Electronic Journal of Education, Social Economics and Technology
Vol. 6, No. 2, (2025), pp. 1~12, Article ID: 1105
ISSN 2723-6250 (online)
DOI: https://doi.org/10.33122/ejeset.v6i2.1105

Research Article

Blood Pressure Monitoring System Using Mamdani Fuzzy Logic Method Based on Microcontroller

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ABSTRACT
Health is a vital aspect that must be continuously monitored, one of which is through blood pressure measurement. In general, blood pressure measurement is carried out using a manual sphygmomanometer that requires medical expertise, so the results are often not well documented. This study aims to design and implement a blood pressure monitoring system based on a microcontroller using the Mamdani fuzzy logic method. The system is developed by integrating a digital blood pressure sensor and a MAX30100 heart rate sensor connected to an Arduino Uno. The Mamdani fuzzy method is employed to classify the measurement results into three categories: hypotension, normal, and hypertension, based on systolic, diastolic, and heart rate (BPM) values. The system is also equipped with an LCD as a visual indicator to display the user's health condition in real time, quickly, and informatively. Experimental results show that the system can operate properly, achieving an average error rate of 3.44% and an accuracy level of 96.28%. These findings indicate that the proposed monitoring system is sufficiently accurate, flexible in handling uncertain biological data, and has great potential to be developed as an initial screening tool for health conditions, particularly at home or in areas with limited access to medical facilities.

Keywords: Blood pressure; Microcontroller; Mamdani fuzzy logic; Health monitoring; Arduino Uno

1. INTRODUCTION

Health is a fundamental need for humans, and one of the influencing factors is blood pressure (Nindita et al., 2023). Each individual has different physical conditions that affect daily activities. In the medical field, blood pressure measurement is an important procedure to assess a patient's health condition (Wahyuni et al., 2024). Blood pressure itself is the force exerted on the arterial walls as the heart pumps blood throughout the body (Wedri et al., 2021). The highest value is called systolic pressure, which occurs when the heart contracts, while the lowest value is called diastolic pressure, occurring when the heart rests between two contractions. The normal heart rate is approximately 72 beats per minute (Kamal et al., 2025). The measurement results are generally expressed in millimeters of mercury (mmHg), for example 120/80 mmHg, where the first number represents systolic pressure and the second number represents diastolic pressure. This condition serves as an important indicator in determining whether a person is in a normal state, hypotension, or hypertension (Caezarian Judhea Tumundo et al., 2025).

In addition, the heart is the main factor that significantly influences blood pressure(Asadha, 2021). As the primary pump in the circulatory system, the strength of contraction and the frequency of the heartbeat determine the level of pressure within the blood vessels. The heart is a muscular organ that works continuously to pump blood throughout the body(Irfan Pure et al., 2021). The blood it circulates carries oxygen and essential nutrients required by body tissues to function properly, while also transporting metabolic waste to be expelled through the lungs and kidneys(Alimov, 2023). Therefore, heart health is closely related to the stability of blood pressure(Simarmata et al., 2025). Any disturbances in cardiac function such as weakened contractions, irregular rhythms, or blocked blood vessels can directly lead to either increased or decreased blood pressure. Thus, maintaining heart health through a healthy lifestyle, regular exercise, and periodic blood pressure monitoring is an essential step in preventing cardiovascular diseases (Fikri Faidul Jihad & Ihsan Murdani, 2024).

Blood pressure monitoring is generally still carried out using a mercury sphygmomanometer, which requires medical expertise to obtain accurate results. However, this method has limitations because the measurement results are often not recorded, making it difficult to compare with subsequent measurements. Based on these shortcomings, this study proposes a Blood Pressure Monitoring System Using the Mamdani Fuzzy Logic Method Based on a Microcontroller. The system is designed to automatically measure blood pressure while classifying the user's health condition based on systolic, diastolic, and heart rate values. By applying Mamdani fuzzy logic, the system is able to mimic human decision-making processes, providing more flexible interpretations when dealing with uncertain biological data. Furthermore, the integration of a microcontroller allows the measurement results to be displayed in real time, stored properly, and compared with previous data, making health monitoring more practical, informative, and beneficial for users (Naviaddin et al., 2023).

Fuzzy logic, introduced by Prof. Lotfi A. Zadeh in 1962, is a control system method for problem-solving that can be applied to various types of systems. Unlike crisp logic, which only recognizes absolute true or false values, fuzzy logic allows for uncertain values between the two, where the degree of truth or falsity is determined by membership weights(Ulfia et al., 2021). Mamdani fuzzy logic, introduced by Ebrahim Mamdani in 1975, is one of the most popular methods in intelligent systems. Also known as the min-max method, it is widely used due to its flexibility and ability to handle complex and uncertain data. In addition, its simple input representation makes the Mamdani method easier for humans to understand and apply(Supriadi & Suhendi, 2024). The Mamdani fuzzy logic system processes uncertain information and makes decisions on a scale between 0 and 1, producing more realistic outcomes by considering multiple factors and compromises(Tauhid et al., 2025). This method consists of two main stages: fuzzification, where input variables are transformed into fuzzy variables with values ranging from 0 to 1, and defuzzification, where these fuzzy variables are converted back into a precise value (Haque & Sriani, 2023).

A microcontroller is a compact computer system on a single chip that contains a processor, memory, and input-output components(Ramu et al., 2022). It operates by reading and writing data and can be programmed to perform specific control tasks. With this capability, microcontrollers enable the development of practical and flexible automation systems(Cakra et al., 2023). A microcontroller is a small computer within a chip designed to control electronic devices with a focus on efficiency and cost-effectiveness. Often referred to as a "small controller," it can replace multiple supporting components such as TTL and CMOS ICs, making electronic systems simpler, more compact, and centralized(Perangin-angin, 2024). Arduino is an electronic board based on the ATmega328 microcontroller, equipped with 14 digital input/output pins (6 of which can be used as PWM), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. Its I/O pins can be configured for various functions such as serial TX/RX, external interrupts, I2C, and SPI(Rohmanu & Gunawan, 2022). A sphygmomanometer is a device used to measure blood pressure, which represents the comparison between the pressure inside blood vessels and the external atmospheric pressure, measured in millimeters of mercury (mmHg)(Ashshiddiq & Rahmadya, 2023). Changes in blood pressure are often associated with hypertension, a condition caused by the narrowing of blood vessels and increased pressure from the heart, and hypotension, or low blood pressure, which may lead to symptoms such as dizziness and fatigue (Zuhdi et al., 2020).

The MAX30100 is an integrated optical sensor designed to measure heart rate and blood oxygen levels (SpO_2) non-invasively using the principle of photoplethysmography (PPG), which detects changes in blood volume through light(Putra et al., 2025). Developed by Maxim Integrated, this two-in-one sensor is widely used in wearable devices, portable medical equipment, and microcontroller-based projects such as Arduino(Awanda Aerin Maesyarani et al., 2024). The MAX30100 sensor is a practical module for real-time health monitoring. Although not an official medical device, it can provide general information about heart rate and blood oxygen levels efficiently and with low power consumption. With its easy integration into microcontrollers such as Arduino, this sensor is an ideal choice for developers, researchers, students, and hobbyists to create affordable yet functional health monitoring devices(Shiddiq & Nugraha, 2022). A 4x4 matrix keypad is an input device commonly used in various electronic applications. It consists of 16 buttons arranged in 4 rows and 4 columns, forming a grid or matrix pattern. Each button functions by connecting the intersection point between a specific row and column (Furwanda et al., 2022).

The research conducted by Panca Muji Sulistyawan (2021), titled *"Design of a Blood Pressure Monitoring System Using the MPX5100GP Pressure Sensor Based on STM32F103"*, explains that when the air pressure decreases, the cuff pressing the blood vessels also loosens. When the blood vessels are no longer compressed and the first pulse occurs, the pressure in the cuff slightly changes, and this change is detected by the MPX5100GP sensor, which is then identified as systolic pressure. The diastolic pressure is obtained as the air pressure in the cuff continues to decrease, causing the pulses detected by the sensor to gradually disappear. The circuit also includes the STM32F103 microcontroller for processing and managing the data, as well as a 20x4 LCD that serves as the output display, showing systolic data, diastolic data, and classification results(Sulistyawan, 2021). The research conducted by Nuril Hidayah and Martinus Mujur Rose (2021), titled *"Design and Development of a Human Stress Level Detection Device Based on Arduino Uno"*, concludes that the device was designed using a Pulse Sensor to detect heart rate at the fingertip (attached to the index or thumb), a DS18B20 Temperature Sensor to measure body temperature from the palm, and a Galvanic Skin Response (GSR) Sensor to detect skin moisture with electrodes attached to the middle and ring fingers. The data from these three parameters are processed by the Arduino Uno R3 microcontroller, which functions as the main control center of the system and is directly connected to the detection unit (Hidayah et al., 2021).

In previous studies, health monitoring systems generally relied on direct sensor-based measurements without the application of intelligent logic methods. Some focused solely on monitoring blood pressure using sensors, while others emphasized stress detection through various physiological parameters. However, the methods used were still limited to basic readings and simple classifications. In contrast, this study develops a blood pressure monitoring system based on a microcontroller with the Mamdani fuzzy logic method, which is capable of processing data more flexibly and accurately in handling uncertainty, thus providing more informative interpretations of blood pressure conditions, such as normal, hypotension, or hypertension. The purpose of this study is to design and implement a blood pressure monitoring system based on Arduino Uno with a digital blood pressure sensor and the MAX30100, using Mamdani fuzzy logic for data processing. The system is intended to monitor blood pressure and heart rate in real-time, classify the user's health condition, and serve as an effective and user-friendly early health screening tool.

2. RESEARCH METHOD

This study uses a quantitative approach to evaluate the accuracy and reliability of a microcontroller-based blood pressure monitoring system using the Mamdani fuzzy logic method(Suryani et al., 2025). The research framework outlines the stages of the process, from system design and testing to analysis. This sequence of steps provides a comprehensive overview of the procedures undertaken to address the research problem, as shown in the following **Figure 1**.

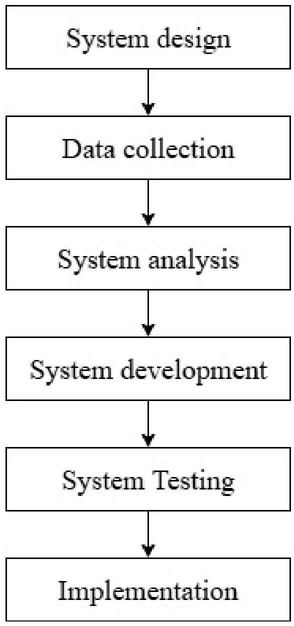

Figure 1. Research Framework

2.1 System design

At this stage, the research process involves the design of the system, aiming to prepare all the tools and materials used for the blood pressure monitoring system. Before designing the system, a system block diagram is created, which serves as the main flow diagram illustrating the scheme or arrangement of the system design. The block diagram of this device is as follows:

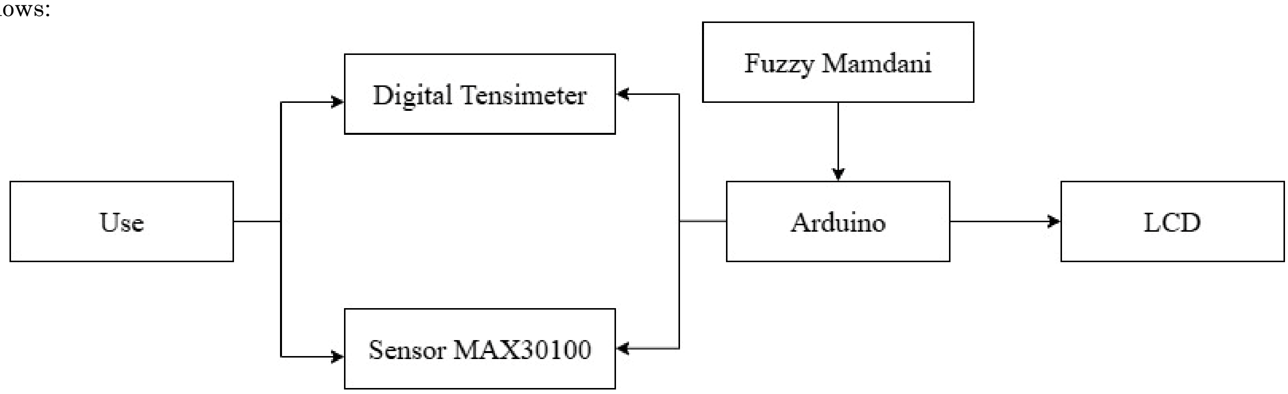

Figure 2. Block diagram of blood pressure monitoring design

2.2 Data Collection

The data collection method in this study was conducted through two approaches: observation and literature review(Nafisatur, 2024). Observation involved directly monitoring the blood pressure monitoring system based on a digital tensiometer, MAX30100 sensor, and Arduino, to assess blood pressure, heart rate, system response, classification using Mamdani fuzzy logic, as well as the accuracy and reliability of the output displayed on the LCD. Meanwhile, the literature review was conducted by collecting, reading, and analyzing relevant sources to serve as a comparative reference in discussing the research results (Adlini et al., 2022).

2.3 System Analysis

At the system analysis stage, problems in the blood pressure monitoring system are identified, which operates using a microcontroller (Arduino) and the Mamdani fuzzy logic method for automatic data processing. The system is designed so that when the digital tensiometer and MAX30100 sensor detect specific blood pressure and heart rate values, the microcontroller can classify the user's condition and display the status on the LCD: low blood pressure (<90/60 mmHg and heart rate 40–60 BPM), normal (around 120/80 mmHg and 60–80 BPM), or high (around 150/95 mmHg and 125–150 BPM), thereby facilitating real-time health monitoring.

2.4 System development

System development is the process of creating a new system to replace the previously analyzed old system, aiming to improve its performance and effectiveness. This process involves three main life cycle stages: system analysis, which includes study validation, project team organization, and defining system requirements and criteria; system design, which involves applying detailed design specifications; and system implementation, which covers the planning, execution, and formulation of the new system.

2.5 System testing

The testing process aims to ensure that the system output meets the expected results. It involves verifying the performance of the microcontroller, including the digital tensiometer and MAX30100 sensor for monitoring blood pressure and heart rate, as well as the operation of the LCD displaying accurate results. Testing is conducted to ensure all system functions operate according to specifications, minimize errors in data analysis, and includes both individual component testing and system integration testing. Through careful testing, errors can be reduced, allowing the system to provide accurate, reliable, and user-appropriate results.

2.6 Implementation

The implementation of this study begins with collecting blood pressure data from a digital tensiometer and the MAX30100 sensor connected to an Arduino Uno. The collected data is then processed and cleaned to remove invalid readings or sensor errors. Next, the blood pressure and heart rate data are tokenized based on specific time intervals. The Mamdani fuzzy logic method is then applied to process and classify the data into three categories: low, normal, and high. This process aims to provide warnings via the LCD if blood pressure exceeds predetermined limits, based on rules programmed into the fuzzy system, with the output displaying blood pressure, heart rate, and the user's health status.

3. RESULTS AND DISCUSSION

3.1 Data Analysis

Data analysis is the process of transforming raw data into meaningful information so that the characteristics of the data can be understood and used for decision-making. In the context of this study, data analysis aims to identify patterns, trends, and relationships between blood pressure and heart rate parameters obtained from the microcontroller-based monitoring system in order to determine the user's health condition.

3.2 Data Representation

The data obtained are the results of measurements using medical devices, namely a tensiometer to measure blood pressure (mmHg) and an oximeter to measure heart rate (BPM). Additionally, the data include information on the user's age. These parameters, which consist of blood pressure values, heart rate per minute, and age categories, are used as inputs in the fuzzy logic system to determine the user's health condition. The following **Table 1** presents the data used.

Table 1. Data Representation

Name	Blood pressure	Heart rate	Age	Output
Nadia azzahra	94	75	17	Healthy
Nurjamilah	127	106	24	At risk
Mardiana	147	69	55	At risk
Bahrum Jamil	162	84	30	At risk
Sofia Syhfitri	148	93	25	At risk

3.2.1 Data processing

Data processing in this study involves handling the measurement results from the blood pressure monitoring system, which uses a digital tensiometer to measure blood pressure and a MAX30100 sensor to measure heart rate. The data obtained consist of two main parameters: blood pressure (systolic and diastolic) and heart rate (BPM). These data are then processed using the Mamdani fuzzy logic method to classify health conditions based on the combination of blood pressure and heart rate values. The output from this fuzzy process provides the status or category of the user's health condition, which can serve as a reference for preliminary medical decision-making. This can be seen in the following **Table 2.**

Table 2. Fuzzy Variable Input Data for Blood Pressure Monitoring System

No	Fuzzy Variables	Linguistic Category	Certain Value (Crips)	Unit
1	Blood pressure	Low	95	mmHg
		Normal	110	mmHg
		Tall	150	mmHg
2	Heart rate	Bradycardia	50	BPM
		Normal	75	BPM
		Tall	110	BPM

3.2.2 Blood Pressure Variables

Blood pressure is a primary parameter in this system, alongside heart rate. According to medical standards, blood pressure consists of two components: systolic (pressure when the heart pumps blood) and diastolic (pressure when the heart relaxes). For simplification in the fuzzy system, blood pressure is classified into three linguistic categories: Low, Normal, and High. In this study, the blood pressure universe of discourse is limited to a range of 80/50 mmHg to 180/120 mmHg, covering various common blood pressure conditions. Fuzzy processing is carried out using the systolic value as the representation of blood pressure, making it simpler while remaining relevant in the context of the monitoring system. This can be seen in the following **Table 3**.

Table 3. Blood Pressure Variable Set

Input Variables	Fuzzy Set	Readers' Universe	Domain
Blood pressure	Low	80-180 mmHg	80 – 90 – 100
	Normal		100 – 120 – 140
	Tall		140 – 160 – 180

The **Figure 3**, shows the blood pressure membership functions, categorizing readings as Low, Normal, or High for use in the fuzzy logic system.

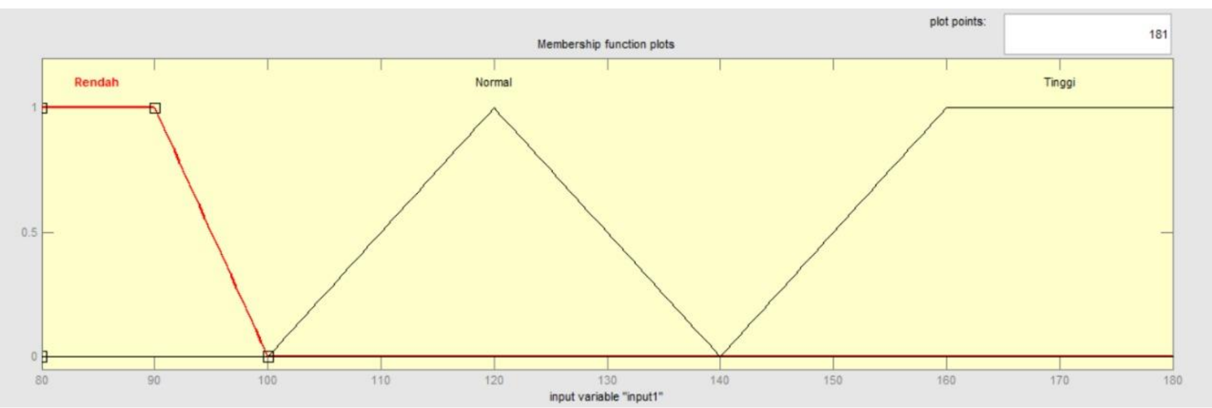

Figure 3. Membership Function of Blood Pressure Variable

Based on **Table 3**, blood pressure values are divided into three fuzzy categories: Low, Normal, and High. The membership functions for each category are structured using rising, triangular, and falling shapes. The determination of these membership functions refers to the blood pressure range in units of mmHg (millimeters of mercury) as follows:

$$\mu Low(x)\begin{cases} 1 & ; x \leq 90 \\ \frac{100-x}{100-90} & ; 90 < x \leq 100 \\ 0 & ; x > 100 \end{cases}$$

$$\mu Normal(x)\begin{cases} 0 ; x \leq 100 \; or \; x \geq 140 \\ \frac{x-100}{120-100} & ; 100 < x \leq 120 \\ \frac{140-x}{140-120} & ; 120 < x \leq 140 \\ 0 & ; x = 140 \end{cases}$$

$$\mu Tall(x)\begin{cases} 0 & , x \leq 140 \\ \frac{x-140}{160-140} & , 140 < x \leq 160 \\ 1 & , x > 160 \end{cases}$$

- **Nadia azzahra**

$$\mu Low\,[94] = \frac{94-80}{100-80} = 0{,}7$$

$\mu Normal\,[94] = 0$

$\mu Tall\,[94] = 0$

- **Nurjamilah**

$\mu Low\,[127] = 0$

$$\mu Normal\,[127] = \frac{140-127}{140-120} = \frac{13}{20} = 0{,}65$$

$\mu Tall\,[127] = 0$

3.2.3 Heart Rate Variables

Based on the data obtained, the minimum observed heart rate is 60 BPM (beats per minute), and the maximum is 100 BPM. For data processing and decision-making within the system, the heart rate variable is classified into three fuzzy sets: Bradycardia, Normal, and High. To ensure proportional categorization and allow the system to accurately recognize value ranges, the universe of discourse for the heart rate variable is set from 0 to 150 BPM. These three linguistic regions are evenly distributed within this range. As shown in the following **Table 4.**

Table 4. Heart Rate Variable Set

Input Variables	Fuzzy Set	Readers' Universe	Domain
Heart rate	Bradycardia	0-150bpm	0 – 40 – 60
	Normal		60 – 80 – 100
	Tall		100 – 125 – 150

The **Figure 4**, illustrates the heart rate membership functions, categorizing readings into three groups: Bradycardia, Normal, and High, for use in the fuzzy logic system.

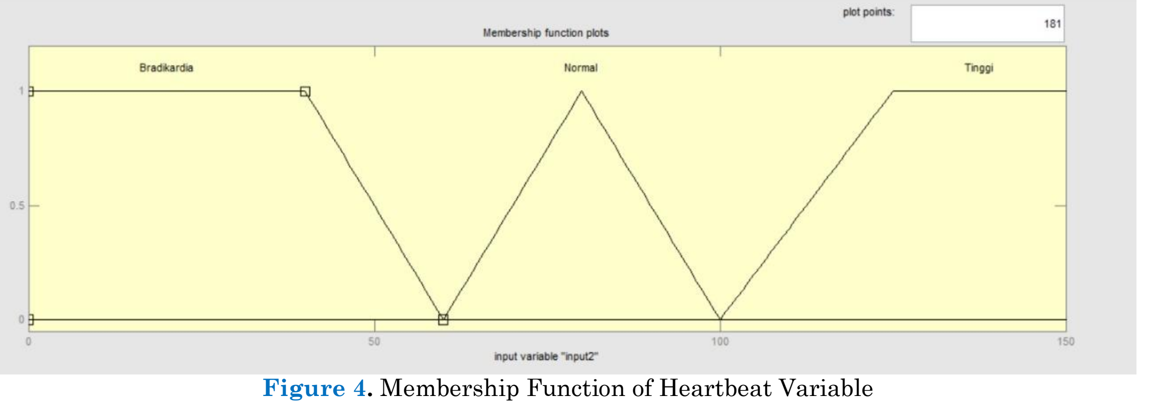

Figure 4. Membership Function of Heartbeat Variable

Based on **Table 4**, heart rate values are divided into three fuzzy categories: Bradycardia, Normal, and High. The membership functions for each category are structured using rising, triangular, and falling graph shapes. The determination of these membership functions refers to the heart rate range in units of beats per minute (BPM) as follows:

$$\mu Bradycardia(x)\begin{cases} 1 & ; x \leq 40 \\ \dfrac{60-x}{60-40}; & 40 < x \leq 60 \\ 0 & ; x > 60 \end{cases}$$

$$\mu Normal(x)\begin{cases} 0\,;\, x \leq 40 \; or \; x \geq 100 \\ \dfrac{x-60}{80-60} & ; 60 < x \leq 80 \\ \dfrac{100-x}{100-180} & ; 80 < x \leq 100 \\ 0; x \geq 100 \end{cases}$$

$$Tall(x)\begin{cases} 0 & ; x \leq 80 \\ \dfrac{x-100}{120-100}; & 100 < x \leq 120 \\ 1 & ; x > 120 \end{cases}$$

- **Nadia azzahra**

$\mu Bradycardia$ [75] = 0

$$\mu Normal\ [75] = \frac{75-60}{80-60} = 0{,}75$$

$\mu Tall$ [75] = 0

- **Nurjamilah**

$\mu Bradycardia$ [106] = 0

$\mu Normal$ [106] = 0

$$\mu Tall\ [106] = \frac{125-106}{125-100} = \frac{19}{25} = 0{,}76$$

3.2.4 Health Status Variable

The fuzzy output variable in this system is health status, which is determined from the combination of two input variables: heart rate and blood pressure. Health status is categorized into three levels: “At Risk” for abnormal or extreme conditions, “Normal” for conditions within an acceptable range, and “Healthy” for optimal conditions. The output values are defuzzified within a range of 0–100 using triangular membership functions, and the defuzzification results determine the appropriate health status category. This can be seen in the following **Table 5**.

Table 5. Health Status Variable Set

Input Variables	Fuzzy Set	Readers' Universe	Domain
Health Status	At risk	0-100	0 – 25 – 50
	Normal		40 – 60 – 80
	Healthy		70 – 85 – 100

The **Figure 5**, below illustrates the membership functions for health status, categorizing the readings into “At Risk,” “Normal,” and “Healthy” for use in the fuzzy logic system.

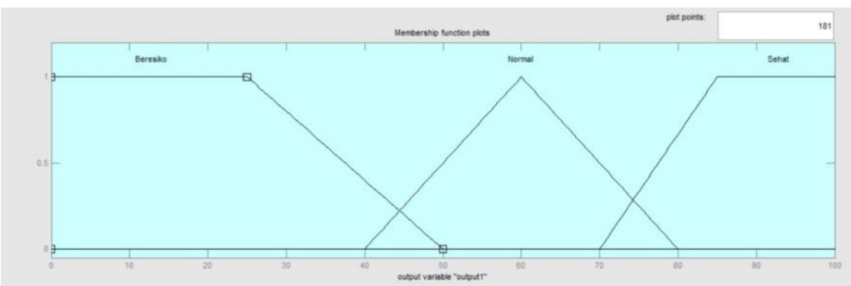

Figure 5. Membership Function of Health Status Variable

Based on **Table 5**, heart health status values are grouped into three fuzzy categories: At Risk, Normal, and Healthy. The membership functions for each category are arranged using increasing, triangular, and decreasing graph shapes.

$$\mu At\ risk(x)\begin{cases} 1 & ,x \le 30 \\ \dfrac{50-x}{50-30} & ,30 < x < 50 \\ 0 & ,x \ge 50 \end{cases}$$

$$.\ \mu Normal(x)\begin{cases} 0\ ;\ x \le 45\ or\ x \ge 70 \\ \frac{x-45}{60-45}\ ;45 < x \le 60 \\ \frac{80-x}{80-60}\ ;60 < x < 70 \\ 1\ \ ;x = 60 \end{cases}$$

$$\mu Healthy(x)\begin{cases} 0 & ,x \le 70 \\ \dfrac{x-70}{90-70} & ,70 < x < 90 \\ 1 & ,x \ge 90 \end{cases}$$

3.2.5 Rules

Based on the general structure of the Mamdani fuzzy rules and the number of fuzzy sets for each input variable, a total of 9 possible fuzzy rules can be formed. These rules are presented in the following table:

Table 6. Rules

No	Variables		
	Input		Output
	Blood Pressure	Heart Rate	Health Status
R1	Low	Bradycardia	Risky
R2	Low	Normal	Normal
R3	Low	Tall	Risky
R4	Normal	Bradycardia	Normal
R5	Normal	Normal	Health
R6	Normal	Tall	Normal
R7	Tall	Bradycardia	Risky
R8	Tall	Normal	Normal
R9	Tall	Tall	Risky

3.2.6 Defuzzification

After each membership degree is calculated, these values are processed using the 9 predefined fuzzy rules. To determine the α-predicate values, the variables are combined using the AND operator. During the inference stage, the system evaluates the applicable rules to obtain output values that will be used in the defuzzification process.

- Nadia Azzahra

$\alpha - [R1] = \min\ (\mu rendah[94] \cap\ \mu Bradycardia\ [75]$ = min (0,7∩ 0) = 0

$\alpha - [R2] = \min\ (\mu rendah[94] \cap\ \mu normal\ [75]$= min (0,7∩ 0,75)= 0,7

Function of rule implications

Zn = Zmax - α-predikatn X (Zmax- Zmin) = 70-0,7 X (70-60)= 63

$\alpha - [R3] = \min\ (\mu low[94] \cap\ \mu tall[75]$ = min (0,7 ∩ 0) = 0

$\alpha - [R4] = \min\ (\mu Normal[94] \cap\ \mu Bradycardia[75]$ = min (0,75 ∩ 0) = 0

$\alpha - [R5] = \min\ (\mu normal[94] \cap\ \mu normal[75]$ = min (0,75 ∩ 0,75) = 0,75

Function of rule implications

Zn = Zmax - α-predikatn X (Zmax- Zmin) = 70-0,75 X (90-70) = 55

$\alpha - [R6] = \min\ (\mu normal[94] \cap\ \mu tall[75]$ = min (0,75 ∩ 0)= 0

$\alpha - [R7] = \min\ (\mu tall[94] \cap\ \mu Bradycardia\ [75]$ = min (0∩ 0) = 0

$\alpha - [R8] = \min(\mu tall[94] \cap \mu normal[75]$ = min (0 ∩ 0,75) 0

$\alpha - [R9] = \min(\mu tall[94] \cap \mu tall[75]$ = min (0 ∩ 0) = 0

Next, the defuzzification value is calculated using the Weighted Average (WA) formula:

$$\text{WA} = \frac{(a_1 * z_n) + a_1 * z_n}{a_1 * z_n} = \frac{(0.50)+(0,7.63)+(0.50)+(0.45)+(0,75.55)+(0.45)+(0.50)+(0.45)+(0.50)}{(0+0,7+0+0+0,75+0+0+0+0)} = \frac{85,35}{1,45} = 58,86$$

- NurJamilah

$\alpha - [R1] = \min(\mu Low[127] \cap \mu Bradycardia[106]$ = min (0 ∩ 0) = 0

$\alpha - [R2] = \min(\mu Low[127] \cap \mu normal[106]$ = min (0 ∩ 0) = 0

$\alpha - [R3] = \min(\mu Low[127] \cap \mu tall[106]$ = min (0 ∩ 0,70) = 0

$\alpha - [R4] = \min(\mu Normal[127] \cap \mu Bradycardia[106]$ = min (0,65 ∩ 0) = 0

$\alpha - [R5] = \min(\mu normal[127] \cap \mu normal[106]$ = min (0,65 ∩ 0) = 0

$\alpha - [R6] = \min(\mu normal[127] \cap \mu tall[106]$ = min (0,65 ∩ 0,76) = 0,65

Function of rule implications

Zn = Zmax - α-predikatn X (Zmax- Zmin) = 80-0,65 X (80-60) = 67

$\alpha - [R7] = \min(\mu tall[127] \cap \mu Bradycardia[106]$ = min (0∩ 0) = 0

$\alpha - [R8] = \min(\mu tall[127] \cap \mu normal[106]$ = min (0 ∩ 0) = 0

$\alpha - [R9] = \min(\mu tall[127] \cap \mu tall[106]$ = min (0 ∩ 0,76) = 0

Next, the defuzzification value is calculated using the Weighted Average (WA) formula:

$$\text{WA} = \frac{(a_1 * z_n) + a_1 * z_n}{a_1 * z_n} = \frac{(0.50)+(0.45)+(0.50)+(0.45)+(0.70)+(0,65.67)+(0.50)+(0.45)+(0.50)}{(0+0+0+0+0+0,65+0+0+0)} = \frac{43,55}{0,65} = 67$$

3.3 System Testing Tools

Testing was conducted to determine whether the designed system functions according to the specified parameters. The purpose of this testing is to ensure that the monitoring system can accurately read data from the sensors, process the data using the Mamdani fuzzy logic method, and display the diagnostic results in real-time on the LCD screen. In a condition where the blood pressure is recorded at 94 mmHg, the user's heart rate falls within the normal category at 75 BPM, and the user is classified as a teenager at 17 years old, the system classifies this state as "Healthy." This status is displayed in real-time on the LCD screen as the text "Healthy," indicating that the user's physical condition is stable, as shown in the **Figure 6.**

Figure 6. Nadia Azzahra's Health Status

When the system detects a blood pressure reading of 127/106 mmHg, with the user's heart rate in the high category at 106 BPM, and the user is classified as a young adult at 25 years old, the system classifies this condition as "At Risk." In this situation, the system provides real-time information on the LCD display in the form of the text "At Risk," indicating that the user's physical condition is unstable, as shown in the **Figure 7.**

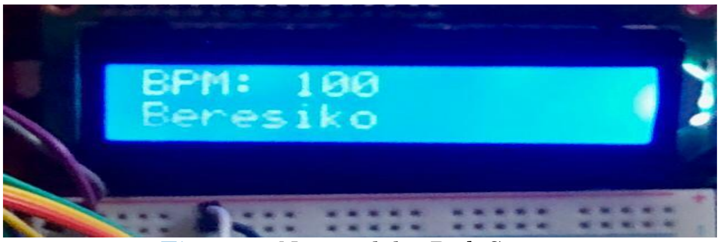

Figure 7. Nurjamilah's Risk Status

3.4 Oxymeter Testing

Sensor testing was conducted by comparing data from an oximeter with data obtained from the MAX30100 pulse sensor series. The study was carried out in Saisentang Village, Dusun Kelapa Rakyat, Kualuh Hilir Subdistrict, North Labuhan Batu Regency. The research involved local adults and my relatives residing in the village. The MAX30100 pulse sensor was used as an input to detect an individual's heart rate (BPM). To ensure reliable readings from this sensor, accuracy verification was conducted by comparing its measurements with actual heart rate values obtained using an oximeter, which serves as the reference standard. Therefore, testing and comparison processes were carried out to confirm that the readings from the MAX30100 sensor matched the actual values. This testing aimed to determine the error rate of the MAX30100 sensor readings relative to the oximeter, allowing assessment of the degree of data deviation. The error between the MAX30100 sensor and the oximeter.

Table 7. Oxymeter Testing

No	Name	Age (Years)	Results from the oximeter (BPM)	Hasil dari sensor MAX30100 (BPM)	Error rate (%)
1	Nurjamilah	24	106	108	1,98
2	Nadia azzahra	17	75	78	4
3	Sopia syhfitri	26	92	97	5,43
4	Mardiana	55	69	74	7,25
5	Bahrum jamil	25	83	83	0
					3,714

Average Error Rate

$$\left(\frac{1{,}89 + 4{,}00 + 5{,}43 + 7{,}25 + 0{,}00}{5}\right) = 3{,}714\%$$

Based on the results, the average error rate was found to be 3.44%, which falls into the moderate category. Based on this value, the system's accuracy can be calculated by subtracting the error percentage from 100%, resulting in an accuracy of 96.28%. Therefore, the system's accuracy achieved during the testing reached 96.28%.

4. CONCLUSION

This study successfully implemented and analyzed a blood pressure monitoring system based on Arduino Uno, integrating a digital blood pressure sensor and the MAX30100 heart rate sensor, with data processed using the Mamdani fuzzy logic method. The system monitors blood pressure (systolic and diastolic) and heart rate (BPM) in real-time, classifying user health into three categories: "Healthy," "Normal," and "At Risk." The Mamdani fuzzy logic provides flexibility in handling uncertain biological data and mimics human decision-making. Using nine fuzzy rules and three membership sets for each input, the system adapts to various combinations of blood pressure and heart rate. Testing showed the system functions effectively, with the LCD providing clear feedback, and sensor readings achieving a 96.28% accuracy, with an average error rate of 3.44%. Overall, the system demonstrates efficient monitoring and potential for further development as an early health screening tool in home or low-resource settings.

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