Journal of Robotics and Control (JRC)
Volume 4, Issue 3, May 2023
ISSN: 2715-5072, DOI: 10.18196/jrc.v4i3.18327

Temperature and Humidity Control System with Air Conditioner Based on Fuzzy Logic and Internet of Things

Furizal [1]*, Sunardi [2], Anton Yudhana [3]
[1] Master Program of Informatics, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
[2,3] Department of Electrical Engineering, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
Email: [1] 2108048014@webmail.uad.ac.id, [2] sunardi@mti.uad.ac.id, [3] eyudhana@ee.uad.ac.id
*Corresponding Author

Abstract—**Work is an activity that takes most of the day to earn a living and improve the standard of living. During work, many people have to work indoors, which can be a less comfortable and unhealthy place if the temperature and humidity are not well controlled. Unsuitable temperature and humidity conditions can negatively affect the health and comfort of workers, as well as interfere with productivity and work quality. However, the problem that often arises is the difficulty of controlling room temperature and humidity effectively, especially in rooms that are closed and do not get air circulation from outside. Therefore, an effective solution is needed to control the temperature and humidity of the room automatically and remotely via the internet. The contribution of this research is to develop an effective and efficient AC control system in controlling room temperature and humidity using Tsukamoto's Fuzzy Inference System (FIS) method and the Internet of Things (IoT). Tsukamoto's FIS is used to produce AC temperature values in room temperature and humidity control as measured by the DHT22 sensor directly integrated with the ESP32 microcontroller. This control system is monitored remotely using IoT concepts through a mobile application interface. The results of this study show that room temperature can be controlled under normal conditions, with an average change of -1.67°C and an overall average temperature of 25.95°C. While the average humidity is at a value of 80.16% which is included in the Wet set. This suggests that humidity cannot be controlled under normal conditions, so it still requires further development. In addition, it is also necessary to further investigate the effectiveness of the tool in various sizes and more complex layouts of rooms.**

Keywords—Artificial Intelligence; Fuzzy Logic; Internet of Things; Precision Control; Room Control.

I. INTRODUCTION

Indonesia is one of the countries that has a summer every year [1]. In this season, usually the temperature in the room feels hot, making it difficult for the body to concentrate [2]. The difficulty of concentration can make productivity decrease so it is not uncommon in the room to always install air conditioners such as fans and Air Conditioners (AC) [3]–[5]. In achieving a comfortable environment, temperature and humidity are important factors [6]–[8]. Proper control of temperature and humidity is required in various sectors such as residential homes [9], industry [10], [11], agriculture [12], poultry farming [13], [14], and others. In industry or agriculture, uncontrolled humidity and temperature can reduce product quality and even damage it [15]. While in a residential house, inappropriate humidity and temperature can affect the comfort of the occupants of the house. Then farm animals such as poultry may die if the temperature and humidity are incorrect. The same is true in other sectors.

Poor temperatures and humidity can cause problems in various sectors. Therefore, a temperature and humidity control system is needed that can control the room with high precision and accuracy. However, controlling temperature and humidity with conventional control methods still has a disadvantage, that is, it is less adaptive in controlling non-linear systems. In addition, control with conventional control methods also tends to require accurate and detailed mathematical models, so that the design and arrangement process becomes more complex. Therefore, in this study the fuzzy control method will be used as an alternative to conventional control methods.

A fuzzy control method is a type of control that produces results based on input values for linked variables. This control method differs from traditional control methods in that it does not require a mathematical model of the controlled system. Therefore, the fuzzy control method is perfect for controlling complex and unpredictable non-linear systems. Basically, fuzzy control serves as a bridge between input and output. Fuzzy control techniques today have been used in various fields, including machine control, robot control, image processing control, and environmental system control.

One of the fuzzy methods is the Fuzzy Inference System (FIS) approach. This type of fuzzy has three models, one of which is the Tsukamoto model chosen for use in this study [16]. This method was chosen because of its ability to solve uncertainty problems along with two other methods, namely probability and certainty factor [17]. In addition to these reasons, the fuzzy method also has the ability to construct fuzzy values from assessment data and draw on the experience of experts without the need for training [18]. FIS is a complete procedure that uses the set of inputs and outputs in the form of crisp numbers [19]. All inputs are converted into linguistic fuzzy values at the fuzzification stage. After that, IF-THEN rules based on such linguistic values were developed. Then, using the AND, OR, and NOT operations, all possible combinations of fuzzy rules and membership functions are used to generate fuzzy output. In defuzzification, any approach is used to convert all fuzzy output into crisp values [20].

As a point of reference, many temperature and humidity control systems with various application functions, such as use in server rooms [21], [22], thermal [23], greenhouses [24], and others have been developed by previous researchers. The application of fuzzy logic and Internet of Things (IoT) to controlling room temperature and humidity is based on various reasons. These reasons mostly concern efficiency and health issues. Fuzzy logic is mainly used as a control system because it eliminates the ON/OFF paradigm seen in traditional control. To make it even better, a control system that uses a fuzzy approach such as FIS should be applied. This is corroborated by previous research showing fuzzy logic can contribute to a more optimal control system than an ON/OFF base [23]. Whereas a fuzzy base gives a value from 0 to 1, the ON/OFF base only provides a value of 1 or 0. Another study used fuzzy logic to create a fan control system. The application of fuzzy logic this research is considered an energy-saving technique based on artificial intelligence [25].

In addition to the use of fuzzy logic, several related studies also discuss the advantages of utilizing IoT in control systems. For its users, IoT applications can make a significant contribution to convenience. According to one of the previous studies, the effect of implementing IoT is quite beneficial because it can improve user convenience, security, and intelligence [26]. According to one other study, IoT systems are a good idea to provide convenience to users of digital technology. Any electrically powered device can be managed using the concept of IoT. Increased system efficiency greatly reduces the amount of electrical energy used by providing central control of the equipment [27].

In addition to some of the literature studies that have been described, this research is also based on previous studies that used fans as a control mechanism [28]. This study shows that a fan that is turned in a closed room does not have too significant an impact in lowering the room temperature. The temperature of the room does not fall but becomes more and more up, although the increase that occurs is not too significant. Therefore, this study intends to continue previous research that was considered not to have obtained its proper target.

This research will create a temperature and humidity management system using a fuzzy-based approach to IoT and air conditioning as a cooling tool based on literature studies as given. Temperature and humidity sensors will be used by this control system to continuously monitor conditions in the regulated space. The value will be processed by a fuzzy controller, which then generates an output that is used to control the cooling device in the controlled chamber. In the world of technology, IoT has made a great contribution in controlling the temperature and humidity of the environment due to the concept of connecting multiple devices together. IoT devices can be minicomputers, sensors, actuators, and other types of equipment [29]–[31]. IoT enables interaction between different devices, making it easy to control temperature and humidity remotely.

This research uses ESP32 hardware as a microcontroller to implement an IoT-based fuzzy control system. The Espressif Systems introduced and created a family of microcontrollers, one of which is the ESP32. The ESP32 microcontroller is a replacement for the ESP8266 [32]–[34]. These two microcontrollers are part of the NodeMCU family [35] along with NodeMCU LoRa [36]. The WiFi module is available on this microcontroller and also has BLE (Bluetooth Low Energy) built into the chip. As a result, it is highly supportive and a suitable choice for building IoT application systems [37]. This microcontroller will act as a processing center tasked with controlling all physically integrated devices [22]. Basically the ESP32 has almost the same functions as Arduino and some other microcontrollers [38]–[40]. This is evidenced by the use of Arduino codes that can also be used on the ESP32 [41], [42]. The Arduino IDE is also compatible with this microcontroller [43].

The contribution of this research is to develop an effective and efficient air conditioning control system in controlling room temperature and humidity using FIS Tsukamoto and IoT methods. It aims to develop more accurate and adaptive fuzzy control techniques to improve the quality of controlled environments. The results of this study are expected to be compared with previous research to develop more optimal results. This comparison is also expected to present opportunities for the application of fuzzy control methods in the field of environmental control.

II. METHOD

A. Stages of Research

Broadly speaking, this research consists of six stages, namely requirement analysis, design tools and mobile applications, developing tools and mobile applications, applying fuzzy logic to tools using coding, testing and analyzing the impact of tools, and drawing conclusions and suggestions for future research.

Requirement Analysis referred to in this study is to determine the research background, research objectives and benefits, and look for literature studies from previous research. This stage is considered important as the basis or cause of the research. After this stage is completed, then step on the stage of designing tools and mobile applications.

The stage of designing tools and mobile applications aims to make it easier to assemble tools and code applications in the development stage. The supporting application used in this stage is Adobe Photoshop 2020 [44], [45]. After all the design is completed, then all these design applications are executed to produce products in the form of control tools and mobile applications.

The Developing tools and mobile applications stage is a stage that aims to develop all application designs and tools that have been made at the design stage. The mobile application is developed using Flutter [46]–[49]. Flutter is a platform used to create multi-platform applications with only one coding base (codebase) [50]–[52]. This means that the resulting application can be used on various platforms, both Android, iOS, web, and desktop mobile. Flutter has two important components, namely, the Software Development Kit (SDK) and also the user interface framework [53]. SDK is a set of tools that function to make applications so that they can run on various platforms [54]. While the UI framework is a UI component, such as text, buttons, navigation, and others, which can be customized as needed [55]–[57]. Flutter is also a free and open-source platform [58], [59]. Flutter was developed by Google using Dart programming [49], [60]–[62].

Next is the stage of applying fuzzy logic to the tools used to control room temperature. The fuzzy logic used is a type of FIS [63]. The FIS model used is FIS Tsukamoto [64], [65]. This fuzzy logic will play a role in adjusting the temperature of the air conditioner according to the input temperature and humidity of the room. This input indicator is measured in real time by a DHT22 sensor integrated with the ESP32 microcontroller as the processing center [66]–[68]. After the fuzzy logic is finished coding inside the microcontroller, then the tool logic is tested and analyzed for its impact in controlling temperature and humidity in the room by utilizing air conditioning. After that, conclusions are drawn according to what has been obtained from the testing stage. If the test has deficiencies that have not been achieved, then suggestions are drawn for further research so that this research will be even better in the future. A summary of the research stages of this study is listed in Fig. 1.

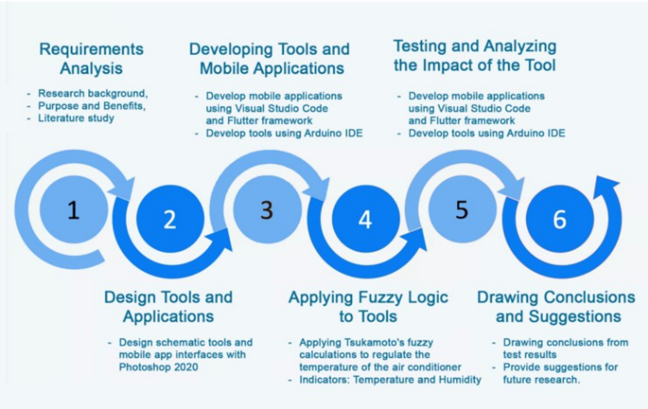


Fig. 1. Stages of research

B. Application Development Methods

This research uses the Waterfall model to create a mobile application which is one of the Software Development Life Cycle (SDLC) models [69], [70]. This model is a model that is often used among existing models, such as spiral, incremental, agile and others [71], [72]. This is based on the advantages of this method in terms of problem solving that is structured in analysis, design, implementation, testing, and maintenance that has been tested in solving problems [73]. This old model is easy to learn [74]. In the waterfall model, progress is observed flowing gradually downwards (like a waterfall). This implies that the development phase can only begin if the phase is before it is completed [75]. In general, the SDLC waterfall model method has 5 phases, namely Requirement Analyst, Design, Development, Testing, and Maintenance [76], [77]. All these stages have their own functions and roles.

The requirements analyst is the stage of defining the specifics of the software requirements, which refers to a complete and detailed description of the behavior of the program to be built. Functional and non-functional requirements that determine how users interact with the product to be developed [78]. These characteristics include scalability, testing capabilities, availability, maintenance, performance, and quality requirements.

The design phase is the process of planning and troubleshooting software solutions. Software developers and designers must decide on a solution strategy, which includes algorithm design, software architecture design, database conceptual schema design, logic diagram design, concept design, graphical user interface design, and data structure definition [79], [80]. All designs in this phase are then executed in the Development phase [81].

The development phase involves writing native code and compiling operational applications [82]. All generated code will be tested and validated in the testing phase. The testing phase is the process of assessing whether a software solution meets the initial requirements and specifications and meets its intended purpose or not [83]. After all the requirements have been met in the Testing phase, then it will enter the last phase, namely Maintenance. All errors that were missed at the previous stage are corrected as part of this phase [84].

A description of each stage in this Waterfall model can be seen in Fig. 2.

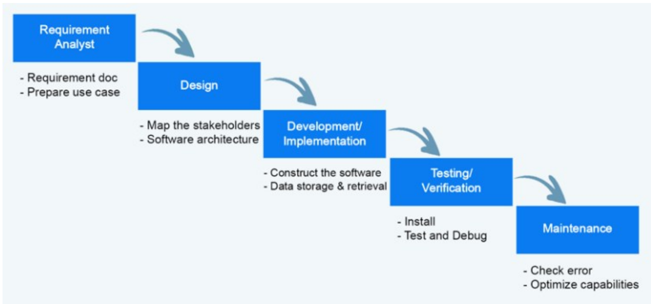


Fig. 2. Waterfall model

C. Fuzzy Logic

The logic known as fuzzy logic has a degree of vagueness between right and wrong. Fuzzy logic outperforms Boolean logic in terms of the idea of truth. Fuzzy logic replaces the level of truth for Boolean truths consisting only of values 1 and 0 [85]. Fuzzy logic accepts the region between black and white (gray) as well as ambiguous linguistic terms such as "few", "passable", and "many" [86]. Lotfi Asker Zadeh is an American Physicist of Iranian descent who first proposed and developed this concept through his 1965 article on fuzzy set theory [87]–[89].

Fuzzy logic can be applied in various fields such as in some cases science management, control theory, and decision theory. The advantage of fuzzy logic is that it is able to process reasoning linguistically (linguistic reasoning), so that in its design there is no need for mathematical equations of controlled objects. In general, fuzzy logic is used to solve problems involving components of uncertainty, inaccuracies, etc [90]. This reasoning combines proper machine language with human language that focuses on meaning. This logic was developed on the basis of human language (natural language) [91].

FIS is a type of fuzzy logic used in this study [92]. FIS or fuzzy inference machine is another name for a computer program that can perform reasoning on the same basis as humans do when using instincts [91]. The crisp value is used as the input for the FIS process and the crisp value is also used for the output [93]. This type of fuzzy has three models, namely Tsukamoto, Sugeno [31], [94], and Mamdani [95]–[97].

The FIS model used in this study is the Tsukamoto model. Any result of the IF-THEN rule in this model needs to be represented by a fuzzy set with monotonous membership functions. As a result, the inference output of each rule is provided explicitly (crisp) depending on the α-predicate [93]. A weighted average approach or other methods are used to obtain the final result [98]–[100].

Broadly speaking, this Tsukamoto model has three stages in producing outputs in the form of crisp values, namely fuzzification, machine inference, and defuzzification [101]. Fuzzification is a process of converting a non-fuzzy (crisp) set into a fuzzy set [94], a non-fuzzy (crisp) input mapped to a fuzzy set form according to the variations of the input speech universe [102]. One of the most important components in the fuzzification step is the membership function. The mapping between 0 and 1 for each data point in the input space is determined by a membership function in the form of a fuzzy curve [85]. Membership in fuzzy sets has different shapes consisting of linear, bell, gaussian, trapezoidal, shoulder curves (left and right), and triangular shapes [103], [104]. In this study, only two types of curves were used, namely the shoulder curve (left and right) and the triangle curve. The shape of the shoulder and triangular curves is depicted on Fig. 3. While the triangular curve notation is listed in Equation (1), the left shoulder curve notation in Equation (2), and the right shoulder curve notation in Equation (3).

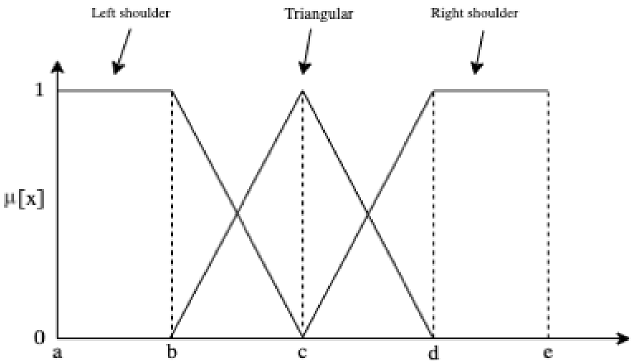


Fig. 3. Curves of the left shoulder, triangle, and right shoulder

$$\mu[x] = \begin{cases} 0;\ x \le b \text{ or } x \ge d \\ \dfrac{(x-b)}{(c-b)};\ b < x < c \\ \dfrac{(d-x)}{(d-c)};\ c < x < d \\ 1;\ x = c \end{cases} \quad (1)$$

$$\mu[x] = \begin{cases} 1;\ x \le b \\ \dfrac{(c-x)}{(c-b)};\ b < x < c \\ 0;\ x \ge c \end{cases} \quad (2)$$

$$\mu[x] = \begin{cases} 0;\ x \le c \\ \dfrac{(x-c)}{(d-c)};\ c < x < d \\ 1;\ x \ge d \end{cases} \quad (3)$$

After the fuzzification process, then there is the inference machine process. Fuzzy establishes theory-based rules in the form of IF-THEN statements used at the inference machine stage [105]. Each of these rules will be executed by using logical operators. Zadeh divides these logical operators into three operators, namely the AND, OR, and NOT operators [106], [107]. The AND operation is used to obtain the most minimum membership value between items in the relevant set (MIN). The representation of the AND operator is annotated like Equation (4). The OR operator relates to union operations on set. α-predicates as a result of operations with the OR operator are obtained by taking the maximum membership value between items in the relevant set (MAX). The representation of the OR operator is denoted like Equation (5). Meanwhile, the NOT operator is related to the complement operation of the set. α-predicates as a result of operations with the NOT operator are obtained by subtracting the value of the element's membership in the corresponding set from the value of 1(one) [108]. The NOT operator is denoted like Equation (6).

$$\mu Y \cap Z = min(\mu Y[i], \mu Z[i]) \quad (4)$$

$$\mu Y \cup Z = max(\mu Y[i], \mu Z[i]) \quad (5)$$

$$\mu Y' = 1 - \mu Y[i] \quad (6)$$

The form of rule used in Tsukamoto's fuzzy is a rule with monotonous reasoning annotated as below:

$$IF\ x\ is\ A\ THEN\ y\ is\ B$$

For example, two input variables are assumed, namely, *x* and *y,* as well as one output variable *z.* Then *x* is assumed to consist of two sets namely *X1* and *X2*, while *y* is also divided into two sets *Y1* and *Y2, z* also consists of two sets namely *Z1* and *Z2*. Based on this description, four fuzzy rules can be formed as in Fig. 4. In addition, the visualization can be seen on Fig. 5.

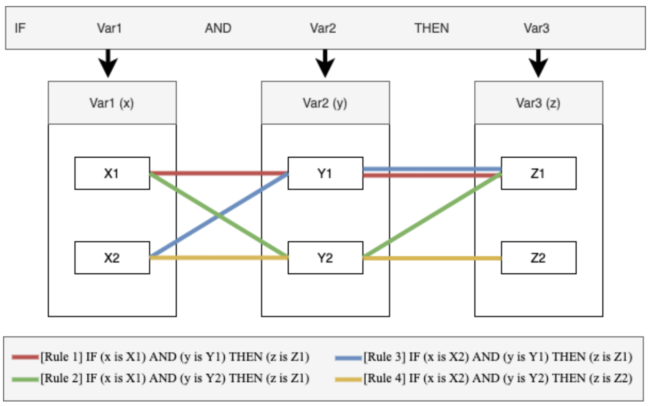


Fig. 4. Examples of fuzzy rules with monotonous reasoning

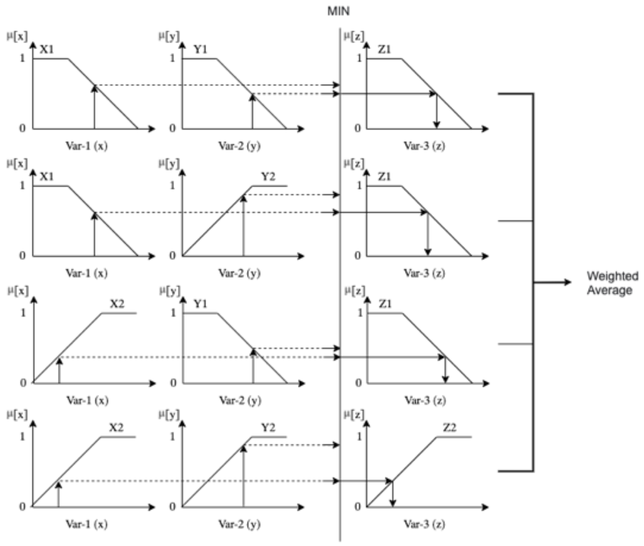


Fig. 5. Inference visualization using the Tsukamoto model

The final stage, known as defuzzification, is the next stage to be achieved after the inference machine stage. The purpose of defuzzification is to convert the results of the inference machine expressed as fuzzy sets into crisp values. The actions taken from fuzzy logic control are the result of conversion at this stage [109]. This stage can be completed using several methods, such as centroid method, mean-max method, weighted average method, and center-of-gravity (COG) method [110], [111]. While the defuzzification method used for this study is weighted average. The formula used in the weighted average method is as in Equation (7).

$$Z = \frac{\sum_{i=1}^{n} w_i X_i}{\sum_{i=1}^{n} w_i} \quad (7)$$

Equation (7) shows Z is the defuzzification, n is the number of terms to be averaged, w_i is the weight applied to the value of x, and X_i is the value of the data to be averaged.

D. Internet of Things

The future use of computers will be able to surpass human labor and surpass human computing capabilities such as utilizing the internet to operate electronic devices remotely such as the Internet of Things (IoT) [112], [113]. IoT is a frequent and interesting technology to discuss. IoT means that the internet is everything. This implies that the applied concept contains technologies, such as sensors and software connected to the internet for the purpose of interacting [36], [114], communicating and sharing data with other devices [115]. It shows how the internet is actively influencing daily digital activities. With this, it will make it easier when you want to transfer data or communicate to someone as long as they still have a connection to the internet. It also opens up wide opportunities for automation, monitoring, and optimization in various fields, including healthcare, manufacturing, transportation, and others [116]–[118].

IoT gives people the ability to manage and optimize electronic equipment by using the internet [112], [113]. The fundamental difficulty in IoT is bridging the gap between the physical and digital worlds, for example, how to process data collected from electronic equipment through user equipment interfaces. IoT devices may detect a variety of environmental factors, including temperature, humidity, and movement, as well as sophisticated machinery like autonomous vehicles or home appliances that can be connected to the internet. IoT combines several technologies that are broadly integrated into a single system, such as sensors that act as data readers, internet connections with various network topologies, radio frequency identification (RFID) [119], wireless sensor networks, and technologies that will continue to advance in answering needs [120]–[122]. In its implementation, IoT works continuously and real-time, so this has the potential to produce a lot of data. This large amount of data can be utilized in various activities, such as forecasting [123], decision support systems, data pattern recognition, and others.

One of the technologies that is closely related to the concept of the IoT is M2M (machine-to-machine) [124]. Smart gadgets are tools used in M2M because they can communicate. Smart devices were developed to assist humans in performing various jobs and solving the difficulties encountered. In response to this, IoT is one of the conveniences created to help everyone's work. The development of this technology is not easy and there are several steps that need to be taken in creating convenience for humans. IoT has a nickname as "the next big things" which makes it have great potential to be developed even better in the future [125]. Because it can be said that this technology can make life much better. The working concept of IoT is explained on Fig. 6.

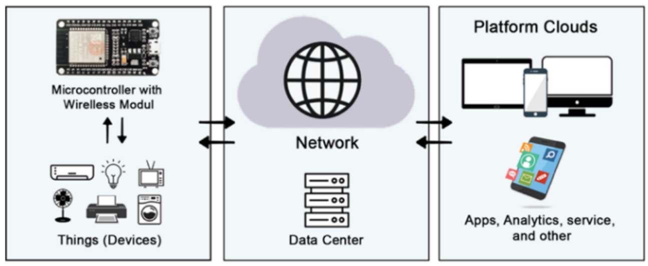


Fig. 6. IoT working concepts

Fig. 6 shows that broadly speaking, the concept of IoT has three interconnected parts, namely a microcontroller with a wireless module that will control devices (things), a network connection with data storage, and a platform as an interface for users. Devices that can be used such as air conditioners, televisions (TVs), lights, fans, and other electronic devices. The microcontroller will be a bridge device to access the internet by utilizing a wireless module. This wireless module will access the internet directly and access data from storage (data center). On the other hand, users can control the device through the application interface. This application will access data from data storage with the help of an internet connection. The application interface displayed to users can be various types of platforms, such as mobile, web, desktop, and others.

E. Design Tools and Applications

This design tool and application was designed using Adobe Photoshop 2020. The designed design takes into account all the necessary needs in the study. The design of these tools and applications aims to provide convenience in developing tools and applications into products that are ready to use. Building applications and tools without design will make the development process more complicated. This is because developers must develop applications while thinking about concepts that must be created simultaneously. Therefore, what must be done before developing is to design and conceptualize the applications and tools to be built.

This research tool was built using the ESP32 microcontroller. This microcontroller was chosen because it is accompanied by an internal WiFi module [126], so there is no need for an external module to access the internet. This microcontroller is integrated directly with several components [68] such as KY-005 InfraRed Transmitter, I2C, PIR Sensor [32], DHT22 Sensor [68], and LED. While some other components such as LCDs are also integrated with ESP32 through I2C intermediaries as a link. AC and smartphones are also integrated wirelessly, namely smartphones through the internet network and AC via infrared. Infrared is electromagnetic radiation from wavelengths increasing in length from visible light, but increasing in short from radio wave radiation. The built suite of tools has been depicted on Fig. 7.

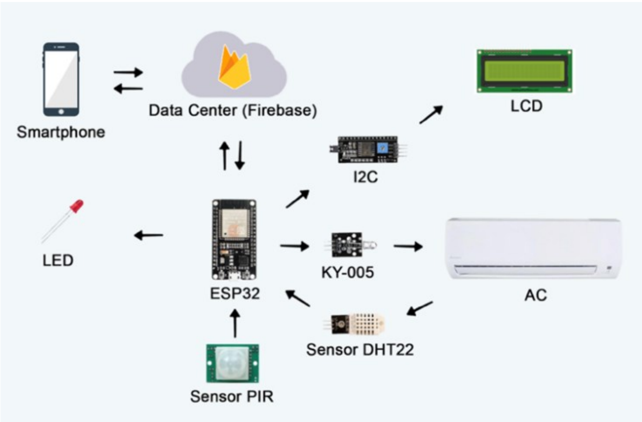


Fig. 7. Tool design

Fig. 7 explains that all components are integrated and work together so that a tool is formed as expected. ESP32 acts as a microcontroller that will become a data processing center. This microcontroller will control all the components that are integrated with it, both directly integrated and with other component intermediaries. The program code will be embedded in its memory, including code programmed for fuzzy logic.

Initially, the ESP32 will command the PIR sensor to detect the presence of humans in the room [32]. If a human object is not detected, then the PIR sensor will detect again until the human object is detected. Once a human object is detected in the room, ESP32 will instruct the DHT22 sensor to read temperature and humidity. Then ESP32 will process this temperature and humidity with a fuzzy method to obtain the temperature value of the air conditioner which will be sent by the KY-005 IR Transmitter with an infrared signal. Then this value will be captured by the air conditioner and will be set to the temperature of the air conditioner. After that, the air conditioner will provide action to the room. The temperature and humidity generated by this AC action will be read again by DHT22 for processing again on the ESP32. This process will take place continuously and in real time.

On the other hand, ESP32 also sends data on room temperature, humidity, air conditioning temperature (fuzzy logic processing), and human presence (Boolean) to Firebase as a data center. This value will be accessed by the smartphone to display on its interface. In addition, smartphones can also provide action on the ESP32. But this action is not sent directly to ESP32 but rather through a Firebase intermediary, meaning that the smartphone will send the value to Firebase. Meanwhile, ESP32 will access the value provided by the smartphone on Firebase. A simple block diagram that will be applied by the tool in controlling the temperature and humidity of the room is contained in Fig. 8.

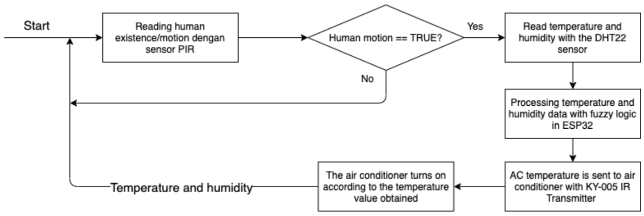


Fig. 8. Block diagram of tools in controlling the temperature and humidity

In addition to tool design, mobile application design is also needed to make it easier to develop mobile applications using programming languages. In the professional world, this job is usually done by UI and UX Designers. UI Designer focuses on the appearance of the application, while UX Designer focuses on the user's feeling or experience when using the application. The collaboration between UI and UX Designer can create an application that is pleasing to the eye, responsive, and easy to use [127], [128].

The application in this study only consists of one interface. In this interface, users can see the status of the fan (ON/OFF), the status of human objects or not (bool type), room temperature, humidity, and air conditioning temperature. In addition, users can also provide several actions, namely activating the mode of turning on the air conditioner without human objects, selecting the automatic mode (with fuzzy logic), and selecting the manual mode (the AC temperature is set manually). The interface design of the mobile application is listed on Fig. 9.

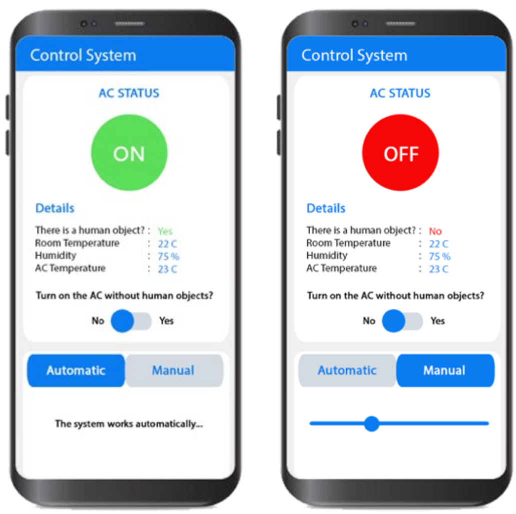


Fig. 9. Mobile app design

F. Developing Tools and Mobile Application

The control tool in this study was developed using the Arduino IDE because in addition to being able to be used to develop Arduino microcontrollers, this application can also be used to develop ESP32 microcontrollers [129]. The development of the ESP32 microcontroller control tool with Arduino IDE involves several basic steps, namely preparing hardware, software, carrying out the develop process to uploading the developed code into the ESP32 flash memory [43].

Hardware needs to be prepared in the form of research tools and supporting tools needed during the development process. In addition to hardware, software also needs to be prepared. Because these two components will be related. In the absence of software, the hardware cannot be operated and used. The required hardware is listed in Table I, while the software is listed in Table II.

TABLE I. HARDWARE NEEDED WHEN DEVELOPING TOOLS

Num	Hardware name	Its Usefulness in this Research
1	ESP32	A microcontroller that serves as a control and data processing center. In addition, it also functions as an internet accessor to apply the concept of IoT to control devices
2	KY-005 IR Transmitter	Serves to send Infrared to the AC
3	AC	Infrared indoor temperature and humidity control device from KY-005 IR Transmitter
4	DHT22 sensor	Sensors used to read room temperature and humidity
5	PIR sensor	Sensors used to detect human/motion objects
6	I2C	Devices used to save cables in the use of LCDs
7	LCD	Output tools used to display control tool information
8	LED	Indicators to provide code that human objects/movements are detected or not
	Jumper cable	Cables used to connect between devices
10	PC/Laptop	The device used to develop the tool. On this PC will be installed the software needed during the develop process
11	Breadboard	Breadboard is a board that serves to design a simple electronic circuit. Tool prototypes can be tested without having to be soldered
	USB cable	The cable used to connect the ESP32 microcontroller to a power source or USB port on the computer

TABLE II. SOFTWARE NEEDED WHEN DEVELOPING TOOLS

Num	Software name	Its Usefulness in this Research
1	Arduino IDE	An application used to develop code on the ESP32 microcontroller
2	Library	A library is a set of code that functions to simplify or simplify programming. The use of Arduino can be extended through the addition of libraries
3	Operating System (OS)	The operating system does not affect the results to be obtained from the develop process. Develop can use operating systems such as Microsoft Windows, Mac OS, and others.

Similar to the tool development process, mobile application development also requires hardware and software preparation so that the development process can be carried out. However, the hardware required during developing mobile applications is relatively less when compared to developing tools. In this study, only three hardware were used, namely smartphones, PCs, and USB cables. Smartphones are used to run mobile applications developed on a PC using a connector in the form of a USB cable. Flutter framework was used in the creation of this mobile application. The framework was developed with the Dart programming language [49], [60]–[62]. In the development process, Visual Studio Code (VSC) is used as a text editor by utilizing the extension provided to simplify the development process.

VSC is one of the open-source code editors that can be used for Windows, Linux, or Macintosh desktop computers [130]. This application was created by one of the big companies in the field of technology, namely Microsoft [131]. Despite being a powerful editor, VSC remains a lightweight program. Source code for various programming languages, including JavaScript, TypeScript, and Node.js, can be created and edited using this code editor. In reality, VSC is also compatible with various programming languages and operating systems, including Java, Python, PHP, and .NET. This is thanks to its extensive ecosystem and abundant availability of extensions [131], [132].

G. Applying Fuzzy Logic to the Tool

The FIS Tsukamoto method has an input variable and an output variable as objects for which the fuzzy value will be searched [133]. Therefore, room temperature and humidity are used as input variables in this study. While the temperature of the air conditioner as the output variable. The details of the input and output variables are listed in Table III.

Temperature is a measure of the hot or cold intensity of an object or environment. Temperature is generally measured in units of degrees Celsius (°C) or Fahrenheit (°F), and can also be measured in units of Kelvin (K) on an absolute thermometer scale. Temperature is influenced by many factors, including heat emitted by the sun, human activities, weather, and many other environmental factors. Temperature has an important role in many fields, including physics, chemistry, and meteorology. Air humidity is a measure of water vapor content in the air. Air humidity can be measured in various ways, such as by using a hygrometer or hygrometer. The unit used to measure air humidity is the percentage of relative humidity (%RH). While AC temperature is the temperature that is regulated or selected on the air conditioning system or air conditioning device used to control the air temperature in the room. Air conditioners regulate temperature by taking hot air from inside the room and expelling cooler air. AC temperature is usually measured in °C or °F.

Table III describes the domain details on each set that have been formed from the fuzzy variables used. The ideal temperature and humidity domains for each country's body will vary [134]. Many factors will influence this difference, one of which is the geographical condition of a country. Not only between different countries, but even the same country with different regions will also experience variations [135]. In 2011, Indonesia's National Standardization Agency (BSN) sought to solve this variation problem by providing a comfortable temperature standard of 25.5°C Ta, a range of

±1.5°C Ta, and a relative humidity of 60% ± 5% [136]. Based on this description, a temperature curve is formed at Fig. 10 and a humidity curve at Fig. 11.

TABLE III. MEMBERSHIP FUNCTION FORMATION SCHEME

Type	Variable name	Universe talk	Fuzzy set	Domain	Membership functions	Parameters
Input	Temperature (°C)	[0, 50]	Very Cold	<=22	Left shoulder	[0, 19, 22]
			Cold	20-25	Triangular	[20, 22.5, 25]
			Normal	24-27	Triangular	[24, 25.5, 27]
			Hot	26-31	Triangular	[26, 28.5, 31]
			Very Hot	>=29	Right shoulder	[29, 32, 50]
	Humidity (%)	[1, 100]	Dry	<=57	Left shoulder	[1, 52, 57]
			Normal	55-65	Triangular	[55, 60, 65]
			Quite Wet	63-75	Triangular	[63, 69, 75]
			Wet	73-85	Triangular	[73, 79, 85]
			Very Wet	>=83	Right shoulder	[83, 95, 100]
Output	AC Temperature (°C)	[18, 32]	Cold	<=25	Left shoulder	[18, 21, 25]
			Normal	24-27	Triangular	[24, 25.5, 27]
			Hot	>=26	Right shoulder	[26, 30, 32]

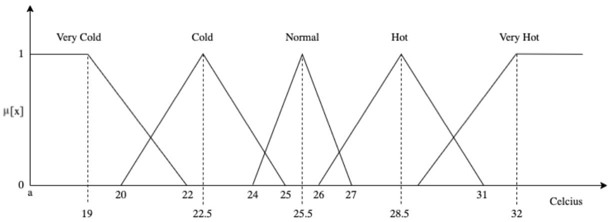


Fig. 10. Room temperature membership function curve

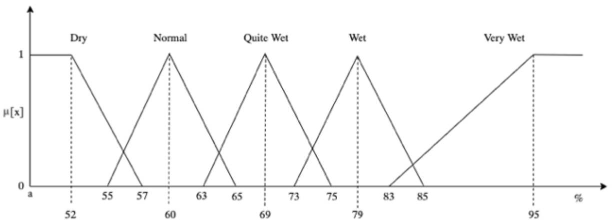


Fig. 11. Room humidity membership function curve

In addition to the variable membership function curve of the room temperature and humidity, there is also a variable curve of air conditioning temperature which acts as an output curve. The variable membership curve of AC temperature was obtained from the temperature range of air conditioners used in this study. The air conditioner temperature listed has a range of 18-32°C. This range is divided into three fuzzy sets, namely Cold, Normal, and Hot. The shape of the air conditioner temperature curve is listed on Fig. 12. While the fuzzy rules applied are 25 fuzzy rules such as Table IV. This number is obtained from two input variables that have a fuzzy set of five sets each.

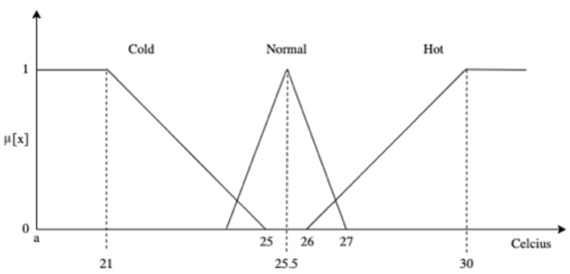


Fig. 12. AC temperature membership function curve

TABLE IV. FUZZY RULES

AC Temperature		Humidity				
		Dry	**Nor-mal**	**Quite Wet**	**Wet**	**Very Wet**
Room Temp	Very Cold	Hot	Hot	Hot	Hot	Normal
	Cold	Hot	Hot	Hot	Nor-mal	Normal
	Normal	Nor-mal	Nor-mal	Nor-mal	Nor-mal	Nor-mal
	Hot	Nor-mal	Nor-mal	Cold	Cold	Cold
	Very Hot	Nor-mal	Cold	Cold	Cold	Cold

III. RESULT AND DISCUSSION

A. Testing and Analyzing the Impact of the Tool

The stage that will determine the impact of this research is the testing and analysis stage. This stage of testing and analysis is carried out after the tools and applications have been successfully developed and the fuzzy logic has been applied to the tools. This developed tool was tested in a room with a length of 600 cm, a width of 300 cm, and a height of 400 cm. The impact of this tool was tested by placing the DHT22 sensor in two different positions, namely in front of the air conditioner with a distance of 400 cm and 600 cm. The position of the AC and its DHT22 sensor are illustrated on the Fig. 13.

Each position of the DHT22 sensor on Fig. 13 was tested three times in a span of 30 minutes. Both of these positions are tested by turning on the air conditioner and analyzing their effect on the temperature and humidity of the room. Fuzzy logic is used directly to control the air conditioner temperature according to the room temperature and humidity inputs read by the DHT22 sensor in real-time. The test results of the DHT22 sensor in the first position are listed on Fig. 14, while the test results of the second position are listed on Fig. 15. On the left, the room temperature and air conditioning temperature are juxtaposed, while on the right is the pair between humidity and air conditioning temperature.

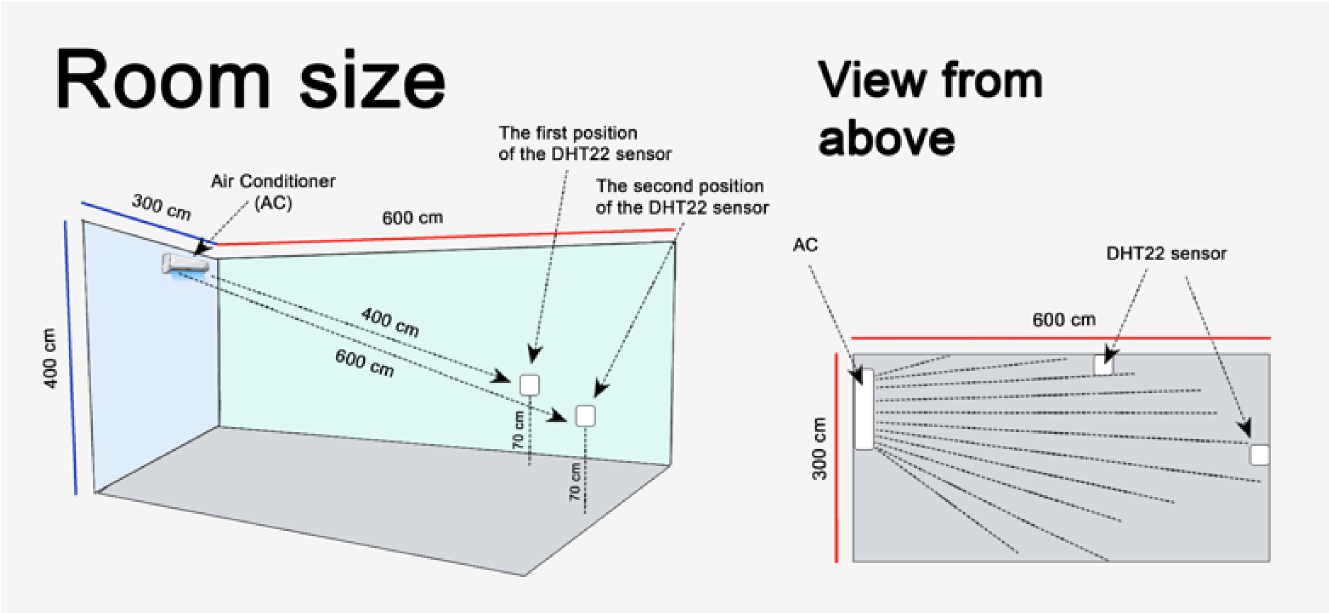
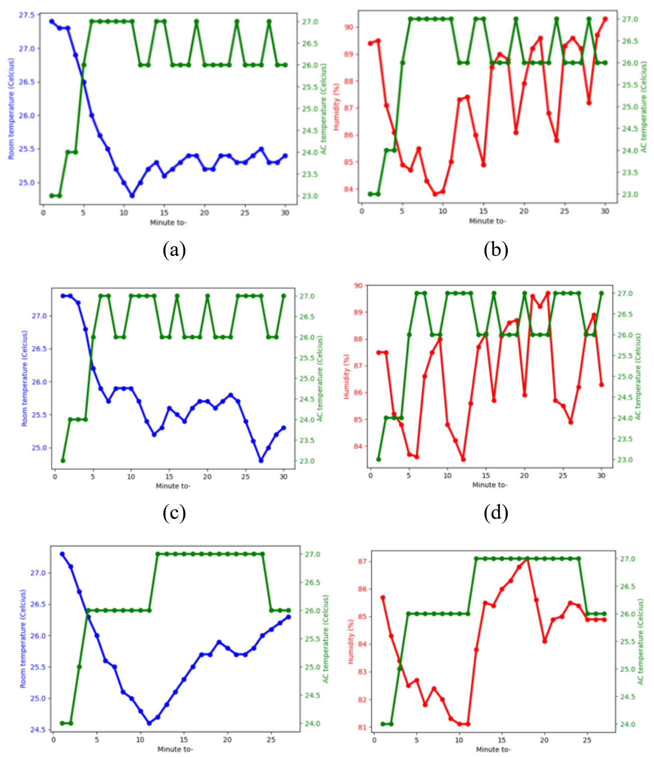
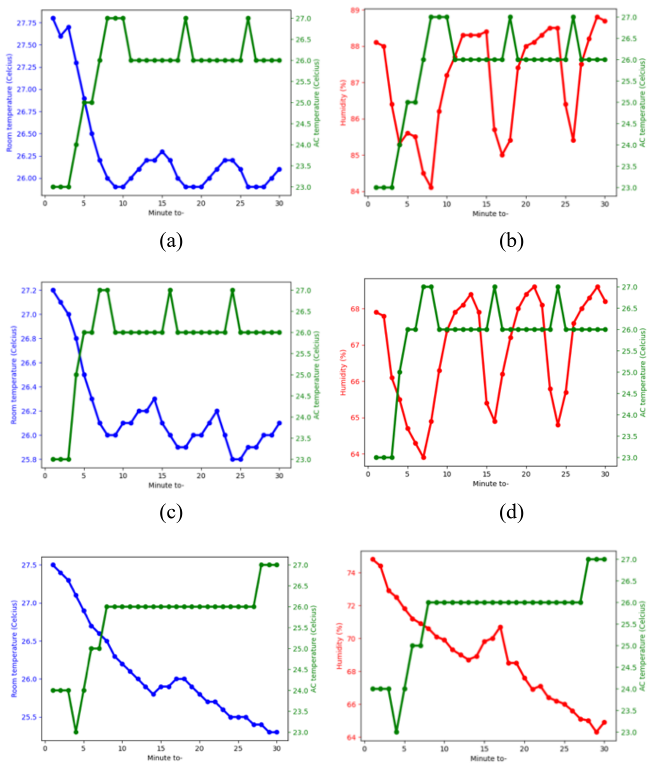


Fig. 13. Illustration of room size, AC position, and DHT22 sensor position



(a) (b) (c) (d) (e) (f)

Fig. 14. (a) Effect of fuzzy on room temperature in the first test, (b) Effect of fuzzy on humidity in the first test, (c) Effect of fuzzy on room temperature in the second test, (d) Effect of fuzzy on humidity in the second test, (e) Effect of fuzzy on room temperature in the third test, (f) Effect of fuzzy on humidity in the third test



(a) (b) (c) (d) (e) (f)

Fig. 15. (a) Effect of fuzzy on room temperature in the first test, (b) Effect of fuzzy on humidity in the first test, (c) Effect of fuzzy on room temperature in the second test, (d) Effect of fuzzy on humidity in the second test, (e) Effect of fuzzy on room temperature in the third test, (f) Effect of fuzzy on humidity in the third test

The first sensor position test on Fig. 14 produced an almost identical output for the temperature in each test. A room that is given a higher air conditioning temperature, will make the temperature higher as well, so that when the temperature is in a high state, the temperature of the air conditioner will be lowered by fuzzy logic to lower the room temperature.

The temperature value generated by fuzzy logic corresponds to the fuzzy literacy value obtained in each set on each of its variables (room temperature and humidity). Fuzzy logic is able to keep the temperature in normal conditions, which is 24-27°C. This result is shown in Fig. 14 points *a, c,* and *e*. As for the humidity at Fig. 14 points b, d, and f show results that have not been maximized. Humidity has not been able to be directed to normal conditions (55%-65%). Meanwhile, testing the position of the second sensor in Fig. 15 showed almost the same results as testing the position of the first sensor. High temperatures can be lowered and maintained under normal conditions. Although the humidity is still the same, it is still uncontrollable to normal conditions.

In detail, the results of the recapitulation of measurements of the impact of fuzzy logic on temperature in the first and second positions are listed in Table V. While the recapitulation of the impact on humidity is listed in Table VI.

TABLE V. Recapitulation of the Impact of Fuzzy Logic on Room Temperature

DHT22 sensor position	**Testing**	**Temperature**							
		First (°C)	**Last (°C)**	**Difference (Last-Fist) (°C)**	**Min (°C)**	**Max (°C)**	**Difference (Max-Min) (°C)**	**Avg (°C)**	**Standard deviation**
First place	First	27.4	25.4	**-2**	24.8	27.4	**2.6**	**25.61**	0.7168
	Second	27.3	25.3	**-2**	24.8	27.3	**2.5**	**25.76**	0.6355
	Third	27.3	26.3	**-1**	24.6	27.3	**2.7**	**25.72**	0.6794
Second place	First	27.8	26.1	**-1.7**	25.9	27.8	**1.9**	**26.30**	0.5648
	Second	27.2	26.1	**-1.1**	25.8	27.2	**1.4**	**26.19**	0.3702
	Third	27.5	25.3	**-2.2**	25.3	27.5	**2.2**	**26.09**	0.6386
Avg		**27.42**	**25.75**	**-1.67**	**25.2**	**27.42**	**2.22**	**25.95**	**0.6009**

TABLE VI. Recapitulation of the Impact of Fuzzy Logic on Humidity

DHT22 sensor position	**Testing**	**Humidity**							
		First (%)	**Last (%)**	**Difference (Last-Fist) (%)**	**Min (%)**	**Max (%)**	**Difference (Max-Min) (%)**	**Avg (%)**	**Standard deviation**
First place	First	89.4	90.3	0.9	83.8	90.3	6.5	87.23	2.0286
	Second	87.5	86.3	-1.2	83.5	89.7	6.2	86.65	1.8628
	Third	85.7	84.9	-0.8	81.1	87.1	6	84.24	1.7897
Second place	First	88.1	88.7	0.6	84.1	88.8	4.7	87.06	1.4381
	Second	67.9	68.2	0.3	63.9	68.6	4.7	66.83	1.4981
	Third	74.8	64.9	-9.9	64.3	74.8	10.5	68.92	2.8248
Avg		**82.23**	**80.55**	**-1.68**	**76.78**	**83.22**	**6.43**	**80.16**	**1.9070**

B. Discussion

Table V shows that fuzzy logic in controlling the air conditioner can have an impact on the temperature in the room. The test was carried out under initial temperature conditions ranging between 27.2°C and 27.8°C. After 30 minutes, the temperature changed with an average change in all tests of -1.67°C, meaning the temperature dropped by an average drop of 1.67°C. The average temperature in each test ranged between 25.61°C and 26.30°C, resulting in an overall average of 25.95°C. This value is still included in the normal temperature set/category. This means that overall the temperature can be controlled under normal conditions.

While on Table VI shows that fuzzy logic does not give the expected impact (controlling humidity to normal/standard conditions). The first sensor position test was performed at initial humidity conditions of 89.4%, 87.5%, and 85.7%. While the second sensor position test was carried out at initial humidity conditions of 88.1%, 67.9%, and 74.8%. After 30 minutes, six tests (three tests of the first position and three tests of the second position) resulted in three changes to higher values and three changes to values lower than the initial humidity value. Meanwhile, the average humidity in the entire test was at 80.16% (Wet set), meaning that humidity has not been able to be controlled under normal conditions. Even so, these results have given better results than the results in previous studies [28]. In previous studies, the temperature could not be controlled to normal conditions by using a device in the form of a fan in a closed room. The results obtained showed that the temperature rose by an average of 0.3–0.5°C within 40-75 minutes. While the implication of this study (using AC and the same method) is that the temperature can be controlled well in the normal range with an average temperature of 25.95 ° C (included in the normal set). But for moisture, further research is still needed to provide optimal results.

IV. Conclusion

This research shows that FIS Tsukamoto can have a good impact on the temperature in a room by utilizing air conditioning. The results showed that the temperature could be controlled under normal conditions, with an average change of -1.67°C and an overall average temperature of 25.95°C. However, the fuzzy logic of this model did not achieve the expected impact on humidity control to normal/standard conditions. From six tests conducted, the average humidity was at a value of 80.16% (Wet set). This indicates that humidity cannot be controlled under normal conditions, so it still requires further development. These results may be influenced by several factors that were not addressed in this study, so in future studies it is advisable to consider several other factors such as air quality, noise level, air circulation, light, number of human objects, individual comfort level as well as include user feedback or conduct user testing to ensure that the tools and mobile applications developed are easy to use and effective in meeting needs end user.

In addition, it is also necessary to further investigate the effectiveness of tools in various sizes and more complex room layouts by trying other FIS methods, such as the Sugeno and Mamdani models. Especially in previous research work, these two methods produced good results in performance and accuracy [94], [99], [100], [137]–[140].

REFERENCES

[1] A. Efendi, A. Nugraha, and R. Baharta, “Manufacturing of Electrical Dryer Machine for Food and Fruit Products,” *IOP Conf Ser Mater Sci Eng*, vol. 692, no. 1, p. 012006, Nov. 2019, doi: 10.1088/1757-899X/692/1/012006.

[2] A. Majdi, A. J. Alrubaie, A. H. Al-Wardy, J. Baili, and H. Panchal, “A novel method for Indoor Air Quality Control of Smart Homes using a Machine learning model,” *Advances in Engineering Software*, vol. 173, p. 103253, Nov. 2022, doi: 10.1016/j.advengsoft.2022.103253.

[3] A. M. Elsaid, H. A. Mohamed, G. B. Abdelaziz, and M. S. Ahmed, “A critical review of heating, ventilation, and air conditioning (HVAC) systems within the context of a global SARS-CoV-2 epidemic,” *Process Safety and Environmental Protection*, vol. 155, pp. 230–261, Nov. 2021, doi: 10.1016/j.psep.2021.09.021.

[4] N. T. Toosty, A. Hagishima, W. Bari, and S. A. Zaki, “Behavioural changes in air-conditioner use owing to the COVID-19 movement control order in Malaysia,” *Sustainable Production and Consumption*, vol. 30, pp. 608–622, Mar. 2022, doi: 10.1016/j.spc.2022.01.001.

[5] M. Vogt, C. Buchholz, S. Thiede, and C. Herrmann, “Energy efficiency of Heating, Ventilation and Air Conditioning systems in production environments through model-predictive control schemes: The case of battery production,” *Journal of Cleaner Production*, vol. 350, p. 131354, May 2022, doi: 10.1016/j.jclepro.2022.131354.

[6] G. A. Ganesh, S. L. Sinha, T. N. Verma, and S. K. Dewangan, “Investigation of indoor environment quality and factors affecting human comfort: A critical review,” *Building and Environment*, vol. 204, p. 108146, Oct. 2021, doi: 10.1016/j.buildenv.2021.108146.

[7] T. Cao, Z. Lian, S. Ma, and J. Bao, “Thermal comfort and sleep quality under temperature, relative humidity and illuminance in sleep environment,” *Journal of Building Engineering*, vol. 43, p. 102575, Nov. 2021, doi: 10.1016/j.jobe.2021.102575.

[8] D. Kong, H. Liu, Y. Wu, B. Li, S. Wei, and M. Yuan, “Effects of indoor humidity on building occupants’ thermal comfort and evidence in terms of climate adaptation,” *Building and Environment*, vol. 155, pp. 298–307, May 2019, doi: 10.1016/j.buildenv.2019.02.039.

[9] G. Tokazhanov, A. Tleuken, M. Guney, A. Turkyilmaz, and F. Karaca, “How is COVID-19 Experience Transforming Sustainability Requirements of Residential Buildings? A Review,” *Sustainability*, vol. 12, no. 20, p. 8732, Oct. 2020, doi: 10.3390/su12208732.

[10] M. Soltani Firouz, K. Mohi-Alden, and M. Omid, “A critical review on intelligent and active packaging in the food industry: Research and development,” *Food Research International*, vol. 141, p. 110113, Mar. 2021, doi: 10.1016/j.foodres.2021.110113.

[11] H. Yin and Y. Yin, “Current status and development trend of dehumidification technology in low-humidity industries,” *IOP Conference Series: Earth and Environmental Science*, vol. 1011, no. 1, p. 012030, Apr. 2022, doi: 10.1088/1755-1315/1011/1/012030.

[12] H. Manoharan, A. R. Basha, Y. Teekaraman, and A. Manoharan, “Smart home autonomous water management system for agricultural applications,” *World Journal of Engineering*, vol. 17, no. 3, pp. 445–455, Apr. 2020, doi: 10.1108/WJE-07-2019-0194.

[13] W. F. Pereira, L. da S. Fonseca, F. F. Putti, B. C. Góes, and L. de P. Naves, “Environmental monitoring in a poultry farm using an instrument developed with the internet of things concept,” *Comput. Electron. Agric.*, vol. 170, p. 105257, Mar. 2020, doi: 10.1016/j.compag.2020.105257.

[14] Md. M. Islam, S. Sourov Tonmoy, S. Quayum, A. R. Sarker, S. Umme Hani, and M. A. Mannan, “Smart Poultry Farm Incorporating GSM and IoT,” in *2019 International Conference on Robotics,Electrical and Signal Processing Techniques (ICREST)*, IEEE, Jan. 2019, pp. 277–280. doi: 10.1109/ICREST.2019.8644300.

[15] I. Ardiansah, N. Bafdal, E. Suryadi, and A. Bono, “Greenhouse Monitoring and Automation Using Arduino: a Review on Precision Farming and Internet of Things (IoT),” *Int. J. Adv. Sci. Eng. Inf. Technol.*, vol. 10, no. 2, p. 703, Apr. 2020, doi: 10.18517/ijaseit.10.2.10249.

[16] U. Sakız, G. U. Kaya, and O. Yaralı, “Prediction of drilling rate index from rock strength and cerchar abrasivity index properties using fuzzy inference system,” *Arabian Journal of Geosciences*, vol. 14, no. 5, p. 354, Mar. 2021, doi: 10.1007/s12517-021-06647-w.

[17] M. M. Gómez, D. T-. Zamora, J. L. M. Martínez, A. R. C. Ortega, J. de J. M. Rodríguez, and X. D-. Galván, “Water Supply Management Index: Leon, Guanajuato, Mexico,” *Water (Basel)*, vol. 14, no. 6, p. 919, Mar. 2022, doi: 10.3390/w14060919.

[18] D. K. Matci and U. Avdan, “Optimization-based automated unsupervised classification method: A novel approach,” *Expert Systems with Applications*, vol. 160, p. 113735, Dec. 2020, doi: 10.1016/j.eswa.2020.113735.

[19] M. Omair *et al.*, “The Selection of the Sustainable Suppliers by the Development of a Decision Support Framework Based on Analytical Hierarchical Process and Fuzzy Inference System,” *International Journal of Fuzzy Systems*, vol. 23, no. 7, pp. 1986–2003, Oct. 2021, doi: 10.1007/s40815-021-01073-2.

[20] A. Guzman-Urbina, K. Ouchi, H. Ohno, and Y. Fukushima, “FIEMA, a system of fuzzy inference and emission analytics for sustainability-oriented chemical process design,” *Appl. Soft. Comput.*, vol. 126, p. 109295, Sep. 2022, doi: 10.1016/j.asoc.2022.109295.

[21] M. O. Onibonoje, P. N. Bokoro, N. I. Nwulu, and S. L. Gbadamosi, “An IoT-Based Approach to Real-Time Conditioning and Control in a Server Room,” in *2019 International Artificial Intelligence and Data Processing Symposium (IDAP)*, pp. 1–6Sep. 2019, doi: 10.1109/IDAP.2019.8875880.

[22] M. Alvan Prastoyo Utomo, A. Aziz, Winarno, and B. Harjito, “Server Room Temperature & Humidity Monitoring Based on Internet of Thing (IoT),” *J. Phys. Conf. Ser.*, vol. 1306, no. 1, p. 012030, Aug. 2019, doi: 10.1088/1742-6596/1306/1/012030.

[23] R. Rakhmawati, Irianto, F. D. Murdianto, A. Luthfi, and A. Y. Rahman, “Thermal Optimization on Incubator using Fuzzy Inference System based IoT,” in *2019 International Conference of Artificial Intelligence and Information Technology (ICAIIT)*, pp. 464–468, Mar. 2019, doi: 10.1109/ICAIIT.2019.8834530.

[24] A. F. Subahi and K. E. Bouazza, “An Intelligent IoT-Based System Design for Controlling and Monitoring Greenhouse Temperature,” *IEEE Access*, vol. 8, pp. 125488–125500, 2020, doi: 10.1109/ACCESS.2020.3007955.

[25] Arlenny and D. Setiawan, “Optimization of electrical energy in the fan using fuzzy logic controllers,” *IOP Conf. Ser. Earth. Environ. Sci.*, vol. 1041, no. 1, p. 012025, Jun. 2022, doi: 10.1088/1755-1315/1041/1/012025.

[26] W. A. Jabbar *et al.*, “Design and Fabrication of Smart Home With Internet of Things Enabled Automation System,” *IEEE Access*, vol. 7, pp. 144059–144074, 2019, doi: 10.1109/ACCESS.2019.2942846.

[27] A. K. Gupta and R. Johari, “IOT based Electrical Device Surveillance and Control System,” in *2019 4th International Conference on Internet of Things: Smart Innovation and Usages (IoT-SIU)*, pp. 1–5, Apr. 2019, doi: 10.1109/IoT-SIU.2019.8777342.

[28] Sunardi, A. Yudhana, and Furizal, “Tsukamoto Fuzzy Inference System on Internet of Things-Based for Room Temperature and Humidity Control,” *IEEE Access*, vol. 11, pp. 6209–6227, 2023, doi: 10.1109/ACCESS.2023.3236183.

[29] Y. Prasetia, A. G. Putrada, and A. Rakhmatsyah, “Evaluation of IoT-Based Grow Light Automation on Hydroponic Plant Growth,” *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 7, no. 2, p. 314, 2021, doi: 10.26555/jiteki.v7i2.21424.

[30] D. Farahiyah and B. W. Purnama, “Design Prototype of Temperature and Humidity Control and Monitoring on Weaver Ant Cage based on Internet of Things,” *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 7, no. 2, p. 326, 2021, doi: 10.26555/jiteki.v7i2.21438.

[31] N. Rinanto, I. Marzuqi, A. Khumaidi, and S. T. Sarena, “Obstacle Avoidance using Fuzzy Logic Controller on Wheeled Soccer Robot,” *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 5, no. 1, pp. 26–35, 2019, doi: 10.26555/jiteki.v5i1.13298.

[32] F. F. Asman, E. Permata, and M. Fatkhurrokhman, “Prototype of Smart Lock Based on Internet Of Things (IOT) With ESP8266,” *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 5, no. 2, p. 101, 2020, doi: 10.26555/jiteki.v5i2.15317.

[33] E. Guney, G. Agirtas, and C. Bayilmis, “MongoDB Based Real-Time Monitoring Heart Rate Using Websocket For Remote Healthcare,” *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 8, no. 4, p. 500, 2022, doi: 10.26555/jiteki.v8i4.25052.

[34] M. F. Wicaksono and M. D. Rahmatya, “IoT for Residential Monitoring Using ESP8266 and ESP-NOW Protocol,” *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 8, no. 1, p. 93, Apr. 2022, doi: 10.26555/jiteki.v8i1.23616.

[35] J. M. Putra, M. Misbahuddin, and S. M. Al Sasongko, “Multi-hop ESP-Mesh Network and MQTT Protocol for Smart Light Systems in High-Rise Buildings,” *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 8, no. 1, p. 51, Apr. 2022, doi: 10.26555/jiteki.v8i1.22535.

[36] P. D. P. Adi, A. Kitagawa, D. A. Prasetya, R. Arifuddin, and S. Yoseph, “LoRaWAN Technology in Irrigation Channels in Batu Indonesia,” *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 7, no. 3, p. 522, Feb. 2022, doi: 10.26555/jiteki.v7i3.22258.

[37] O. Barybin, E. Zaitseva, and V. Brazhnyi, “Testing the Security ESP32 Internet of Things Devices,” in *2019 IEEE International Scientific-Practical Conference Problems of Infocommunications, Science and Technology (PIC S&T)*, pp. 143–146, Oct. 2019, doi: 10.1109/PICST47496.2019.9061269.

[38] A. Yudhana, D. Sulistyo, and I. Mufandi, “GIS-based and Naïve Bayes for nitrogen soil mapping in Lendah, Indonesia,” *Sens. Biosensing. Res.*, vol. 33, p. 100435, Aug. 2021, doi: 10.1016/j.sbsr.2021.100435.

[39] N. H. Wijaya, A. Yudhana, Robiyansah, and D. Sukwono, “X-Ray machine control with wireless based on mA parameters,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1088, no. 1, p. 012080, Feb. 2021, doi: 10.1088/1757-899X/1088/1/012080.

[40] A. Yudhana *et al.*, “Multi sensor application-based for measuring the quality of human urine on first-void urine,” *Sens. Biosensing. Res.*, vol. 34, p. 100461, Dec. 2021, doi: 10.1016/j.sbsr.2021.100461.

[41] A. Yudhana, J. Rahmawan, and C. U. P. Negara, “Flex sensors and MPU6050 sensors responses on smart glove for sign language translation,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 403, p. 012032, Oct. 2018, doi: 10.1088/1757-899X/403/1/012032.

[42] A. Yudhana, Sunardi, and Priyatno, “Development of Door Safety Fingerprint Verification using Neural Network,” *J. Phys. Conf. Ser.*, vol. 1373, no. 1, p. 012053, Nov. 2019, doi: 10.1088/1742-6596/1373/1/012053.

[43] H. Kareem and D. Dunaev, “The Working Principles of ESP32 and Analytical Comparison of using Low-Cost Microcontroller Modules in Embedded Systems Design,” in *2021 4th International Conference on Circuits, Systems and Simulation (ICCSS)*, pp. 130–135, May 2021, doi: 10.1109/ICCSS51193.2021.9464217.

[44] J. Guo, J. Yang, H. Yue, H. Tan, C. Hou, and K. Li, “CDnetV2: CNN-Based Cloud Detection for Remote Sensing Imagery With Cloud-Snow Coexistence,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 59, no. 1, pp. 700–713, Jan. 2021, doi: 10.1109/TGRS.2020.2991398.

[45] H. Zeng, J. Cai, L. Li, Z. Cao, and L. Zhang, “Learning Image-adaptive 3D Lookup Tables for High Performance Photo Enhancement in Real-time,” *IEEE Trans Pattern Anal Mach Intell*, pp. 1–1, 2020, doi: 10.1109/TPAMI.2020.3026740.

[46] S. Ghosal, A. Kumar, V. Udutalapally, and D. Das, “gluCam: Smartphone Based Blood Glucose Monitoring and Diabetic Sensing,” *IEEE Sensors Journal*, vol. 21, no. 21, pp. 24869–24878, Nov. 2021, doi: 10.1109/JSEN.2021.3116191.

[47] S. Boukhary and E. Colmenares, “A Clean Approach to Flutter Development through the Flutter Clean Architecture Package,” in *2019 International Conference on Computational Science and Computational Intelligence (CSCI)*, pp. 1115–1120, Dec. 2019, doi: 10.1109/CSCI49370.2019.00211.

[48] R. Mamoun, M. Nasor, and S. H. Abulikailik, “Design and Development of Mobile Healthcare Application Prototype Using Flutter,” in *2020 International Conference on Computer, Control, Electrical, and Electronics Engineering (ICCCEEE)*, pp. 1–6, Feb. 2021, doi: 10.1109/ICCCEEE49695.2021.9429595.

[49] E. Lee and C.-Y. Lee, “PPG-Based Smart Wearable Device With Energy-Efficient Computing for Mobile Health-Care Applications,” *IEEE Sensors Journal*, vol. 21, no. 12, pp. 13564–13573, Jun. 2021, doi: 10.1109/JSEN.2021.3069460.

[50] K. Kishore, S. Khare, V. Uniyal, and S. Verma, “Performance and stability Comparison of React and Flutter: Cross-platform Application Development,” in *2022 International Conference on Cyber Resilience (ICCR)*, pp. 1–4, Oct. 2022, doi: 10.1109/ICCR56254.2022.9996039.

[51] K. Nagaraj, B. Prabakaran, and M. O. Ramkumar, “Application Development for a Project using Flutter,” in *2022 3rd International Conference on Smart Electronics and Communication (ICOSEC)*, pp. 947–951, Oct. 2022, doi: 10.1109/ICOSEC54921.2022.9951938.

[52] M. A. Faiz, D. S. Kusumo, and M. J. Alibasa, “Flutter Framework Code Portability Measurement on Multiplatform Applications with ISO 9126,” in *2022 1st International Conference on Software Engineering and Information Technology (ICoSEIT)*, pp. 36–40, Nov. 2022, doi: 10.1109/ICoSEIT55604.2022.10030045.

[53] P. S. Wazarkar, A. D. Karnale, D. A. Chhabariya, A. R. Tiwari, and R. R. Kandelwal, “Early Disease Detection using Android Application based on Nail’s Image,” in *2021 IEEE Bombay Section Signature Conference (IBSSC)*, pp. 1–6, Nov. 2021, doi: 10.1109/IBSSC53889.2021.9673386.

[54] A. M. Qadir and P. Cooper, “GPS-based Mobile Cross-platform Cargo Tracking System with Web-based Application,” in *2020 8th International Symposium on Digital Forensics and Security (ISDFS)*, pp. 1–7, Jun. 2020, doi: 10.1109/ISDFS49300.2020.9116336.

[55] D. Sheppard, N. Felker, and J. Schmalzel, “Development of Voice Commands in Digital Signage for Improved Indoor Navigation Using Google Assistant SDK,” in *2019 IEEE Sensors Applications Symposium (SAS)*, pp. 1–5, Mar. 2019, doi: 10.1109/SAS.2019.8706120.

[56] F. Oprea, D. Rosner, F. Popescu, and A. Scrab, “Mediminder – Medication Management and Reminder Application,” in *2021 20th RoEduNet Conference: Networking in Education and Research (RoEduNet)*, pp. 1–6, Nov. 2021, doi: 10.1109/RoEduNet54112.2021.9637712.

[57] A. Khan and S. Khusro, “Blind-friendly user interfaces – a pilot study on improving the accessibility of touchscreen interfaces,” *Multimedia Tools and Applications*, vol. 78, no. 13, pp. 17495–17519, Jul. 2019, doi: 10.1007/s11042-018-7094-y.

[58] B. Halder, Md. H. Chowdhury, and Md. S. Rahman Kohinoor, “Look After: A Context-Aware Mobile Computing Based Smart Agent to Manage Personal Events,” in *2022 IEEE 3rd Global Conference for Advancement in Technology (GCAT)*, pp. 1–5, Oct. 2022, doi: 10.1109/GCAT55367.2022.9971827.

[59] S. Periyanayagi, A. Manikandan, M. Muthukrishnan, and M. Ramakrishnan, “BDoor App-Blood Donation Application using Android Studio,” *J. Phys. Conf. Ser.*, vol. 1917, no. 1, p. 012018, Jun. 2021, doi: 10.1088/1742-6596/1917/1/012018.

[60] U. S, A. B. T S R, S. V, and G. B. K, “IoT based Approach to Estimate the Vacant Seats Available,” in *2022 4th International Conference on Inventive Research in Computing Applications (ICIRCA)*, pp. 354–358, Sep. 2022, doi: 10.1109/ICIRCA54612.2022.9985657.

[61] K. Wasilewski and W. Zabierowski, “A Comparison of Java, Flutter and Kotlin/Native Technologies for Sensor Data-Driven Applications,” *Sensors*, vol. 21, no. 10, p. 3324, May 2021, doi: 10.3390/s21103324.

[62] S. Sharma, S. Khare, V. Unival, and S. Verma, “Hybrid Development in Flutter and its Widgits,” in *2022 International Conference on Cyber Resilience (ICCR)*, pp. 1–4, Oct. 2022, doi: 10.1109/ICCR56254.2022.9995973.

[63] A. C. Jahagirdar and K. K. Gupta, “Cumulative Distribution Sharpness Profiling Based Bearing Fault Diagnosis Framework Under Variable Speed Conditions,” *IEEE Sensors Journal*, vol. 21, no. 13, pp. 15124–15132, Jul. 2021, doi: 10.1109/JSEN.2021.3072368.

[64] S. Misra, S. Pal, P. K. Deb, and E. Gupta, “KEdge: Fuzzy-Based Multi-AI Model Coalescence Solution for Mobile Healthcare System,” *IEEE Systems Journal*, pp. 1–8, 2023, doi: 10.1109/JSYST.2023.3239395.

[65] F. Pradana, F. A. Bachtiar, and E. R. Widasari, “Fuzzy Tsukamoto Implementation to Detect Physiological Condition on IoT-Based e-Learning Users,” *International Journal of Information and Education Technology*, vol. 12, no. 7, pp. 663–667, 2022, doi: 10.18178/ijiet.2022.12.7.1668.

[66] M. T. Maiza Henanda, H. H. Nuha, and E. Ariyanto, “Utilization of Smart Greenhouse to Increase Chrysanthemum Growth in the Vegetative Phase by Monitoring Using Firebase,” in *2022 9th International Conference on Electrical Engineering, Computer*

Science and Informatics (EECSI), pp. 204–209, Oct. 2022, doi: 10.23919/EECSI56542.2022.9946632.

[67] A. López-Vargas and A. Ledezma-Espino, "Iot application for energy poverty detection based on thermal comfort monitoring," *Heliyon*, vol. 9, no. 1, p. e12943, Jan. 2023, doi: 10.1016/j.heliyon.2023.e12943.

[68] I. Riadi and R. Syaefudin, "Monitoring and Control Food Temperature and Humidity using Internet of Things Based-on Microcontroller," *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 7, no. 1, p. 108, 2021, doi: 10.26555/jiteki.v7i1.20213.

[69] A. Baharum *et al.*, "Mobile learning application: flipped classroom," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 17, no. 2, p. 1084, Feb. 2020, doi: 10.11591/ijeecs.v17.i2.pp1084-1090.

[70] N. Yahya and S. S. Maidin, "The Waterfall Model with Agile Scrum as the Hybrid Agile Model for the Software Engineering Team," in *2022 10th International Conference on Cyber and IT Service Management (CITSM)*, pp. 1–5, Sep. 2022, doi: 10.1109/CITSM56380.2022.9936036.

[71] N. Koussani, A. Leshob, P. Hadaya, I. Benzarti, and H. Mili, "Towards an Agile Approach for Business Process Reengineering," in *2022 IEEE International Conference on e-Business Engineering (ICEBE)*, pp. 130–135, Oct. 2022, doi: 10.1109/ICEBE55470.2022.00031.

[72] V. Hema, S. Thota, S. Naresh Kumar, C. Padmaja, C. B. Rama Krishna, and K. Mahender, "Scrum: An Effective Software Development Agile Tool," *IOP Conference Series: Materials Science and Engineering*, vol. 981, no. 2, p. 022060, Dec. 2020, doi: 10.1088/1757-899X/981/2/022060.

[73] L. Hao, J. Zhang, and X. Ma, "Development Trend of Software Process Model," *IOP Conference Series: Materials Science and Engineering*, vol. 569, no. 5, p. 052077, Jul. 2019, doi: 10.1088/1757-899X/569/5/052077.

[74] T. K. Rahayu, Susanto, and Suwarjono, "Application Report Process Of Islamic School Based On Pesantren Boarding Using Waterfall Model," *J. Phys. Conf. Ser.*, vol. 1569, no. 2, p. 022025, Jul. 2020, doi: 10.1088/1742-6596/1569/2/022025.

[75] I. Häring, "Models for Hardware and Software Development Processes," in *Technical Safety, Reliability and Resilience*, pp. 179–192, 2021, doi: 10.1007/978-981-33-4272-9_10.

[76] T. Saravanan, S. Jha, G. Sabharwal, and S. Narayan, "Comparative Analysis of Software Life Cycle Models," in *2020 2nd International Conference on Advances in Computing, Communication Control and Networking (ICACCCN)*, pp. 906–909, Dec. 2020, doi: 10.1109/ICACCCN51052.2020.9362931.

[77] F. I. Maulana, V. Susanto, P. Shilo, J. Gunawan, G. Pangestu, and D. R. B. Raharja, "Design and Development of Website Dr.Changkitchen Diet Catering Using SDLC Waterfall Model," in *6th International Conference on Sustainable Information Engineering and Technology 2021*, pp. 75–79, Sep. 2021, doi: 10.1145/3479645.3479652.

[78] D. Sudrajat *et al.*, "The Implementation of Innovation in Educational Technology to Improve The Quality of Website Learning in Industrial Revolution Era 4.0 Using Waterfall Method," *J. Phys. Conf. Ser.*, vol. 1364, no. 1, p. 012044, Dec. 2019, doi: 10.1088/1742-6596/1364/1/012044.

[79] G. N and S. Kumar, "QoS Aware Modified Harmony Search Optimization for Route Selection in Vanets," *Indian Journal of Computer Science and Engineering*, vol. 13, no. 2, pp. 288–299, Apr. 2022, doi: 10.21817/indjcse/2022/v13i2/221302014.

[80] H. Meileni, D. Juniansyah Putra, D. Apriyanti, I. Satriadi, and S. Oktapriandi, "Inventory Of Goods Data Processing Using The Economic Order Quantity (Eoq) Method," *J. Phys. Conf. Ser.*, vol. 1500, no. 1, p. 012112, Apr. 2020, doi: 10.1088/1742-6596/1500/1/012112.

[81] B. Sobandi *et al.*, "Batik AR ver.1.0: Augmented Reality application as gamification of batik design using waterfall method," *J. Phys. Conf. Ser.*, vol. 1987, no. 1, p. 012021, Jul. 2021, doi: 10.1088/1742-6596/1987/1/012021.

[82] D. Tantscher and B. Mayer, "Digital Retrofitting of legacy machines: A holistic procedure model for industrial companies," *CIRP Journal of Manufacturing Science and Technology*, vol. 36, pp. 35–44, Jan. 2022, doi: 10.1016/j.cirpj.2021.10.011.

[83] J. Imanuel, L. Kintanswari, Vincent, M. S. Anggreainy, S. Yusuf, and S. Y. Sembiring Kembaren, "Development of Financial Planner Application Software Based on Waterfall Model," in *2022 International Conference on ICT for Smart Society (ICISS)*, pp. 01–06, Aug. 2022, doi: 10.1109/ICISS55894.2022.9915039.

[84] A. Sinha and P. Das, "Agile Methodology Vs. Traditional Waterfall SDLC: A case study on Quality Assurance process in Software Industry," in *2021 5th International Conference on Electronics, Materials Engineering & Nano-Technology (IEMENTech)*, pp. 1–4, Sep. 2021, doi: 10.1109/IEMENTech53263.2021.9614779.

[85] D. K. Sharma, B. Singh, S. Agarwal, N. Pachauri, A. A. Alhussan, and H. A. Abdallah, "Sarcasm Detection over Social Media Platforms Using Hybrid Ensemble Model with Fuzzy Logic," *Electronics (Basel)*, vol. 12, no. 4, p. 937, Feb. 2023, doi: 10.3390/electronics12040937.

[86] H. Leon-Garza, H. Hagras, A. Pena-Rios, A. Conway, and G. Owusu, "A Big Bang-Big Crunch Type-2 Fuzzy Logic System for Explainable Semantic Segmentation of Trees in Satellite Images using HSV Color Space," in *2020 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE)*, pp. 1–7, Jul. 2020, doi: 10.1109/FUZZ48607.2020.9177611.

[87] L. A. Zadeh, "Fuzzy sets as a basis for a theory of possibility," *Fuzzy Sets and Systems*, vol. 1, no. 1, pp. 3–28, Jan. 1978, doi: 10.1016/0165-0114(78)90029-5.

[88] S. Tokat, K. Karagul, Y. Sahin, and E. Aydemir, "Fuzzy c-means clustering-based key performance indicator design for warehouse loading operations," *Journal of King Saud University - Computer and Information Sciences*, vol. 34, no. 8, pp. 6377–6384, Sep. 2022, doi: 10.1016/j.jksuci.2021.08.003.

[89] S. A. M. Al-taie and B. I. Khaleel, "Palm Print Recognition Using Intelligent Techniques: A review," *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 9, no. 1, pp. 156–164, 2023, doi: 10.26555/jiteki.v9i1.25777.

[90] A. E. Zaenchkovski, E. A. Kirillova, M. V. Golovinskaya, E. A. Sazonova, and V. L. Borisova, "Cognitive Fuzzy-Logic Modeling Tools to Develop Innovative Process Management Procedures for Scientific-Industrial Clusters," in *Frontier Information Technology and Systems Research in Cooperative Economics*, pp. 209–221, 2021, doi: 10.1007/978-3-030-57831-2_22.

[91] Shwetank, Suhas, and J. K. Chaudhary, "A Comparative Study of Fuzzy Logic and WQI for Groundwater Quality Assessment," *Procedia Computer Science*, vol. 171, pp. 1194–1203, 2020, doi: 10.1016/j.procs.2020.04.128.

[92] R. Tabbussum and A. Q. Dar, "Performance evaluation of artificial intelligence paradigms—artificial neural networks, fuzzy logic, and adaptive neuro-fuzzy inference system for flood prediction," *Environmental Science and Pollution Research*, vol. 28, no. 20, pp. 25265–25282, May 2021, doi: 10.1007/s11356-021-12410-1.

[93] T. P. Sihaloho, M. K. M. Nasution, and Z. Situmorang, "Level of student satisfaction on lecturer performance with fuzzy inference system (FIS) tsukamoto method," *IOP Conference Series: Materials Science and Engineering*, vol. 725, no. 1, p. 012130, Jan. 2020, doi: 10.1088/1757-899X/725/1/012130.

[94] M. Z. Dini, A. Rakhmatsyah, and A. A. Wardana, "Detection of Oxygen Levels (SpO2) and Heart Rate Using a Pulse Oximeter for Classification of Hypoxemia Based on Fuzzy Logic," *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 8, no. 1, p. 17, 2022, doi: 10.26555/jiteki.v8i1.22139.

[95] L. T. H. Lan *et al.*, "A New Complex Fuzzy Inference System With Fuzzy Knowledge Graph and Extensions in Decision Making," *IEEE Access*, vol. 8, pp. 164899–164921, 2020, doi: 10.1109/ACCESS.2020.3021097.

[96] M. I. Fale and Y. G. Abdulsalam, "Dr. Flynxz – A First Aid Mamdani-Sugeno-type fuzzy expert system for differential symptoms-based diagnosis," *Journal of King Saud University - Computer and Information Sciences*, vol. 34, no. 4, pp. 1138–1149, Apr. 2022, doi: 10.1016/j.jksuci.2020.04.016.

[97] S. Nurhayati, R. Lubis, and M. F. Wicaksono, "Application of the Machine Learning Method for Predicting International Tourists in West Java Indonesia Using the Averege- Based Fuzzy Time Series Model," *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 9, no. 1, pp. 1–11, 2023, doi: 10.26555/jiteki.v9i1.25475.

[98] S. Hardi, A. Triwiyono, and A. Amalia, "Expert System for Diagnosing Osteoarthritis with Fuzzy Tsukamoto Method," *J. Phys. Conf. Ser.*, vol.

1641, no. 1, p. 012107, Nov. 2020, doi: 10.1088/1742-6596/1641/1/012107.

[99] F. Umam, A. Dafid, and A. D. Cahyani, "Implementation of Fuzzy Logic Control Method on Chilli Cultivation Technology Based Smart Drip Irrigation System," *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 9, no. 1, pp. 132–141, 2023, doi: 10.26555/jiteki.v9i1.25813.

[100] Y. Yuliza, N. Sari, R. Muwardi, L. Lenni, and Y. Rahmawati, "Fiber Optic Attenuation Analysis Based on Mamdani Fuzzy Logic in Gambir Area, Central Jakarta," *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 8, no. 4, pp. 610-620, 2022, doi: 10.26555/jiteki.v8i4.24549.

[101] Yusfrizal, M. Sovina, F. A. Harahap, D. Adhar, W. Fahrozi, and H. Kurniawan, "Decision Support System for Determining the Amount of Production Based on Inventory Data and the Amount of Demand using the Tsukamoto Method," in *2021 IEEE 7th International Conference on Smart Instrumentation, Measurement and Applications (ICSIMA)*, pp. 270–275, Aug. 2021, doi: 10.1109/ICSIMA50015.2021.9526321.

[102] J. I. Obianyo, O. E. Okey, and G. U. Alaneme, "Assessment of cost overrun factors in construction projects in Nigeria using fuzzy logic," *Innovative Infrastructure Solutions*, vol. 7, no. 5, p. 304, Oct. 2022, doi: 10.1007/s41062-022-00908-7.

[103] S. Gupta, P. K. Biswas, B. Aljafari, S. B. Thanikanti, and S. K. Das, "Modelling, simulation and performance comparison of different membership functions based fuzzy logic control for an active magnetic bearing system," *The Journal of Engineering*, vol. 2023, no. 2, Feb. 2023, doi: 10.1049/tje2.12229.

[104] M. Suthar, "Modeling of UCS value of stabilized pond ashes using adaptive neuro-fuzzy inference system and artificial neural network," *Soft Computing*, vol. 24, no. 19, pp. 14561–14575, Oct. 2020, doi: 10.1007/s00500-020-04806-x.

[105] M. M. Ferdaus, S. G. Anavatti, M. Pratama, and M. A. Garratt, "Towards the use of fuzzy logic systems in rotary wing unmanned aerial vehicle: a review," *Artificial Intelligence Review*, vol. 53, no. 1, pp. 257–290, Jan. 2020, doi: 10.1007/s10462-018-9653-z.

[106] E. F. Yogachi, V. M. Nasution, and G. Prakarsa, "Design and Development of Fuzzy Logic Application Mamdani Method in Predicting The Number of Covid-19 Positive Cases in West Java," *IOP Conference Series: Materials Science and Engineering*, vol. 1115, no. 1, p. 012031, Mar. 2021, doi: 10.1088/1757-899X/1115/1/012031.

[107] P. G. Singerman, S. M. O'Rourke, R. M. Narayanan, and M. Rangaswamy, "Language-Based Cost Functions: Another Step Toward a Truly Cognitive Radar," in *IEEE Transactions on Aerospace and Electronic Systems*, vol. 57, no. 6, pp. 3827-3843, Dec. 2021, doi: 10.1109/TAES.2021.3082714.

[108] A. Krol and G. Sierpinski, "Application of a Genetic Algorithm With a Fuzzy Objective Function for Optimized Siting of Electric Vehicle Charging Devices in Urban Road Networks," *IEEE Transactions on Intelligent Transportation Systems*, vol. 23, no. 7, pp. 8680–8691, Jul. 2022, doi: 10.1109/TITS.2021.3085103.

[109] A. Ali, U. Heneash, A. Hussein, and M. Eskebi, "Predicting Pavement Condition Index Using Fuzzy Logic Technique," *Infrastructures (Basel)*, vol. 7, no. 7, p. 91, Jul. 2022, doi: 10.3390/infrastructures7070091.

[110] F. S. Alakbari, M. E. Mohyaldinn, M. A. Ayoub, A. S. Muhsan, and I. A. Hussein, "A robust fuzzy logic-based model for predicting the critical total drawdown in sand production in oil and gas wells," *PLoS One*, vol. 16, no. 4, p. e0250466, Apr. 2021, doi: 10.1371/journal.pone.0250466.

[111] B. Erfianto and A. Rahmatsyah, "Application of ARIMA Kalman Filter with Multi-Sensor Data Fusion Fuzzy Logic to Improve Indoor Air Quality Index Estimation," *JOIV : International Journal on Informatics Visualization*, vol. 6, no. 4, p. 771, Dec. 2022, doi: 10.30630/joiv.6.4.889.

[112] M. Tahir, Q. Mamoon Ashraf, and M. Dabbagh, "Towards Enabling Autonomic Computing in IoT Ecosystem," in *2019 IEEE Intl Conf on Dependable, Autonomic and Secure Computing, Intl Conf on Pervasive Intelligence and Computing, Intl Conf on Cloud and Big Data Computing, Intl Conf on Cyber Science and Technology Congress (DASC/PiCom/CBDCom/CyberSciTech)*, pp. 646–651, Aug. 2019, doi: 10.1109/DASC/PiCom/CBDCom/CyberSciTech.2019.00122.

[113] M. F. Wicaksono, S. Syahrul, and M. Dwi Rahmatya, "Development of Laboratory Equipment Inventory System Using Radio Frequency and Internet of Things," *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 7, no. 2, pp. 249-258, 2021, doi: 10.26555/jiteki.v7i2.21114.

[114] P. Purnomo, A. Aripriharta, A. N. Handayani, R. N. Hasanah, N. Rosmin, and G.-J. Horng, "Realtime IoT based Harmonics Monitoring System Review with Potential Low-Cost Devices with Experimental Case Study," *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 7, no. 2, p. 259-268, Aug. 2021, doi: 10.26555/jiteki.v7i2.21166.

[115] P. Bellini, P. Nesi, and G. Pantaleo, "IoT-Enabled Smart Cities: A Review of Concepts, Frameworks and Key Technologies," *Applied Sciences*, vol. 12, no. 3, p. 1607, Feb. 2022, doi: 10.3390/app12031607.

[116] K. Wójcicki, M. Biegańska, B. Paliwoda, and J. Górna, "Internet of Things in Industry: Research Profiling, Application, Challenges and Opportunities—A Review," *Energies (Basel)*, vol. 15, no. 5, p. 1806, Feb. 2022, doi: 10.3390/en15051806.

[117] P. Singh, Z. Elmi, V. Krishna Meriga, J. Pasha, and M. A. Dulebenets, "Internet of Things for sustainable railway transportation: Past, present, and future," *Cleaner Logistics and Supply Chain*, vol. 4, p. 100065, Jul. 2022, doi: 10.1016/j.clscn.2022.100065.

[118] Z. Fatima *et al.*, "Production Plant and Warehouse Automation with IoT and Industry 5.0," *Applied Sciences*, vol. 12, no. 4, p. 2053, Feb. 2022, doi: 10.3390/app12042053.

[119] W. A. Farag and M. Abouelela, "Low-Cost Active Monitoring of Attendance using Passive RFID Technology," *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 8, no. 4, pp. 552-564, 2022, doi: 10.26555/jiteki.v8i4.25168.

[120] X. Zhu, "Complex event detection for commodity distribution Internet of Things model incorporating radio frequency identification and Wireless Sensor Network," *Future Generation Computer Systems*, vol. 125, pp. 100–111, Dec. 2021, doi: 10.1016/j.future.2021.06.024.

[121] W. Kassab and K. A. Darabkh, "A–Z survey of Internet of Things: Architectures, protocols, applications, recent advances, future directions and recommendations," *Journal of Network and Computer Applications*, vol. 163, p. 102663, Aug. 2020, doi: 10.1016/j.jnca.2020.102663.

[122] W. Chen, "Intelligent manufacturing production line data monitoring system for industrial internet of things," *Computer Communications*, vol. 151, pp. 31–41, Feb. 2020, doi: 10.1016/j.comcom.2019.12.035.

[123] F. I. Indikawati and G. M. Zamroni, "Household Power Consumption Forecasting using IoT Smart Home Data," *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 5, no. 1, pp. 8-15, Jul. 2019, doi: 10.26555/jiteki.v5i1.13184.

[124] S. Leminen, M. Rajahonka, R. Wendelin, and M. Westerlund, "Industrial internet of things business models in the machine-to-machine context," *Industrial Marketing Management*, vol. 84, pp. 298–311, Jan. 2020, doi: 10.1016/j.indmarman.2019.08.008.

[125] S. Al-Sarawi, M. Anbar, R. Abdullah, and A. B. Al Hawari, "Internet of Things Market Analysis Forecasts, 2020–2030," in *2020 Fourth World Conference on Smart Trends in Systems, Security and Sustainability (WorldS4)*, pp. 449–453, Jul. 2020, doi: 10.1109/WorldS450073.2020.9210375.

[126] N. Inas Fikri, V. Louis Nathaniel, M. Syahrul Gunawan, and T. Abuzairi, "Design of Real-Time Aquarium Monitoring System for Endemic Fish on the Smartphone," *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 7, no. 2, pp. 269-276, Aug. 2021, doi: 10.26555/jiteki.v7i2.21137.

[127] M. Sandesara *et al.*, "Design and Experience of Mobile Applications: A Pilot Survey," *Mathematics*, vol. 10, no. 14, p. 2380, Jul. 2022, doi: 10.3390/math10142380.

[128] Wijayanti and R. Tanone, "Design Thinking and Emotional Intelligence in UI/UX Design of Website-Based Online Foreign Service Travel Expenses (BPDL) Applications," in *2021 2nd International Conference on Innovative and Creative Information Technology (ICITech)*, pp. 130–135, Sep. 2021, doi: 10.1109/ICITech50181.2021.9590156.

[129] H. I. Shahadi, M. K. Kadhim, N. M. Almeyali, and A. T. Hadi, "Design and Implementation of a Smart, Interactive and Portable System for Monitoring of Human Vital Signs," *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika*, vol. 7, no. 1, pp. 30-42, 2021, doi: 10.26555/jiteki.v7i1.20209.

[130]B. H. M. Mooers and M. E. Brown, "Templates for writing PyMOL scripts," *Protein Science*, vol. 30, no. 1, pp. 262–269, Jan. 2021, doi: 10.1002/pro.3997.

[131]S. bin Uzayr, "Introduction to Visual Studio Code," in *Optimizing Visual Studio Code for Python Development*, pp. 1–46, 2021, doi: 10.1007/978-1-4842-7344-9_1.

[132]V. K. Saini, C. S. Purohit, R. Kumar, and A. S. Al-Sumaiti, "Proof of Work Consensus Based Peer to Peer Energy Trading in the Indian Residential Community," *Energies (Basel)*, vol. 16, no. 3, p. 1253, Jan. 2023, doi: 10.3390/en16031253.

[133]E. F. Yogachi, V. M. Nasution, and G. Prakarsa, "Design and Development of Fuzzy Logic Application Mamdani Method in Predicting The Number of Covid-19 Positive Cases in West Java," *IOP Conference Series: Materials Science and Engineering*, vol. 1115, no. 1, p. 012031, Mar. 2021, doi: 10.1088/1757-899X/1115/1/012031.

[134]L. G. Ioannou *et al.*, "The Impacts of Sun Exposure on Worker Physiology and Cognition: Multi-Country Evidence and Interventions," *Int. J. Environ. Res. Public Health*, vol. 18, no. 14, p. 7698, Jul. 2021, doi: 10.3390/ijerph18147698.

[135]A. H. M. Eldesoky, J. Gil, and M. B. Pont, "The suitability of the urban local climate zone classification scheme for surface temperature studies in distinct macroclimate regions," *Urban Clim*, vol. 37, p. 100823, May 2021, doi: 10.1016/j.uclim.2021.100823.

[136]T. Karyono, "Predicting Comfort Temperature in Indonesia, an Initial Step to Reduce Cooling Energy Consumption," *Buildings*, vol. 5, no. 3, pp. 802–813, Jul. 2015, doi: 10.3390/buildings5030802.

[137]W. B. Zulfikar, Jumadi, P. K. Prasetyo, and M. A. Ramdhani, "Implementation of Mamdani Fuzzy Method in Employee Promotion System," *IOP Conference Series: Materials Science and Engineering*, vol. 288, p. 012147, Jan. 2018, doi: 10.1088/1757-899X/288/1/012147.

[138]D. Wahyuni, E. Sumarminingsih, and S. Astutik, "COVID-19 Vaccination and PPKM Policy with the Implementation of the Fuzzy Sugeno Method to Income Classification," *JTAM (Jurnal Teori dan Aplikasi Matematika)*, vol. 6, no. 4, p. 937, Oct. 2022, doi: 10.31764/jtam.v6i4.10096.

[139]G. Shahana, P. Ezhilarasi, and S. RajeshKannan, "Comparison of Mamdani and Sugeno fuzzy based data aggregation models for developing smart aquaculture system," in *2022 International Conference on Innovative Computing, Intelligent Communication and Smart Electrical Systems (ICSES)*, pp. 1–8, Jul. 2022, doi: 10.1109/ICSES55317.2022.9914378.

[140]Kms. M. Apriyansah, M. Maryaningsih, and I. Kanedi, "Application of Fuzzy Mamdani Logic in Determining Teacher Performance To The Learning System at Public High School 6 Bengkulu Middle," *Journal of Applied Engineering and Technological Science (JAETS)*, vol. 4, no. 1, pp. 460–468, Dec. 2022, doi: 10.37385/jaets.v4i1.1254.