leq 40 \\ 1 & x \geq 40 \end{Bmatrix} \tag{3}$$

The humidity parameter is divided into two categories: "moist" and "not moist." The categorization of humidity is determined by the humidity sensor's measurements within the range of 0 to 100. The specific humidity categories are detailed in Table 3.

Table 3
Humidity set function

Humidity Set Function	Value Range
Not Moist	0-20
Moist	3-100

We can write fuzzy humidity function as follows:

$$\mu_{not\ moist}[x]\begin{Bmatrix} 0.3, & x \leq 3 \\ \frac{20-x}{20-3} & 3 \leq x \leq 20 \\ 0 & x \geq 20 \end{Bmatrix} \tag{3}$$

$$\mu_{medium}[x]\begin{Bmatrix} 0, & x \leq 3 \\ \frac{x-3}{100-3} & 3 \leq x \leq 100 \\ 1 & x \geq 100 \end{Bmatrix} \tag{4}$$

when forming these fuzzy rules based on knowledge, the fuzzy rules can be seen in Table 4.

Table 4
Rule base convenience

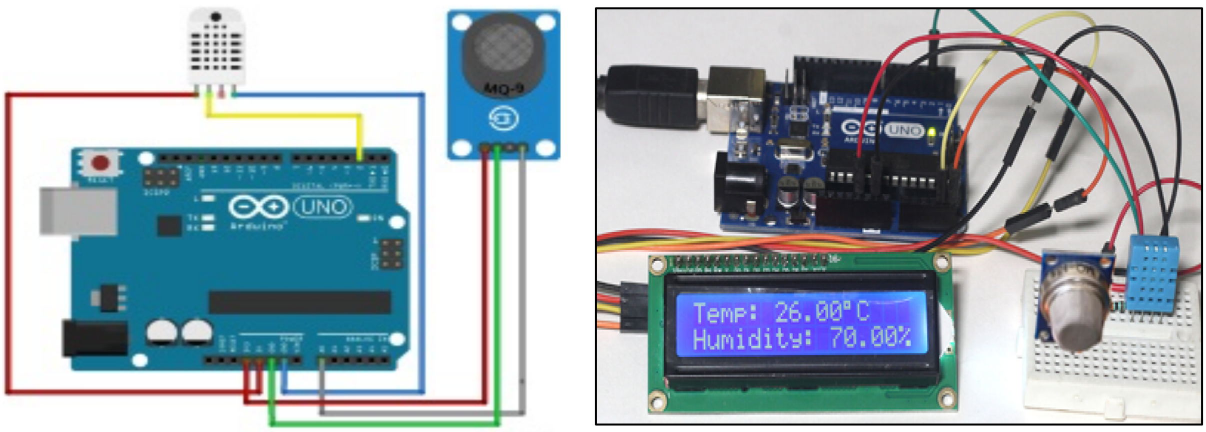
Rule	Input	Output
R1	Medium temperature and not humid humidity	comfortable
R2	Medium temperature and sticky humidity	comfortable
R3	Cold temperature and not humid humidity	uncomfortable
R4	Cold temperatures and humid humidity	uncomfortable
R5	Heat and humidity are not humid	uncomfortable
R6	Hot temperatures and humid humidity	uncomfortable

3.2 Sensor Validation

The implementation of the hardware configuration elucidates the design of the hardware components for the temperature, humidity, and CO2 gas monitoring system utilizing Arduino Uno. This involves the interconnection of all the elements as depicted in Figure 2 and Table 5 provides a comprehensive listing of the pin connections that link various components to the Arduino Uno.

Table 5
Series of pins

No	Component	Pin	Arduino Uno
1.	MQ -9	VCC	3V (Vin)
		GND	GND
		A0	A0
		D0	
2.	DHT 22	-	5V (Vin)
		+	GND



(a) (b)

Fig. 2. Hardware implementation scheme: (a) Electronic schematic using fritzing (b) Hardware

The Arduino Uno and Ethernet Shield are subjected to a network connectivity test by utilizing the Arduino IDE Serial Monitor (See Figure 3a). Furthermore, the objective of testing the DHT22 sensor is to measure both temperature and humidity accurately. The testing of the DHT22 sensor aims to assess its capability to precisely detect and report temperature and humidity levels (See Figure 3b). Finally, the goal of testing the MQ-9 sensor is to monitor fluctuations in gas concentration values, with the data displayed and observed through the Arduino IDE Serial Monitor (See Figure 3c).

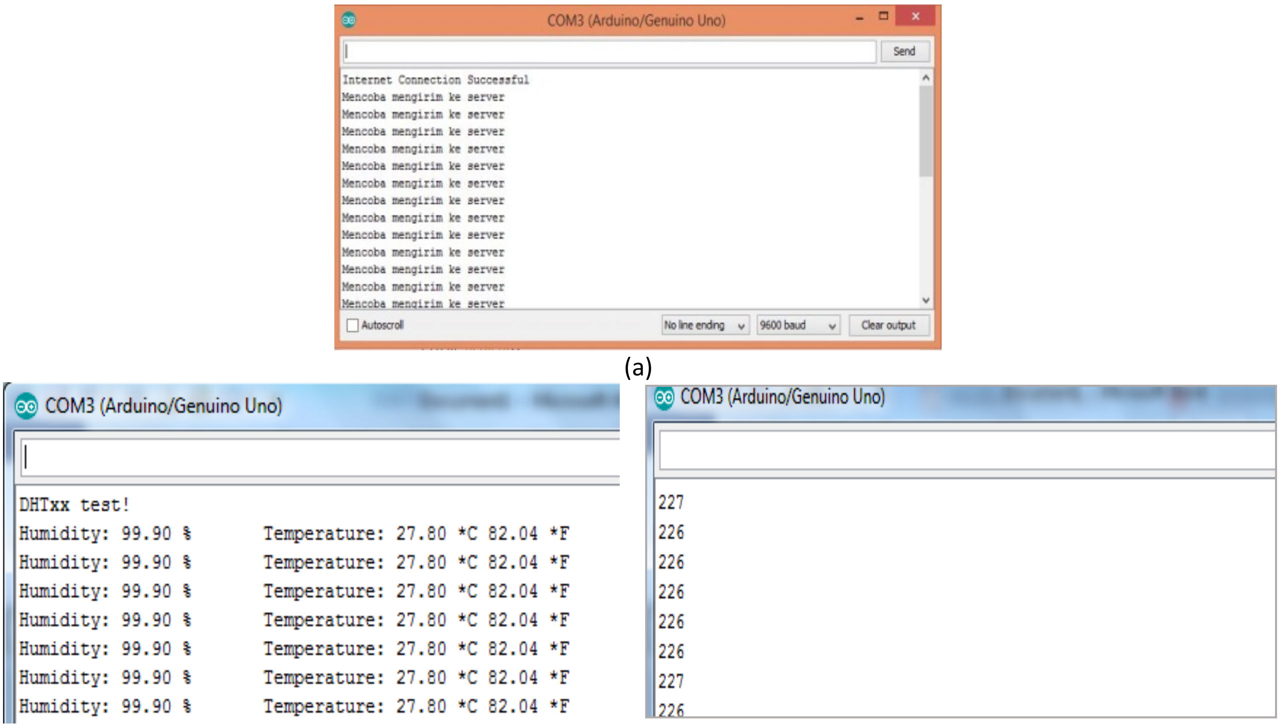


Fig. 3. Validation sensor test: (a) Shield ethernet connection, (b) DHT sensor, and (c) MQ9 sensor

3.3 Discussion

The testing of the DHT22 sensor is conducted to ascertain its ability to detect cold, moderate, and hot temperatures. This evaluation involves subjecting the sensor to alternating cold, moderate, and hot air conditions. The recorded temperature sensor data results and the humidity test results are presented in both Table 6 and Table 7.

Table 6
Temperature sensor testing

No	Condition	Prev Value	1st Value	2nd Value	3rd Value
1	Cold	26.62	9.10	4.20	3.40
2	Medium	27.19	25.40	26	26.80
3	Hot	27.56	29.20	30.40	34.40

Regarding the MQ-9 sensor testing, the primary aim is to determine the sensor's capability to detect the presence of CO_2 gas. This assessment is carried out by alternately exposing the sensor to open air. The results obtained from testing the MQ-9 sensor data can be found in Table 7, with CO_2 value data being recorded every three seconds.

Table 7
Moisture sensor testing

No	Condition	Prev Value	1st Value	2nd Value	3rd Value
1	Moist	93.90	94.10	97.20	99.90
2	Not moist	90	19.20	17.20	16.40

Subsequently, the fuzzy logic calculation process is initiated based on the input values listed in Section 3 of Table 8, which corresponds to the fuzzy method applied within the system. The fuzzy logic approach employed in this study is the Mamdani fuzzy method. This test seeks to determine both the system's fuzzy value output results and the manual calculations of fuzzy output results.

Table 8
MQ-9 sensor testing

No	MQ-9 sensor	Information
1	160 PPM	Succeed
2	172 PPM	Succeed
3	150 PPM	Succeed

Data retrieval for each condition in the predefined fuzzy rule is performed once, representing the conditions specified within the fuzzy rule. The temperature and humidity values designated for testing the fuzzy process, both manually and by the system, are detailed in Table 9 under "Fuzzy Input Value Data - Air Status. The fuzzy manual calculation process based on the input values found in number 1 in Table 9.

Table 9
Fuzzy input value data for air status

No	Temperature	Humidity (%)	Status
1	18	90	Uncomfortable

[R1] IF Moisture No Moisture and Medium Temperature THEN status Comfortable;

The antecedent set value for the fuzzy rule [R1] denoted by α1 is obtained by the following formula:

α1= μ MoistureNo Moisture∩Middle Temperature
= min (MoistureNotMoisturized [90]), Medium Temperature [18])
= min (0; 0)
= 0

According to the set function set the status is comfortable in fuzzy rules [R1] then the z1 value is:
COMFORTABLE = minstatus– α1 * (minStatus-maxStatus)
Z1 = 0-0 * (0-1)
Z1 = 0-0 * (- 1)
Z1 = 0 - (- 0)
Z1 = 0

[R2] IF Moisture Moisture and Intermediate Temperature THEN Comfortable status;

The antecedent set value for the fuzzy rule [R2] denoted by α2 is obtained by the following formula:

α2 = μ Moisture Moisture∩Middle Temperature
= min (Moisture Moisture [90]), Medium Temperature [18])
= min (1; 0)
= 0

According to the set function set the status is comfortable in fuzzy rules [R2] then the z2 value is:
COMFORTABLE = minstatus– α2 * (minStatus-maxStatus)
Z2 = 0-0 * (0-1)
Z2 = 0-0 * (- 1)
Z2 = 0 - (- 0)
Z2 = 0

[R3] IF Moisture No Moisture and Cold Temperature THEN status Uncomfortable;

The antecedent set value for the fuzzy rule [R3] denoted by α3 is obtained by the following formula:

α3= μ MoistureNo Moisture∩Cooling Temperature
= min (Humidity, No Moisture [90]), Cold Temperature [18])
= min (0; 1)
= 0

According to the set function set the status is comfortable in fuzzy rules [R3] then the z3 value is:

CONVENIENT = maxStatus– α3 * (maxStatus-minStatus)
Z3 = 1-0 * (1-0)
Z3 = 1-0 * (1)
Z3 = 1- (0)
Z3 = 1

[R4] IF Moisture No Moisture and Hot Temperature THEN status Uncomfortable;

The antecedent set value for the fuzzy rule [R4] denoted by α4 is obtained by the following formula:

A4 = μ MoistureNo Moisture∩Heat Temperature
= min (Humidity, No Moisture [90]), Heat Temperature [18])
= min (0; 0)
= 0

According to the set function set the status is comfortable in fuzzy rules [R4] then the z4 value is:

CONVENIENT = maxStatus– α4 * (maxStatus-minStatus)
Z4 = 1-0 * (1-0)
Z4 = 1-0 * (1)
Z4 = 1- (0)
Z4 = 1

[R5] IF Moisture Humidity and Cold Temperature THEN status Uncomfortable;

The antecedent set value for the fuzzy rule [R5] denoted by α5 is obtained by the following formula:

A5= μ Moisture Moisturizing uhuCooling Temperature
= min (Moisture Moisture [90]), Cold Temperature [18])
= min (1; 1)
= 1

According to the set function set the status is comfortable in fuzzy rules [R5] then the z5 value is:

COMFORTABLE = maxStatus– α5 * (maxStatus-minStatus)
Z5 = 1-1 * (1-0)
Z5 = 1-1 * (1)
Z5 = 1-1
Z5 = 0

[R6] IF Moisture Moisture and Heat Temperature THEN status Uncomfortable;

The antecedent membership value for the fuzzy rule [R6] denoted by α6 is obtained by the following formula:

A6= μ Moisture Moisturizing anasHeat Temperature

= min (Moisture Moisture [90]), Heat Temperature [18])
= min (1; 0)
= 0

According to the membership function set the status is comfortable in fuzzy rules [R6] then the value of z6 is:
COMFORTABLE = maxStatus– α6 * (maxStatus-minStatus)
Z6 = 1-0 * (1-0)
Z6 = 1-0 * (1)
Z6 = 1- (0)
Z6 = 0

The outcomes of the tests detailed in both Table 10 provide insights into the system's performance. These results encompass the system's output as well as the findings derived from manual calculations. It is noteworthy that the system-generated output aligns with the manually computed results, indicating the system's aptitude for executing fuzzy calculations effectively. With a single input with varying conditions, the system consistently produces results in concordance with manual calculations.

Table 10
Fuzzy logic testing results from air status

No	Temperature	Humidity	System Calculation Output	Manual Calculation Output	Status
1	18	90	0	0	Uncomfortable

The comprehensive evaluation of the entire system involves monitoring data transmission from the Arduino Uno hardware setup. Subsequently, the data is transmitted to the database and presented through the web application. The testing process encompasses observing the transmission of three specific datasets sent to the server, followed by retrieval through the application. Additionally, the assessment involves tracking the delay or time taken for data transmission.

Table 11
Entire system testing using Arduino

No	Sensor	Arduino Uno (Temperature)	Testing time	Database (Temperature)
1	Succeed	25 C	21:21:29	25 C
2	Succeed	25 C	21:21:36	25 C
3	Succeed	25 C	21:21:43	25 C

The outcomes of the holistic system evaluation are recorded in Table 11 and Table 12. Notably, the results in Table 11 highlight that all five data sets were transmitted and received by the server and application with a remarkable 100% success rate.

Table 12
Entire system testing web application

No	Time to receive data 1	Web application	Time to receive data 2
1	21:21:34	25 C	21:21:34
2	21:21:41	25 C	21:21:41
3	21:21:48	25 C	21:21:48

The average delay times for data transmission are detailed in Table 13.

Table 13
All system delay testing difference

Trial to	Delay		
	From Arduino Uno to server	From Server to application	From Arduino Uno to Application
1	2 Seconds	1 Second	3 Seconds
2	2 Seconds	1 Second	3 Seconds
3	2 Seconds	1 Second	3 Seconds
Average delay	2 Seconds	1 Second	3 Seconds

The outcomes obtained from examining the delay variations in Table 12 reveal specific time intervals: 2 seconds for data transmission from Arduino Uno to the server, 1 second from the server to the application, and 3 seconds for data transmission from Arduino Uno to the application. As for the success rate in the comprehensive system evaluation:

$$Accuration = \left(\frac{The\ amount\ of\ DHT22\ sensor\ data}{Number\ of\ trials} + \frac{The\ amount\ of\ sensor\ data\ MQ9}{Number\ of\ trials}\right) x\ 100\% = \left(\frac{5}{5} + \frac{5}{5}\right) x\ 100\% = 100\%$$

Based on the comprehensive system testing conducted, it can be concluded that the system consistently and successfully transmits data from the hardware to both the server and the application, achieving a 100% success rate

4. Conclusions

In conclusion, our system successfully employs fuzzy Mamdani logic to determine the comfort level of green open spaces by analysing data from the DHT22 sensor, which dynamically establishes value limits based on temperature and humidity. The DHT22 sensor, in conjunction with the MQ-9 sensor, efficiently captures temperature, humidity, and CO2 gas readings. The collected data is seamlessly transmitted to the database with specified time delays: 2 seconds from the sensors to the server, 1 second from the server to the application, and 3 seconds from the hardware to the application. Notably, our system attains a remarkable 100% success rate in sending test data to the database. This underscores the system's reliability and its potential for enhancing the assessment of environmental conditions in green open spaces for the benefit of users and urban planners alike.

The project's monitoring system provides valuable data for urban planners and designers. It enables them to make informed decisions about the layout, features, and amenities of green open spaces to enhance user comfort and well-being. Integrate machine learning algorithms to further analyse and predict user comfort and environmental conditions. This can provide insights into long-term trends and help in proactive maintenance and improvements.

Acknowledgement
This research was not funded by any grant.

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