Design and implementation of an internet of things enabled stress level detection system using fuzzy logic method for enhanced accuracy and real-time monitoring

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ABSTRACT

Stress can affect individuals of all ages, from the young to the elderly, leading to a compromised immune system and increased susceptibility to illness. This study addresses this issue by developing an internet of things (IoT) based stress level detection system utilizing fuzzy logic methods. The device measures multiple physiological parameters and processes the data using an ESP32 microcontroller. This allows individuals to monitor and understand their stress levels efficiently and automatically through a liquid crystal display (LCD) display and Android devices. The system integrates various sensors to capture vital signs such as heart rate (HR), respiration rate, and body temperature. These readings are then analyzed using its algorithms to determine the stress level, which is displayed on both the onboard LCD and the connected Android device via an IoT interface. This real-time feedback mechanism empowers users to take proactive measures in stress management. Testing and validation of the device were conducted by comparing its readings with the depression anxiety stress scales (DASS-42) test results. The comparison showed an 80% correlation, demonstrating the device's accuracy and reliability in detecting stress levels. This innovative approach leverages the advantages of IoT and fuzzy logic to provide a practical and effective solution for stress monitoring and management.

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1. INTRODUCTION

In psychological terms, stress is defined as a state of mental strain and tension. While moderate levels of stress can serve as a motivator and enhance performance by sharpening focus and energy, chronic stress at elevated levels poses significant risks. These risks span across biological, psychological, and social domains, severely affecting overall well-being [1]. Stress can originate from a variety of external environmental factors, such as job pressure, financial difficulties, and social relationships, or from internal perceptions within individuals, such as personal expectations and self-criticism. This ubiquitous nature of stress means it affects individuals across all ages, from children and adolescents to adults and the elderly.

Prolonged exposure to stress can potentially weaken the immune system, rendering individuals more susceptible to illnesses and diseases [2]. Physiologically, the body responds to stress with a series of reactions. These include an increased heart rate (HR) as the body prepares to deal with the perceived threat, cold sweating due to the activation of sweat glands, rapid breathing as the respiratory system tries to deliver more oxygen to the muscles, and elevated blood pressure as blood vessels constrict. These reactions are part of the body's 'fight or flight' response, which, while useful in short bursts, can be harmful when prolonged [3]. Elizabeth Scott provides a framework for understanding the various states of stress by categorizing it into four conditions: stressed, tense, calm, and relaxed. 'stressed' and 'tense' describe states of heightened alertness and pressure, where the body and mind are in a constant state of readiness to respond to challenges. 'Calm' and 'relaxed,' on the other hand, represent states of low tension and high ease, where the body and mind are at rest. This framework highlights the diverse psychological and physiological responses to stress, emphasizing that not all stress is detrimental, and some levels can indeed be beneficial [4]. Stress is a complex and multi-faceted phenomenon with significant implications for health and well-being. Understanding its origins, manifestations, and effects is crucial for developing effective strategies to manage and mitigate its impact [5].

Current research commonly employs three parameters-HR, body temperature, and skin moisture-to measure stress levels, as evidenced [6]. However, the accuracy of stress detection using these parameters remains limited due to the exclusion of respiratory or pressure sensors [7]. Recent studies, such as those, which focus on internet of things (IoT)-based stress and dehydration detection devices, which explore the use of electrocardiography, galvanic skin response, and skin temperature for stress detection, highlight advancements and correlations in stress measurement methodologies [8]. Additionally, study [9] investigated stress diagnosis systems using fuzzy logic, comparing device outputs with psychological stress assessment tools like the depression anxiety stress scales (DASS-42) questionnaire [10]. By addressing these facets, this research aims to contribute significantly to the field of stress management and technological innovation in health monitoring systems [11].

The internet of things (IoT) refers to the interconnected network of physical devices embedded with sensors, software, and other technologies with the aim of connecting and exchanging data with other devices and systems over the internet [12]. This concept extends the capabilities of the internet beyond traditional devices like computers and smartphones to a vast array of everyday objects. IoT represents a significant advancement in technology, connecting devices and systems in ways that enhance efficiency, provide valuable insights, and improve the quality of life. However, it also brings challenges that need to be addressed to realize its full potential [13], [14]. Understanding the adverse health implications of stress underscores the importance of individuals comprehending their body conditions and proactively managing severe stress, which can detrimentally affect both physical and mental health. Therefore, this study aims to develop a stress detection device titled "Design and implementation of a stress level detection device using fuzzy logic." The research utilizes fuzzy logic with Mamdani rules to compute and determine values for parameters that exhibit ambiguity. The device integrates four key parameters: detecting HR at the fingertip using the MAX30102 sensor, measuring body temperature with the MLX90614 sensor, assessing skin moisture using the galvanic skin response (GSR) sensor, and evaluating respiratory rate using the KY-037 sensor. Control and data processing are managed by the ESP32 microcontroller, employing Mamdani fuzzy programming. Results are displayed automatically, efficiently, and practically on LCD and Android interfaces, providing real-time insights into an individual's stress levels. This research seeks to evaluate the performance of a stress level detection device using ESP32-based fuzzy logic, addressing human stress conditions comprehensively. The primary objective is to develop a human stress level detection device using fuzzy logic, enabling effective stress management interventions. Additionally, the study aims to enhance the understanding of temperature sensors, HR sensors, skin moisture sensors, and respiratory sensors, potentially inspiring future advancements in health monitoring systems.

This paper is organized as follow: section 2 is basic theory in the form of concept of stress and test of DASS-42. Section 3 is method in form of design of system, system overview, schematic diagram of stress level detection device, fuzzy logic design, ruled-based fuzzy logic, step of the research, real-time firebase structure and user interface, implementation, and system testing. Section 4 is result in form of hardware design result, interface design, testing device, testing with DASS-42, comparison of device test and DASS-42 test and analysis of fuzzy logic on sensor data. Section 5 is conclusion.

2. BASIC THEORY

2.1. Concept of stress

Stress is an adaptive response to situations perceived as challenges or threats. It can affect anyone, from infants to adults. Stress can lead to more severe mental health issues if not managed properly [15]. According to the WHO in [16], stress is the body's reaction to psychosocial stressors. Another expert, Davis and Soistmann [17] defines stress as an imbalance between oneself and daily life realities requiring adjustment. Stress triggers both physical and mental health issues, making effective management crucial. It is a common part of life, with daily stimuli causing stress. Stress is a non-specific response of the body to any demand and is unavoidable in daily life. It prompts individuals to think and solve problems or challenges they face [18]. Signs of stress include increased HR, elevated blood pressure, and cold hands. Elizabeth Scott identifies four stress conditions: stressed, tense, calm, and relaxed. Given the many negative health impacts of stress, a tool to measure human stress levels is necessary [19]. Stress level parameters is shown in Table 1.

Table 1. Stress level parameters in adulthood [19]

Condition	Parameter			
	GSR (Siemens)	HRB (Bpm)	T (°Celsius)	F (minute)
Relax	< 2	60 – 70	35 – 37	12 – 14
Calm	2 – 4	70 – 90	34 – 36	14 – 17
Worried	4 – 6	90 – 100	33 – 35	17 – 20
Tense	> 6	> 100	< 33	> 20

2.2. Test of depression anxiety stress scales (DASS-42)

The DASS-42 is a self-report questionnaire made up of 42 items designed to assess negative emotional states like depression, anxiety, and stress. Its main value in clinical settings lies in clarifying the focus of emotional disturbances within a broader clinical evaluation [20]. The DASS is crucial for determining the severity of core symptoms associated with depression, anxiety, and stress. Due to its high internal consistency and ability to provide meaningful distinctions across various contexts, the DASS scale is suitable for researchers and clinicians who need to assess current emotional states or track changes over time, such as during treatment [21]. Each of the 42 items is scored on a scale from 0 to 3. A score of 0 means the statement does not apply to the individual's current condition. A score of 1 indicates the statement applies but occurs infrequently. A score of 2 means the statement applies and occurs frequently. A score of 3 signifies that the statement applies and happens very frequently [22]. Stress severity is categorized into four levels: normal, moderate, severe, and extremely severe. DASS-42 categories can be seen in Table 2.

Table 2. Category of DASS-42 [22]

Level	Depression	Worry	Stress
Normal	0 – 9	0 – 7	0 – 14
Slight	10 – 13	8 – 9	15 – 18
Moderate	14 – 20	10 – 14	19 – 25
Severe	21 – 27	15 – 19	26 – 33
Extremely Severe	> 28	> 20	> 34

3. METHOD

3.1. Design of system

This phase meets all user requirements as analyzed, including the design of the system interface and helping to define the overall system architecture. The use case diagram describes the relationship between one or more actors and the system to be developed. It is used to identify the functions within a system and the actors entitled to use these functions [23]. Based on the analysis of the existing application, the use case diagram for the stress detector application to be developed is shown in Figure 1. The diagram illustrates that the system has only one actor, the user. The user has access to monitor the results of the checks performed.

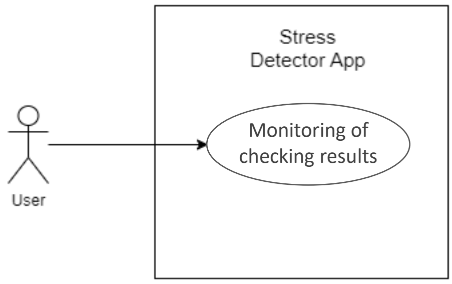


Figure 1. Use case diagram

3.2. System overview

The general overview of a system illustrates the overall workflow of the system's processes. The system operates once the program is executed. The workflow can be seen in Figure 2. The system overview in Figure 3 shows that the device can determine a person's stress level based on combined data from the galvanic skin response (GSR) sensor, HR, body temperature, and respiration sensors. The algorithm used to determine stress levels is fuzzy logic, processed by the ESP32 microcontroller [24]. Results are displayed on an LCD, then the data is sent to firebase and shown on an Android device.

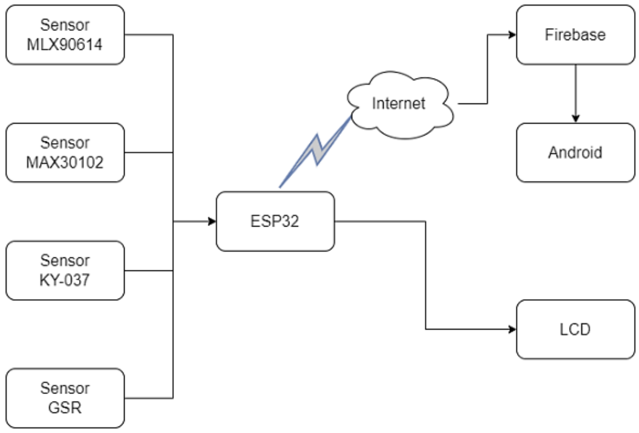


Figure 2. System overview

3.3. Schematic diagram of stress level detection device

In Figure 3, the setup illustrates the integration of various components, including the ESP32 microcontroller, which serves as the core of the system. The sensors connected to it include the MLX90614 for temperature measurement, the MAX30102 for HR and SpO_2 monitoring, the KY-037 for sound detection, and the GSR sensor for measuring skin conductivity. Additionally, the system features a 20×4 LCD that displays real-time data from these sensors, providing a comprehensive overview of the monitored parameters.

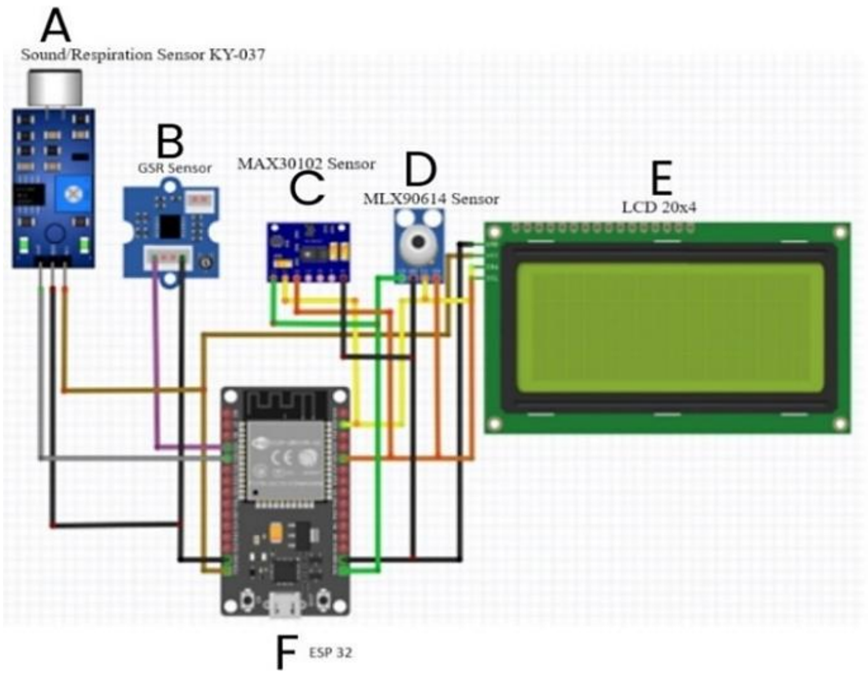


Figure 3. Schematic diagram device

3.4. Fuzzy logic design

In this research, the problem is simplified by focusing on four key input parameters: body temperature, HR, GSR, and body respiration. These inputs are crucial for accurately determining the system's output, which is the final decision. The specific details of these input parameters are presented in Table 3 and the output will be divided into four type body conditions, as shown in Table 4, providing a clear framework for the study.

Next, it is formulated into (1) to (4);

$$\mu \text{ (Relaxed)} = \begin{cases} 0, & x \leq 10 \text{ } or \text{ } x \geq 25 \\ \frac{x-10}{12-10}, & 10 \leq x \leq 12 \\ \frac{25-x}{25-12}, & 12 \leq x \leq 25 \end{cases} \tag{1}$$

$$\mu \text{ (Calm)} = \begin{cases} 0, & x \leq 25 \text{ } or \text{ } x \geq 50 \\ \frac{x-25}{37-25}, & 25 \leq x \leq 37 \\ \frac{50-x}{50-37}, & 37 \leq x \leq 50 \end{cases} \tag{2}$$

$$\mu \text{ (Anxious)} = \begin{cases} 0, & x \leq 50 \text{ } or \text{ } x \geq 75 \\ \frac{x-50}{62-50}, & 50 \leq x \leq 62 \\ \frac{75-x}{75-62}, & 62 \leq x \leq 75 \end{cases} \tag{3}$$

$$\mu \text{ (Tense)} = \begin{cases} 0, & x \leq 75 \text{ } or \text{ } x \geq 100 \\ \frac{x-75}{87-75}, & 75 \leq x \leq 87 \\ \frac{100-x}{100-87}, & 87 \leq x \leq 100 \end{cases} \tag{4}$$

From (1)-(4), the output values for the parameters are obtained. If the output value is below 12.5, it falls into the relaxed (R) category. If the output value is between 12.6 and 37.5, it falls into the calm (C) category. If the output value is between 37.6 and 62.5, it falls into the anxious (A) category. If the output value is between 62.6 and 87.5, it falls into the tense (T) category.

Table 3. The inputs parameters

Body temperature parameters		HR parameters		GSR body parameters		Body respiration parameters	
Parameter	^{0}C	Parameter	HRB (Bpm)	Parameter	GSR	Parameter	Respiration (/minute)
Very hot	35-37	Very slow	60-70	Very Wet	<2	Very Slow	12-14
Hot	34-36	Slow	70-90	Wet	2-4	Slow	14-17
Cold	33-35	Fast	90-100	Dry	4-6	Fast	17-20
Very cold	< 33	Very fast	>100	Very Dry	>6	Very Fast	>20

Table 4. Body condition

Condition	Value
Relaxed (R)	0-25
Calm (C)	25-50
Anxious (A)	50-75
Tense (T)	75-100

3.5. Rule-based fuzzy logic

Fuzzy logic is a powerful tool used to handle the uncertainty and vagueness inherent in many real-world problems. It mimics the way humans make decisions, using approximate reasoning rather than precise calculations [25]. In a fuzzy logic system, the rule base plays a crucial role. The rule base consists of a set of if-then rules that define the relationship between input variables and output variables. These rules are formulated based on expert knowledge or empirical data [26]. In this study, the fuzzy logic system for stress level detection is designed using a rule base that considers four input parameters: HR, body temperature, skin moisture, and respiratory rate. The output is the categorized stress level. The system utilizes the Mamdani fuzzy inference method, which is one of the most commonly used approaches in fuzzy logic systems [27]. Based on the input data obtained, rules are created to produce decisions, which serve as the output. The sensors for temperature, HR, respiration, and GSR will generate 64 rules. Temperature, HR, respiration, and

GSR are categorized into four conditions: relaxed, calm, anxious, and tense. From the four input conditions, 64 possible output conditions are obtained, as shown in Table 5.

Table 5. Rule-based fuzzy logic

No	Input Condition	Output
1	If TEMPERATURE is very hot and HR is very slow and RESPIRATION is very slow and GSR is very wet	Relaxed
2	If TEMPERATURE is hot and HR is very slow and RESPIRATION is slow and GSR is very wet	Relaxed
3	If TEMPERATURE is cold and HR is very slow and RESPIRATION is fast and GSR is very wet	Calm
4	If TEMPERATURE is very cold and HR is very slow and RESPIRATION is very fast and GSR is very wet	Anxious
5	If TEMPERATURE is very hot and HR is slow and RESPIRATION is very slow and GSR is very wet	Relaxed
6	If TEMPERATURE is hot and HR is slow and RESPIRATION is slow and GSR is very wet	Calm
7	If TEMPERATURE is cold and HR is slow and RESPIRATION is fast and GSR is very wet	Calm
8	If TEMPERATURE is very cold and HR is slow and RESPIRATION is very fast and GSR is very wet	Anxious
9	If TEMPERATURE is very hot and HR is fast and RESPIRATION is very slow and GSR is very wet	Calm
10	If TEMPERATURE is hot and HR is fast and RESPIRATION is slow and GSR is very wet	Calm
11	If TEMPERATURE is cold and HR is fast and RESPIRATION is fast and GSR is very wet	Anxious
12	If TEMPERATURE is very cold and HR is fast and RESPIRATION is very fast and GSR is very wet	Anxious
13	If TEMPERATURE is very hot and HR is very fast and RESPIRATION is very slow and GSR is very wet	Calm
14	If TEMPERATURE is hot and HR is very fast and RESPIRATION is slow and GSR is very wet	Calm
15	If TEMPERATURE is cold and HR is very fast and RESPIRATION is fast and GSR is very wet	Anxious
16	If TEMPERATURE is very cold and HR is very fast and RESPIRATION is very fast and GSR is very wet	Anxious
17	If TEMPERATURE is very hot and HR is very slow and RESPIRATION is very slow and GSR is wet	Relaxed
18	If TEMPERATURE is hot and HR is very slow and RESPIRATION is slow and GSR is wet	Calm
19	If TEMPERATURE is cold and HR is very slow and RESPIRATION is fast and GSR is wet	Calm
20	If TEMPERATURE is very cold and HR is very slow and RESPIRATION is very fast and GSR is wet	Calm
21	If TEMPERATURE is very hot and HR is slow and RESPIRATION is very slow and GSR is wet	Calm
22	If TEMPERATURE is hot and HR is slow and RESPIRATION is slow and GSR is wet	Calm
23	If TEMPERATURE is cold and HR is slow and RESPIRATION is fast and GSR is wet	Calm
24	If TEMPERATURE is very cold and HR is slow and RESPIRATION is very fast and GSR is wet	Anxious
25	If TEMPERATURE is very hot and HR is fast and RESPIRATION is very slow and GSR is wet	Anxious
26	If TEMPERATURE is hot and HR is fast and RESPIRATION is slow and GSR is wet	Calm
27	If TEMPERATURE is cold and HR is fast and RESPIRATION is fast and GSR is wet	Anxious
28	If TEMPERATURE is very cold and HR is fast and RESPIRATION is very fast and GSR is wet	Anxious
29	If TEMPERATURE is very hot and HR is very fast and RESPIRATION is very slow and GSR is wet	Calm
30	If TEMPERATURE is hot and HR is very fast and RESPIRATION is slow and GSR is wet	Anxious
31	If TEMPERATURE is cold and HR is very fast and RESPIRATION is fast and GSR is wet	Anxious
32	If TEMPERATURE is very cold and HR is very fast and RESPIRATION is very fast and GSR is wet	Anxious
33	If TEMPERATURE is very hot and HR is very slow and RESPIRATION is very slow and GSR is dry	Calm
34	If TEMPERATURE is hot and HR is very slow and RESPIRATION is slow and GSR is dry	Calm
35	If TEMPERATURE is cold and HR is very slow and RESPIRATION is fast and GSR is dry	Anxious
36	If TEMPERATURE is very cold and HR is very slow and RESPIRATION is very fast and GSR is dry	Anxious
37	If TEMPERATURE is very hot and HR is slow and RESPIRATION is very slow and GSR is dry	Calm
38	If TEMPERATURE is hot and HR is slow and RESPIRATION is slow and GSR is dry	Calm
39	If TEMPERATURE is cold and HR is slow and RESPIRATION is fast and GSR is dry	Anxious
40	If TEMPERATURE is very cold and HR is slow and RESPIRATION is very fast and GSR is dry	Anxious
41	If TEMPERATURE is very hot and HR is fast and RESPIRATION is very slow and GSR is dry	Anxious
42	If TEMPERATURE is hot and HR is fast and RESPIRATION is slow and GSR is dry	Anxious
43	If TEMPERATURE is cold and HR is fast and RESPIRATION is fast and GSR is dry	Anxious
44	If TEMPERATURE is very cold and HR is fast and RESPIRATION is very fast and GSR is dry	Anxious
45	If TEMPERATURE is very hot and HR is very fast and RESPIRATION is very slow and GSR is dry	Anxious
46	If TEMPERATURE is hot and HR is very fast and RESPIRATION is slow and GSR is dry	Anxious
47	If TEMPERATURE is cold and HR is very fast and RESPIRATION is fast and GSR is dry	Anxious
48	If TEMPERATURE is very cold and HR is very fast and RESPIRATION is very fast and GSR is dry	Tense
49	If TEMPERATURE is very hot and HR is very slow and RESPIRATION is very slow and GSR is very dry	Calm
50	If TEMPERATURE is hot and HR is very slow and RESPIRATION is slow and GSR is very dry	Calm
51	If TEMPERATURE is cold and HR is very slow and RESPIRATION is fast and GSR is very dry	Anxious
52	If TEMPERATURE is very cold and HR is very slow and RESPIRATION is very fast and GSR is very dry	Anxious
53	If TEMPERATURE is very hot and HR is slow and RESPIRATION is very slow and GSR is very dry	Calm
54	If TEMPERATURE is hot and HR is slow and RESPIRATION is slow and GSR is very dry	Anxious
55	If TEMPERATURE is cold and HR is slow and RESPIRATION is fast and GSR is very dry	Anxious
56	If TEMPERATURE is very cold and HR is slow and RESPIRATION is very fast and GSR is very dry	Anxious
57	If TEMPERATURE is very hot and HR is fast and RESPIRATION is very slow and GSR is very dry	Anxious
58	If TEMPERATURE is hot and HR is fast and RESPIRATION is slow and GSR is very dry	Anxious
59	If TEMPERATURE is cold and HR is fast and RESPIRATION is fast and GSR is very dry	Anxious
60	If TEMPERATURE is very cold and HR is fast and RESPIRATION is very fast and GSR is very dry	Tense
61	If TEMPERATURE is very hot and HR is very fast and RESPIRATION is very slow and GSR is very dry	Anxious
62	If TEMPERATURE is hot and HR is very fast and RESPIRATION is slow and GSR is very dry	Anxious
63	If TEMPERATURE is cold and HR is very fast and RESPIRATION is fast and GSR is very dry	Tense
64	If TEMPERATURE is very cold and HR is very fast and RESPIRATION is very fast and GSR is very dry	Tense

3.6. Step of the research

A system flowchart is a diagram that illustrates the overall workflow or process within a system and explains the sequence of procedures. In other words, a flowchart graphically describes the sequence of interconnected procedures that form a system. The flowchart for the created program is shown in Figure 4. From Figure 4, it can be explained that the use of the device begins with placing sensors on the human body. The GSR sensor is placed on the index and middle fingers of the right hand, the respiration sensor is positioned below the nose, and the body temperature and HR sensors are placed by positioning a finger on the sensor. Once the sensors are correctly placed, the next step is to connect to Wi-Fi. If Wi-Fi is on, it will connect to the device; if not, it will return to Wi-Fi settings. Then, data from the MLX90614, MAX30102, KY-037, and GSR sensors are read and processed by the ESP32 using fuzzy logic with rule-based fuzzy logic incorporated into the program. The final stage in fuzzy logic is defuzzification, which maps fuzzy values back to produce the final output. The results are displayed on an LCD and Android application, showing the tested individual's condition as relaxed, calm, anxious, or tense.

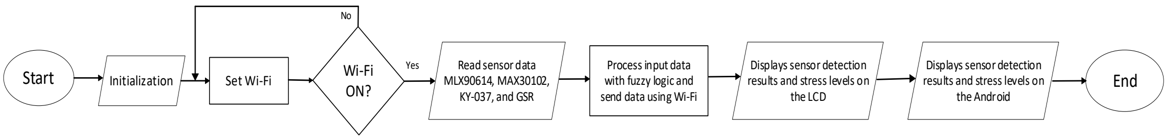


Figure 4. Step of the research

3.7. Real-time firebase structure and user interface

Firebase real-time database is a cloud-hosted database that allows data to be stored and synchronized in real-time across all clients connected to the application [28]. Its structure is designed to support real-time data updates and provides a flexible way to store and manage data. The stress level detection system uses firebase as its database platform [29]. This platform concept employs a real-time database to store and manage the collected data [30]. The concept of this platform can be seen in Figure 5.

In this study, the developed application features a user-friendly interface to facilitate ease of use. Figure 6 shows the application's user-side design. Upon opening the application, it displays the monitoring page with the results of the stress level check.

Figure 5. Real-time firebase structure

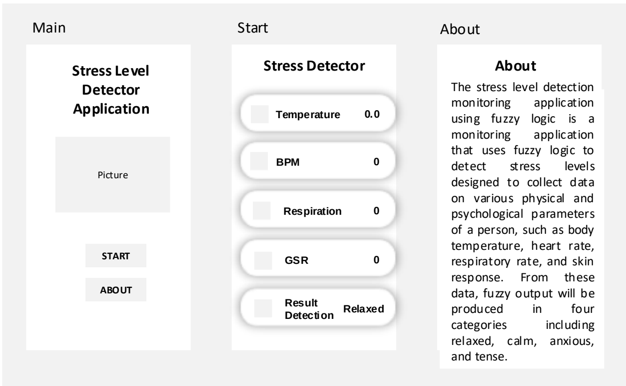


Figure 6. User interface

3.8. Implementation

At this stage, the system implementation includes acquiring hardware, configuring, coding scripts, and compiling the system according to the requirements derived from the analysis and design phases. This stage realizes the system's needs, such as developing the application using a programming language suited to the requirements based on the predefined user interface design. The application is developed using Android Studio with Java programming language. The application code listing can be seen in Figure 7.

The stress detection device requires a program code to be integrated into its hardware for effective functionality. This program utilizes fuzzy logic principles to enhance its decision-making process. The code is developed in the C/C++ programming language and is implemented using the Arduino IDE application for seamless integration.

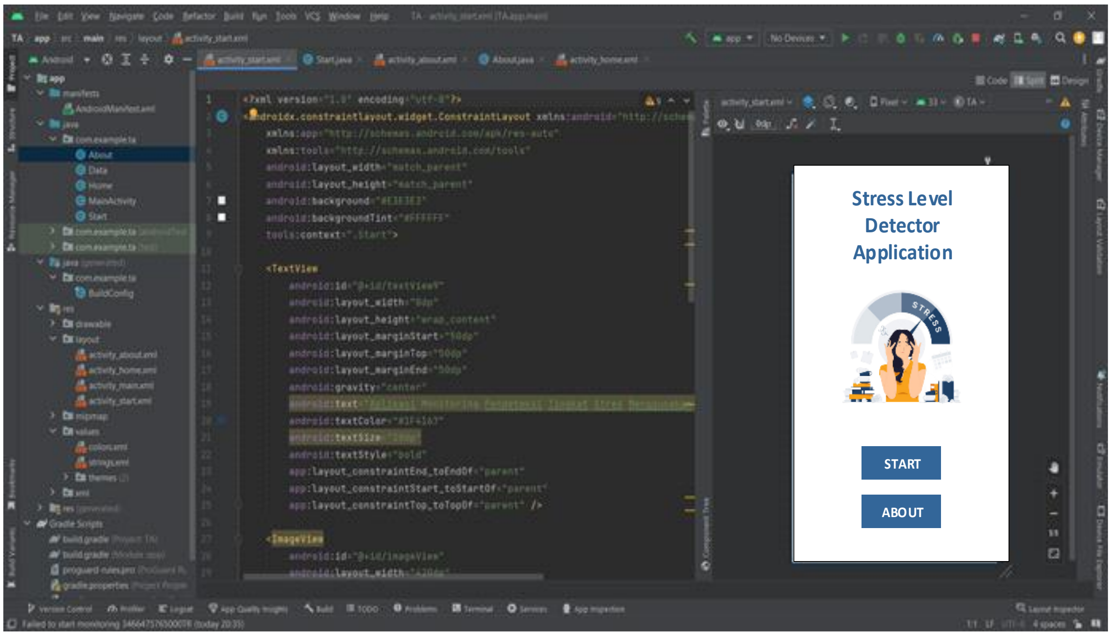


Figure 7. View of implementation program

3.9. System testing

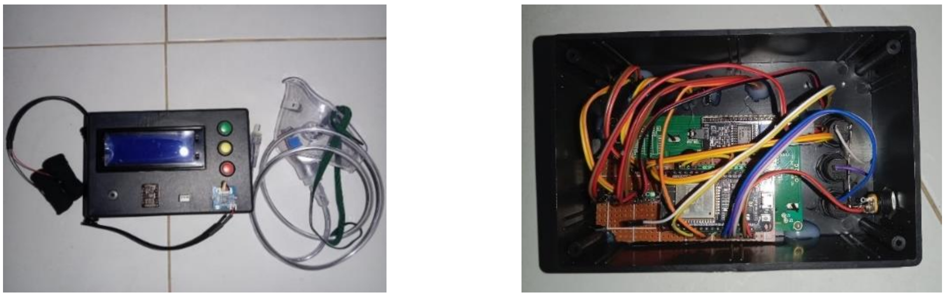
The purpose of system testing is to identify errors in the implemented system and to determine if the system meets the planning objectives. Testing serves as a benchmark for system reliability, ensuring that the system functions correctly and that any errors can be addressed. The testing process includes:

a. MLX90614 temperature sensor testing. This test aims to assess the accuracy of the temperature sensor.
b. MAX30102 sensor testing. This test aims to evaluate the accuracy of the HR sensor.
c. Respiration rate sensor testing. This test measures the number of breaths per minute using the KY-037 sensor.
d. GSR sensor testing. This test measures the conductivity of sweat glands.
e. Overall system testing. This test checks the ability of the device to detect stress levels accurately.
f. DASS-42 test evaluation. This test determines the effectiveness and validity of the stress detection device by comparing it to responses from the DASS-42 questionnaire.
g. Comparison of device testing and DASS-42 test. This test compares the results from the device with those from the DASS-42 test to evaluate their correlation.

4. RESULTS

4.1. Hardware design result

The design and construction of the stress measurement device are illustrated in detailed visual representations. A top view of the device is provided in Figure 8(a), highlighting its external layout. Meanwhile, the internal configuration of the device, as seen inside the box, is depicted in Figure 8(b).



(a) (b)

Figure 8. Stress level detection device: (a) the top view of the box and (b) interior view of the box

4.2. Interface design result

The interface result of the previously designed stress detector application from the user interface perspective. The Android-based application interface can be seen in Figure 9. It is showing the initial screen displayed when the application is launched. On this screen, the user can monitor the results of the checks conducted in real-time.

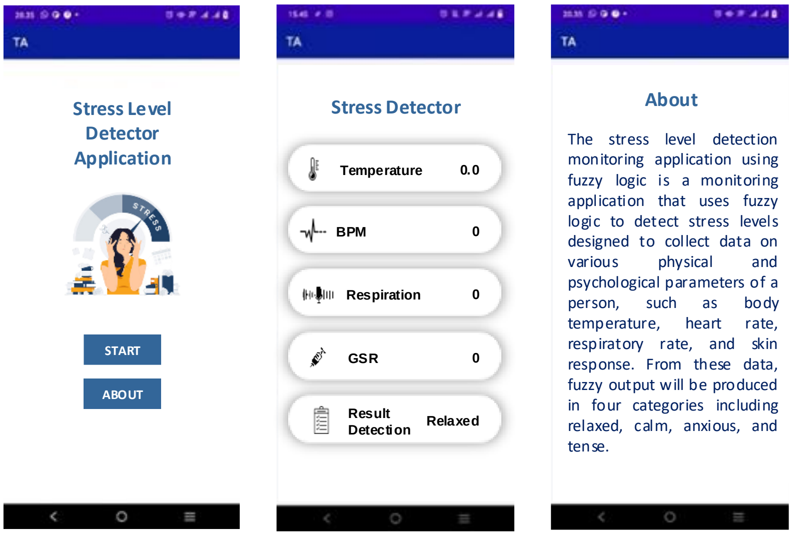


Figure 9. User interface display

4.3. Testing devices

The overall testing of the device involved 10 students as participants, with each student completing 10 trials to ensure thorough evaluation. These trials were conducted at the Department of Electrical Engineering, Politeknik Negeri Ujung Pandang, under controlled conditions. The detailed results from this comprehensive testing process are summarized and presented in Table 6.

Table 6. Equipment testing result

Sample	Student	Experiment										Value	Result
		1	2	3	4	5	6	7	8	9	10		
1	A	C	R	R	C	C	R	C	A	C	C	R=3 C=6 A=1	Calm
2	B	R	C	C	C	A	C	C	A	A	C	R=1 C=6 A=3	Calm
3	C	A	T	T	T	A	A	A	A	T	A	T=4 A=6	Anxious
4	D	R	C	C	R	R	C	C	C	C	C	R=3 T=7	Calm
5	E	R	R	C	C	C	C	A	C	C	C	R=2 C=7 A=1	Calm
6	F	C	A	C	A	C	C	A	C	C	C	C=7 A=3	Calm
7	G	R	C	C	A	A	C	C	C	C	C	R=1 C=7 A=2	Calm
8	H	A	C	C	C	R	C	A	C	C	C	R=1 C=7 A=2	Calm
9	I	C	R	C	C	R	C	C	C	C	A	R=2 C=7 A=1	Calm
10	J	C	C	A	C	C	R	A	C	A	C	R=1 C=6 A=3	Calm

Table 6 shows the results of the comprehensive testing of the device, conducted on 10 students with each student undergoing 10 trials. From the 10 students who each underwent 10 trials, the results were 14 instances of a relaxed condition, 64 instances of a calm condition, and 22 instances of an anxious condition, resulting in an average condition of calm.

4.4. Testing with DASS-42

Stress levels in a person are categorized into five scales: normal, mild, moderate, severe, and extremely severe. These classifications provide a comprehensive framework for assessing the severity of stress experienced by individuals. The results of the DASS-42 test, which measure these stress levels, are detailed in Table 7.

The results of the DASS-42 test conducted on 10 students revealed varying levels of emotional conditions. Specifically, there were 7 instances of normal depression, 2 instances of mild depression, and 1 instance of moderate depression. Additionally, the test identified 3 instances of mild anxiety, 6 instances of moderate anxiety, 1 instance of severe anxiety, 8 instances of normal stress, and 2 instances of moderate stress. Based on these findings, the average condition of the students was categorized as normal depression and moderate anxiety.

Table 7. Result of DASS-42 test

Sample	Student	Depression	Anxious	Stress	Condition	Result
1	A	5	12	13	Normal depression, moderate anxiety, normal stress	Moderate anxiety
2	B	14	12	22	Moderate depression, moderate anxiety. Moderate stress	Moderate stress
3	C	10	15	12	Mild depression, heavy depression, normal stress	Heavy depression
4	D	8	14	10	Normal depression, moderate anxiety, normal stress	Moderate anxiety
5	E	10	12	14	Mild depression, moderate anxiety, normal stress	Moderate anxiety
6	F	9	13	11	Normal depression, moderate anxiety, normal stress	Moderate anxiety
7	G	7	9	20	Normal depression, mild anxiety, moderate stress	Moderate stress
8	H	8	14	12	Normal depression, moderate anxiety, normal stress	Moderate anxiety
9	I	7	9	8	Normal depression, mild anxiety, normal stress	Mild anxiety
10	J	8	8	10	Normal depression, mild anxiety, normal stress	Mild anxiety

4.4. Comparison of device test and DASS-42 test

The comparison of the device testing and the DASS-42 test is conducted to evaluate the accuracy of the stress detection device in relation to the DASS-42 stress assessment tool. This comparison ensures the results are reliable. The conversion criteria are as follows:

a. If an individual experiences depression, anxiety, or stress at a normal or mild level according to the DASS-42, this corresponds to the “relaxed” state on the device.
b. If an individual experiences depression, anxiety, or stress at a moderate level according to the DASS-42, this corresponds to the “calm” state on the device.
c. If an individual experiences depression, anxiety, or stress at a severe level according to the DASS-42, this corresponds to the “anxious” state on the device.
d. If an individual experiences depression, anxiety, or stress at an extremely severe level according to the DASS-42, this corresponds to the “tense” state on the device.

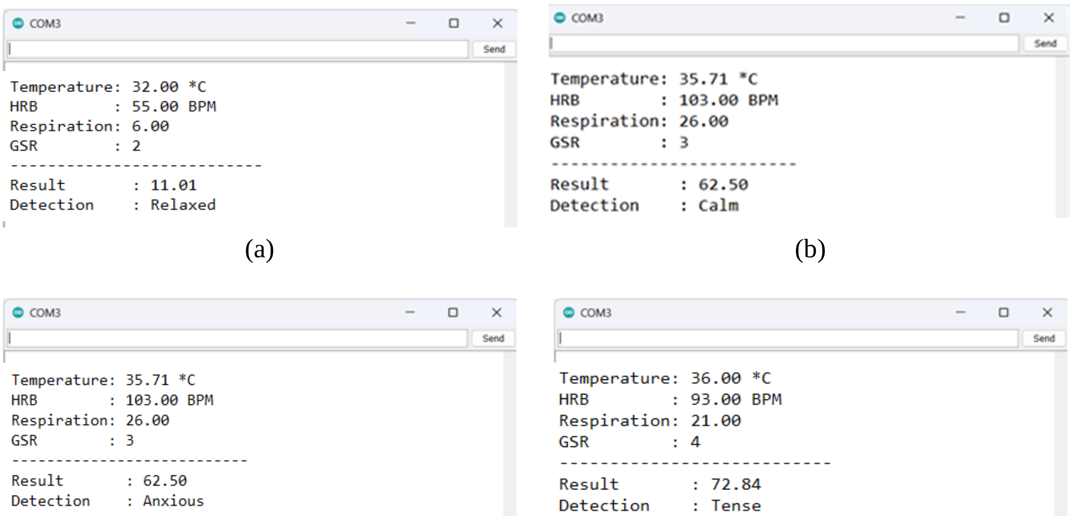
DASS is categorized into three conditions: depression, anxiety, and stress. Each of these negative emotional states has several levels: normal or mild, moderate, severe, and extremely severe. In Table 8, if two or more DASS conditions have levels that match those detected by the device, the most dominant level is considered. The comparison results between the device testing and the DASS-42 test can be seen in Table 8. From the 10 respondents, the comparison between the device test results and the DASS-42 test shows an accuracy rate of 80%.

Table 8. Comparison of device test and DASS-42 test

No	Student	Device	DASS-Test	Result
1	A	Calm	Moderate anxiety	Match
2	B	Calm	Moderate stress	Match
3	C	Anxious	Severe anxiety	Match
4	D	Calm	Moderate anxiety	Match
5	E	Calm	Moderate anxiety	Match
6	F	Calm	Moderate anxiety	Match
7	G	Calm	Moderate stress	Match
8	H	Calm	Moderate anxiety	Match
9	I	Calm	Mild anxiety	Not a match
10	J	Calm	Mild anxiety	Not a match

4.5. Analysis of fuzzy logic on sensor data

The fuzzy logic analysis of the sensor data from the stress measurement device can be seen in Figure 1. In Figure 10(a), the parameters show very cold body temperature, very slow HR (HRB), very slow respiration, and very wet GSR. These conditions fit into the predefined rule base and result in the relaxed state. Figure 10(b) shows the parameters with a hot body temperature, fast HR (HRB), rapid respiration, and very wet GSR. These conditions fit into the predefined rule base and result in a calm state. Figure 10(c) shows the parameters with a hot body temperature, very fast HR (HRB), rapid respiration, and wet GSR. These conditions fit into the predefined rule base and result in an anxious state. Figure 10(d) shows the parameters with a very hot body temperature, fast HR (HRB), rapid respiration, and dry GSR. These conditions fit into the predefined rule base and result in a tense state. The results from the testing phase show that the device is capable of classifying stress levels effectively based on the integrated sensors and fuzzy logic rules. The overall accuracy of the device was evaluated against known benchmarks, and it demonstrated a good alignment with expected stress levels based on physiological parameters. The testing also highlighted some areas for further refinement, such as the need for more robust calibration and potential improvements in sensor accuracy.



(a) (b) (c) (d)

Figure 10. Serial monitor display for all conditions: (a) relax condition, (b) calm condition, (c) anxious condition, and (d) tense condition

5. CONCLUSION

The stress detection device, utilizing fuzzy logic and various sensors, has been successfully designed and implemented. The system provides real-time stress level assessment and integrates well with Android applications for user interaction. Future improvements could involve refining the fuzzy logic rules, enhancing sensor precision, and expanding the device’s application to broader use cases. An accuracy results of 80% in comparing the stress detection tool with the DASS-42 test indicates that the developed tool performs well in detecting stress levels compared to the standard psychological assessment methods. With this accuracy, the tool can be used as an additional aid for daily stress monitoring or in contexts that require a quick assessment of stress levels. However, for clinical applications or more in-depth evaluations, the tool should be used as a complement rather than a replacement for more comprehensive psychological tests. This accuracy result can also help ensure that users feel confident in the results provided by the tool, thereby enhancing the acceptance and use of the system in real-world situations. The integration of firebase for real-time data management also proves effective for remote monitoring and analysis. This conclusion summarizes the effectiveness and potential areas of improvement for the stress detection device while highlighting its current success in real-time stress assessment and integration with modern technology

REFERENCES

[1] F. C. Silva, M. T. Ferreira, and J. N. Souza-Talarico, “Mapping stress-mindset definitions, measurements and associated factors: a scope review,” *Psychoneuroendocrinology*, vol. 153, p. 106227, Jul. 2023, doi: 10.1016/j.psyneuen.2023.106227.

[2] C. Hill, P. Waite, and C. Creswell, "Anxiety disorders in children and adolescents," *Paediatrics and Child Health (United Kingdom)*, vol. 26, no. 12, pp. 548–553, Dec. 2016, doi: 10.1016/j.paed.2016.08.007.
[3] G. Fink, "Stress: concepts, definition and history," in *The Curated Reference Collection in Neuroscience and Biobehavioral Psychology*, Elsevier, 2016, pp. 549–555, doi: 10.1016/B978-0-12-809324-5.02208-2.
[4] V. Lambert and N. Lapusta, "Absolute stress levels in models of low-heat faults: links to geophysical observables and differences for crack-like ruptures and self-healing pulses," *Earth and Planetary Science Letters*, vol. 618, p. 118277, Sep. 2023, doi: 10.1016/j.epsl.2023.118277.
[5] P. Gómez, C. Pina, R. Acero, and J. A. Abadía, "Characterization and evaluation of stress resistance in the structural bonding of electric cooktops," *International Journal of Adhesion and Adhesives*, vol. 129, p. 103568, Feb. 2024, doi: 10.1016/j.ijadhadh.2023.103568.
[6] A. Kumar, K. Sharma, and A. Sharma, "Hierarchical deep neural network for mental stress state detection using IoT based biomarkers," *Pattern Recognition Letters*, vol. 145, pp. 81–87, May 2021, doi: 10.1016/j.patrec.2021.01.030.
[7] J. F. Cevallos M., A. Rizzardi, S. Sicari, and A. C. Porisini, "NERO: Neural algorithmic reasoning for zeRO-day attack detection in the IoT: A hybrid approach," *Computers and Security*, vol. 142, p. 103898, Jul. 2024, doi: 10.1016/j.cose.2024.103898.
[8] K. Vaisakhkrishnan, G. Ashok, P. Mishra, and T. G. Kumar, "Guarding digital health: deep learning for attack detection in medical IoT," *Procedia Computer Science*, vol. 235, pp. 2498–2507, 2024, doi: 10.1016/j.procs.2024.04.235.
[9] N. Köse Kabakcıoğlu and S. Ayaz-Alkaya, "The effect of progressive muscle relaxation on stress, anxiety, and depression in adolescents: a quasi-experimental design," *Journal of Pediatric Nursing*, vol. 78, pp. 89–96, Sep. 2024, doi: 10.1016/j.pedn.2024.06.014.
[10] B. Abberger and K. Kieselbach, "Rasch analysis of the depression, anxiety, and stress scale in patients with chronic pain," *Journal of Psychosomatic Research*, vol. 178, p. 111597, Mar. 2024, doi: 10.1016/j.jpsychores.2024.111597.
[11] K. Y. Moon and D. C. Shin, "Correlation between psychosocial stresses, stress coping ability, pain intensity and degree of disability in patients with non-specific neck pain," *Physiology and Behavior*, vol. 275, p. 114433, Mar. 2024, doi: 10.1016/j.physbeh.2023.114433.
[12] M. Al-Shabi and A. Abuhamdah, "Using deep learning to detecting abnormal behavior in internet of things," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 12, no. 2, pp. 2108–2120, Apr. 2022, doi: 10.11591/ijece.v12i2.pp2108-2120.
[13] S. Venkatraman, S. Parvin, W. Mansoor, and A. Gawanmeh, "Big data analytics and internet of things for personalised healthcare: opportunities and challenges," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 13, no. 4, pp. 4306–4316, Aug. 2023, doi: 10.11591/ijece.v13i4.pp4306-4316.
[14] F. Boumehrez, A. Hakim Sahour, and N. Doghmane, "Telehealth care enhancement using the internet of things technology," *Bulletin of Electrical Engineering and Informatics (BEEI)*, vol. 10, no. 5, pp. 2652–2660, Oct. 2021, doi: 10.11591/eei.v10i5.2968.
[15] G. Jacob, K. Shimomura, and N. Nakamura, "Biologic therapies in stress fractures: current concepts," *Journal of ISAKOS*, vol. 9, no. 6, p. 100256, Dec. 2024, doi: 10.1016/j.jisako.2024.04.008.
[16] L. Maynor, M. Gálvez-Peralta, A. Barrickman, A. Hanif, and G. Baugh, "Perceived stress, academic self-concept, and coping mechanisms among pharmacy students following a curricular revision," *Currents in Pharmacy Teaching and Learning*, vol. 14, no. 2, pp. 159–165, Feb. 2022, doi: 10.1016/j.cptl.2021.11.013.
[17] S. L. Davis and H. C. Soistmann, "Child's perceived stress: a concept analysis," *Journal of Pediatric Nursing*, vol. 67, pp. 15–26, Nov. 2022, doi: 10.1016/j.pedn.2022.07.013.
[18] J. D. Parreira *et al.*, "A proof-of-concept investigation of multi-modal physiological signal responses to acute mental stress," *Biomedical Signal Processing and Control*, vol. 85, p. 105001, Aug. 2023, doi: 10.1016/j.bspc.2023.105001.
[19] T. Badrasawi, Z. Nazzal, N. Massad, E. Salameh, and A. Ibdah, "Stress and occupational burnout levels among Palestinian dentists, and associated factors: A cross-sectional study in 2023," *Heliyon*, vol. 10, no. 11, Jun. 2024, doi: 10.1016/j.heliyon.2024.e32034.
[20] L. Parkitny and J. McAuley, "The depression anxiety stress scale (DASS)," *Journal of Physiotherapy*, vol. 56, no. 2, p. 204, 2010, doi: 10.1016/s1836-9553(10)70030-8.
[21] A. Pilika and A. Simaku, "Depression, anxiety and stress symptoms among students in Albania explored by DASS-42," *European Psychiatry*, vol. 41, no. S1, pp. 412–412, Apr. 2017, doi: 10.1016/j.eurpsy.2017.01.352.
[22] Y. H. Sun, Q. Liu, N. Y. Lee, X. Li, and K. Lee, "A novel machine learning approach to shorten depression risk assessment for convenient uses," *Journal of Affective Disorders*, vol. 312, pp. 275–291, Sep. 2022, doi: 10.1016/j.jad.2022.06.035.
[23] C. Yang, Z. Liu, C. Ma, and L. Chen, "Design of universal network interface detection system for avionics system based on protocol model framework," in *Proceedings of 2020 IEEE 2nd International Conference on Civil Aviation Safety and Information Technology, ICCASIT 2020*, Oct. 2020, pp. 221–227, doi: 10.1109/ICCASIT50869.2020.9368537.
[24] S. M. Hardi, I. S. M. Pohan, and I. Jaya, "Smart aquascape: fuzzy logic control for real-time water quality optimization in IoT environment," in *Proceeding - ELTICOM 2023: 7th International Conference on Electrical, Telecommunication and Computer Engineering: Sustainable and Resilient Communities with Smart Technologies*, Dec. 2023, pp. 156–161, doi: 10.1109/ELTICOM61905.2023.10443184.
[25] F. Rama, E. Mulyana, R. Mardiati, and A. Fathonih, "Design of automatic watergate system using ESP32 microcontroller based on fuzzy logic method," in *Proceeding of 2021 7th International Conference on Wireless and Telematics, ICWT 2021*, Aug. 2021, pp. 1–6, doi: 10.1109/ICWT52862.2021.9678410.
[26] Y. Pamungkas, N. C. Romadhona, Z. S. A. Syahputra, K. N. Rayhani, A. S. Wibowo, and F. A. Parinduri, "Implementation of fuzzy logic control on the ESP32 microcontroller for an automatic infusion monitoring system," in *Proceedings: ICMERALDA 2023 - International Conference on Modeling and E-Information Research, Artificial Learning and Digital Applications*, Nov. 2023, pp. 289–294, doi: 10.1109/ICMERALDA60125.2023.10458205.
[27] M. K. Awsaj, Y. Al Mashhadany, and L. C. Fourati, "Real-time healthcare monitoring and treatment system based microcontroller with IoT," in *Proceedings - International Conference on Developments in eSystems Engineering, DeSE*, Jan. 2023, vol. 2023-Janua, pp. 515–520, doi: 10.1109/DeSE58274.2023.10099758.
[28] T. Ahmed, A. T. Bin Nuruddin, A. Bin Latif, S. S. Arnob, and R. Rahman, "A real-time controlled closed loop IoT-based home surveillance system for Android using Firebase," in *2020 6th International Conference on Control, Automation and Robotics, ICCAR 2020*, Apr. 2020, pp. 601–606, doi: 10.1109/ICCAR49639.2020.9108016.
[29] U. A. Madaminov and M. R. Allaberganova, "Firebase database usage and application technology in modern mobile applications," in *Proceedings of the 2023 IEEE 16th International Scientific and Technical Conference Actual Problems of Electronic Instrument Engineering, APEIE 2023*, Nov. 2023, pp. 1690–1694, doi: 10.1109/APEIE59731.2023.10347828.

[30] M. F. Younis and Z. S. Alwan, "Monitoring the performance of cloud real-time databases: a firebase case study," in *AICCIT 2023 - Al-Sadiq International Conference on Communication and Information Technology*, Jul. 2023, pp. 240–245, doi: 10.1109/AICCIT57614.2023.10217953.

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