

# Motorized Vehicle Diagnosis Design Using the Internet of Things Concept with the Help of Tsukamoto's Fuzzy Logic Algorithm

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**Abstract**—There are many popular branches, including the Internet of Things (IoT) and Artificial Intelligence (AI), which have solved many problems. Same as that, the automotive field is also growing with the technology of OBD-II. Unfortunately, not many people are familiar with OBD-II even though the features offered are very varied to prevent vehicle damage. This proposed work uses an IoT and AI system to make a vehicle diagnosis system with a help of OBD-II technology. By using ESP32 to collect data in each vehicle and using one Mini-PC to run the diagnosis with Fuzzy Logic Tsukamoto for three or more vehicles, this work can decrease the research cost. This work also uses the Fuzzy Logic Tsukamoto to diagnose vehicle health which is considered very suitable in real-time data situations. The method that we proposed is using Iterative Waterfall because of its simplicity and because there is a feedback path in every step. Iterative Waterfall is divided into 4 stages, Requirement Gathering and Analysis, System Design, implementation of Development, and Testing. Numerical validation is included by using MAPE for the testing in the IoT system and AI system. According to the MAPE result for the IoT system, the engine off voltage is 0.9510789847% and the engine start voltage is 3.136217503% which is considered a very good result. The MAPE result for the AI system is quite high, which is 20.74364412%, and because of that, the AI system needed more research for better performance. Overall, the system that has been proposed is already successful in monitoring vehicle health based on the parameters that have been determined.

**Keywords**—Artificial Intelligence; Fuzzy Logic Tsukamoto; Diagnosis Vehicle Health; Internet of Things

## I. INTRODUCTION

Technological developments in this era have changed how computing and communication systems work. The internet has undergone a massive expansion in recent years, leading to its widespread use by people of all generations [1]. According to [1], the development of the internet has become a separate trend and has become very popular in recent years. There are 204.7 million Internet users in Indonesia, reaching 73.7 percent of the population in 2022 [2]. The use of the internet has become very popular in many fields in the last few decades [1].

One of the uses of the internet that is growing quite rapidly today is the Internet of Things (IoT) [3], [4] because the technology supports and allows a system to retrieve data through sensors and then connect to the internet. Because the

system can connect to the internet and users directly, the IoT [5] system will always use a smart device to support its work system [6]. Therefore, IoT [7]–[12] is considered an alternative to many problems that can be found in today's developing industries [6]. Many smart tools see the success of IoT developments solutions to an existing issue, namely smart parking systems, smart garbage boxes, air pollution detectors and many others [13]. However, the implementation of IoT is not just that. One example of the implementation of IoT in the automotive industry is to improve the quality and safety of existing motorized vehicles [14].

Like the internet, the automotive sector is also experiencing rapid progress, one of which is the development of the Electronic Control Unit (ECU), which almost 80% of vehicles have used [15]. In the ECU, a standard can assist a technician in diagnosing the vehicle's condition, namely the OBD-II standard. According to [16], this OBD-II standard has been arranged by CARB (California Air Resources Board), ISO (International Standardization Organization), EPA (Environmental Protection Agency), and SAE (Society of Automotive Engineers). According to [17], the use of OBD-II is beneficial for motor vehicle users and technicians, then OBD-II has also been widely sold in the market.

However, it is very adverse because just minor people or companies have used the OBD-II standard for monitoring vehicle health [17]. Using technology to assist people in maintaining vehicle health is a very good solution because using traditional fault detection methods is not efficient [18]. In the last decade, several studies focus on how to make a system for diagnosing a vehicle's health to help people maintain the vehicle more easily [14], [17], [18].

In connection with diagnosing vehicle health [19]–[25], there are many branches with many functions and uses in the world of computers. One of them is decision-making. Decision-making that has a close relationship with IoT is Fuzzy Logic [26]. Fuzzy Logic has a relatively light process, so it is very suitable to be combined with IoT, which has uncertain conditions and data that quickly changes [26]. Fuzzy Logic is so simple because the rule of Fuzzy Logic itself is just IF-THEN.

Several similar studies have been carried out, such as in [14] which utilizes a Mini-PC (Raspberry Pi 3) [27], [28] to



retrieve data from OBD-II which will be processed using Machine Learning [29], [30] with K-Nearest Neighbour (KNN) [31]–[33] dan Naive Bayesian methods [34]–[36].

Other studies, such as by [37], explain how to handle overheating cases in large vehicles that occur in international mining contractors using the sensor DS18B20 to measure the engine temperature. The topics raised are similar, but not many have discussed how to apply the system in cases with many vehicles [17].

Moved by all of the studies that have been reported in this work, a diagnosis of vehicle health is designed a system using IoT as a data collector and AI to decide the vehicle health. The main contributions in this work are as follows:

- In research that has been conducted by [14], the author uses a Mini-PC for data collection and processing of data using Machine Learning. However, this research can be very costly because if it is applied to 2 or more vehicles, more tools are needed. In this work, using ESP32 for data retrieval, then using a separate mini-PC as a place for processing AI using Fuzzy Logic Tsukamoto can cut costs incurred if you want to implement it into 2 or more motorized vehicles.
- Then studies [17], [37], [38] also use a similar concept, by displaying vehicle health results but there is no diagnostic process on vehicle health using a combination of several different parameters. In this work, a system is formulated using AI in the form of Tsukamoto's Fuzzy Logic which can display vehicle data along with vehicle health diagnosis results using 3 parameters, namely engine off voltage, engine start voltage, and engine coolant temperature.

Therefore, the authors wants to develop a solution in the form of an IoT-based system by utilizing technology, namely OBD-II which can retrieve existing data on motorized vehicle ECUs. From OBD-II and using ESP32, the authors want to take 3 data, which are the vehicle engine off voltage, engine start voltage, and the engine coolant temperature. This research is also completed with Artificial Intelligence (AI) [39]–[45] in the form of Fuzzy Logic, which is the decision-making for vehicle health diagnosis results. By using Fuzzy Logic, the designed system can provide diagnostic results according to the limitations by experts. The result from Fuzzy Logic is a percentage on a scale from 0 (very bad) to 100 (very good). This research is expected to assist users in monitoring vehicles operating in large numbers and predicting the maintenance time for operating vehicles.

## II. BASE THEORY

### A. Basic Theory

#### 1) IoT

IoT [46]–[48] is one of the most famous paradigms in informatics fields that allow users to connect between electronic devices and sensors or actuators via the internet. IoT itself is a combined term of 2 words, namely "Internet" and "Things", and when combined with an item on the internet [49].

IoT [50]–[55] cannot stand alone, but by combining smart systems, frameworks, smart devices, and the internet, IoT becomes a complete system. Many parties have used IoT as a solution to existing problems because they use smart devices and the internet [6].

#### 2) ECU

ECU or Electronic Control Unit is an embedded system that is already installed in a vehicle to regulate an electronic and mechanical system. The ECU will take data from sensors and ECUs in other systems as input and will issue output to actuators. Each sensor and actuator are connected with a specific bus, so each bus and read and send data to ECU [56] At present, most vehicles use ECU to facilitate the technician to monitor the vehicle.

#### 3) Artificial Intelligence (Fuzzy Logic)

According to [57], Artificial Intelligence or AI [58]–[66] is one of many branches from computer science that is commonly used to fill an important role in a system. AI technology has many conveniences. Generally, what AI can do, is to make decisions, problems solving, language understanding, and or logical reasoning for a system.

One branch of AI's ability to make decisions is Fuzzy Logic. Fuzzy Logic is an advancement of Boolean Logic that show results other than true and/or false [67]. Three methods are used to achieve defuzzification Tsukamoto, Mamdani, and Sugeno [68]. Next, according to [69], the application of Fuzzy using the Tsukamoto method is considered very good and efficient in solving and simplifying problems whose context and scope are complex.

Four parts of the Fuzzy logic process must be carried out in the algorithm [69], namely:

- Fuzzification, the initial stage of the Fuzzy method, converts the existing values from the expertise into Fuzzy variables with their respective membership degrees. The membership degrees can be divided according to the threshold that we use. For example, when there are 2 indicators like good or bad, there are 2 membership degrees that are formed by that. Let's say that the good one is linear up and the bad one is linear down, so the membership degree for the "good" indicator is shown in the Fig. 1.

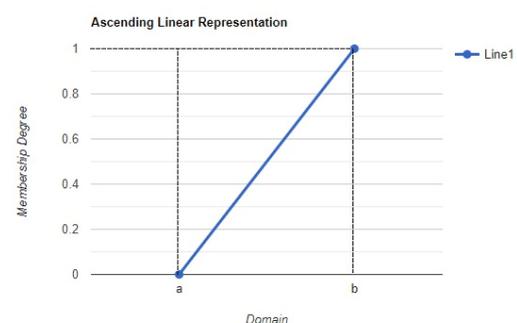


Fig. 1. Example of the Ascending Linear Representation

$$\mu_{(x)} \begin{cases} 0: x \leq a \\ \frac{x-a}{b-a}: a < x < b \\ 0: x \geq b \end{cases} \quad (1)$$

After that the, the membership degree for “bad” indicator is shown in Fig. 2.

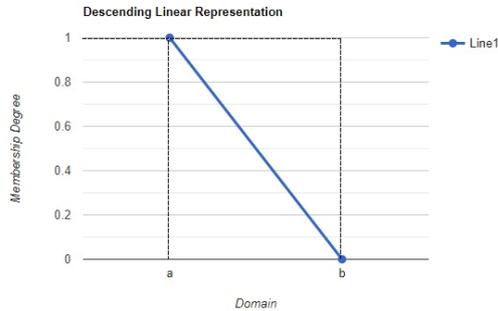


Fig. 2. Example of the Descending Linear Representation

$$\mu_{(x)} \begin{cases} 1: x \leq a \\ \frac{x-a}{b-a}: a < x < b \\ 0: x \geq b \end{cases} \quad (2)$$

- Define Fuzzy Rules: Defining Fuzzy rules is the stage that makes rules based on experts to achieve maximum control.
- Inference Process, the inference process is the calculation stage, where the main process is to search the alpha-predicate value ( $\alpha$ -predicate1, -predicate2, ... -predicate). The alpha-predicate value is used to find the inference value or is usually announce as  $z$  ( $z_1, z_2, \dots, z_n$ ). Implication functions in mathematics are used to complete this process, but it is conditional on the Fuzzy rules that are made, if the conjunction in the Fuzzy rules use "AND", then the implication function must be MIN. However, if the conjunction of the Fuzzy rules use "OR", then the implication function must be MAX.
- Defuzzification is the last step in the Fuzzy logic method. In this step, the writer uses the Tsukamoto Method instead of Mamdani Method, and Sugeno Method because of the simplicity of Tsukamoto Method. By using the average method to find the result of Fuzzy Logic. Therefore, the equation for Tsukamoto's Defuzzification is using the average [69]:

$$Z_i = \frac{\sum_{i=1}^j (\alpha - pred_i * x_i)}{\sum_{i=1}^j \alpha - pred_i} \quad (3)$$

Where  $Z_i$  is defuzzification value to  $i$ ,  $\alpha - pred_i$  is alpha predicate  $x_i$  is inference value to- $i$ ,  $j$  is amount of fuzzy rules.

### B. Testing with MAPE

The author wants to use the MAPE [70], [71] or Mean Absolute Percentage Error because MAPE is one of the few testing methods that really suits IoT and Fuzzy Logic [72]. This method aims to find the error rate of every testing data from the system that was designed. Therefore, to find MAPE is based on Error Rate, so the equations for Error Rate is [73]:

$$e_i = \left( \frac{|H_m - H_p|}{H_m} \right) \times 100\% \quad (4)$$

Where  $e_i$  is error rate ( $i$ ),  $H_m$  is result value from a system,  $H_p$  is predicted value.

After calculating the error rate, MAPE can be found by [73]:

$$MAPE = \frac{1}{N} \sum_{i=1}^N [e_i] \quad (5)$$

Where MAPE is Mean Absolute Percentage Error,  $e_i$  is error rate ( $i$ ),  $N$  is sum of tested data.

Therefore, an article says that MAPE are more advantageous than RMSE or MSE because of the result that MAPE and MAE yield is more natural [74]. The authors also say that with MAPE methods, the report will be easier for readers [74].

### C. Related Works

The previous research by [16] explains how to retrieve data from the vehicle to the MCU (Master Controller Unit) via OBD-II. The system described can provide additional features that do not yet exist in motorized vehicles such as GPS Tracking.

Previous research was also conducted by [75] who described retrieving and collecting OBD data on vehicles by communicating via Android phones with OBD and ELM327 Bluetooth modules. In this study, [75] used Android assistance to retrieve data on OBD so that the data could later be uploaded to the server. After uploading, the data obtained will be analysed and processed so that users can view vehicle information in real time.

Similar research [76], discusses how to retrieve data in the form of vehicle conditions and GPS from OBD-II and send it to FMS. This research also uses Message Queuing Telemetry Transport (MQTT) [77]–[80] to send data from IoT devices to servers.

Similar research was also conducted by [18], explaining how to create a system that can upload GPS data and OBD-II information via a wireless network using a 3.5G network module.

Another study conducted by [81] also discusses retrieving data from the ELM327 device, which will be processed by an Android phone to determine the condition of the motor vehicle from a predetermined threshold. In addition, [81] describes how to send the data to the back end, which the user can use via the web portal.

Based on previous research that already exists, we take topics related to vehicle diagnosis but by applying a different process, namely Fuzzy Logic with Tsukamoto Methods as an algorithm for vehicle health diagnosis for displaying management and monitoring of vehicle health conditions.

### III. METHOD

#### A. Methodology

This research method uses the Iterative Waterfall method, as it shown in the Fig 3, which is based on the Waterfall and Iterative development paradigms.

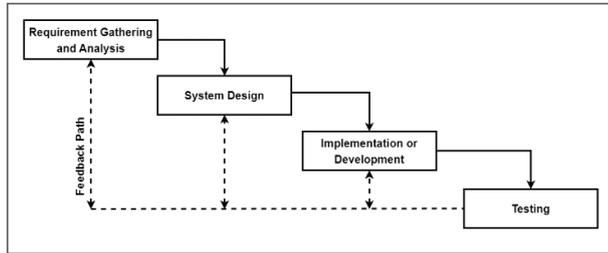


Fig. 3. Iterative Waterfall Methodology flow for this works

This model uses an efficient Software Development Life Cycle framework phase. The unique feature of The Iterative Waterfall model is that there is a feedback path to the previous step, which is very useful in solving problems in the software in particular phases. The following is a development method from this research [82]. The author uses this workflow method and can be divided as follows:

- *Requirement Gathering and Analysis*

Collecting and searching for the right problem formulation, topical information originating from scientific report sources, international journals related to OBD-II technical data, vehicle health, IoT, AI for decision making, MQTT protocol, platform Thingspeak, vehicle diagnostic algorithms, programming languages for software and hardware that can help strengthen the foundation of the chosen topic. The expected result in this phase is that the project has a strong knowledge base to proceed to the next stage.

- *System Design*

Create a hardware design for IoT system that includes an OBD-II Reader (ELM327) and microcontroller using ESP32 by creating a mock-up scheme or device flow, flowchart, wiring scheme, schematic diagram that will simplify the hardware system development process and will implement using C++ programming language. Design a software development using flowchart, block diagram, define the threshold, and designing every steps of Fuzzy Logic that will implement using Python programming language. The expected result in this phase is to have a strong design, both in software and hardware, that will facilitate the system implementation phase.

- *Implementation of Development*

Carry out the system implementation process by assembling hardware and coding using the programming language based on the System Design that has been designed for each system, both hardware and software. The expected results in this phase are hardware and software that can be integrated into a complete system and complete their tasks properly.

- *Testing*

Conduct trials on hardware and software systems by carrying out manual tests with a predetermined number of frequencies. The testing methods is using MAPE or Mean Absolute Percentage Error for both IoT and AI system. For IoT system, the tested parameters are Engine Off Voltage and Engine Start Voltage. The expected results are data from manual testing that align with the system that have been design, which mean the MAPE result shows quit low value.

#### B. Data Collection from IoT

The author plans to take 3 data, namely the battery voltage when the engine is off, the battery voltage when cranking, and the engine coolant's temperature. Retrieval of these 3 data will be carried out by ESP32 [83], [84], which is connected directly to ELM327 as follows in Fig. 4.

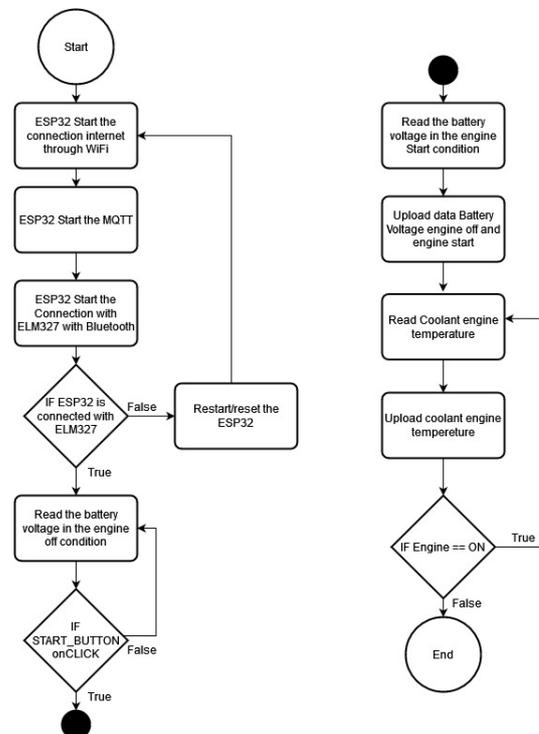


Fig. 4. Flowchart Data Collection for proposed IoT system

In the Fig. 4, it is explained how the system works. First, the system will initialize and start all the systems needed, like Wi-Fi, MQTT, and ELM327. Secondly, the system will check the engine condition. If the "Start Button" haven't pressed, the system will assume the engine is in off condition, then the system will read and upload the "voltage\_off" data repeatedly to the IoT Platform.

After that, while the "Start Button" is pressed and the engine is cranking, the system will read the "voltage\_start" and upload it to IoT Platform. After the engine is running and the "Start button" is not pressed, the system will read and upload "coolant\_temp" to IoT Platform repeatedly and will not read "engine\_off" and "engine\_start" anymore until the system shut down when ignition keys is turned off.

To complete for designing the IoT system, Fig. 5 is a device flow for IoT devices, starting from connect the ELM327 to OBD-II port in vehicle. After that, when ESP32 is powered on, that will connect to ELM327 using Bluetooth to collect the data. By requesting PID from ESP32, ELM327 can access and collect data from OBD-II. After ELM327 gets the data, ELM327 will send the data back to ESP32, and ESP32 will upload the data to the IoT Platform in form of ThingSpeak using MQTT.



Fig. 5. The Device Flow from Starting of IoT System

After designing the Device flow on general, the authors designed an wiring scheme and schematic diagram for the IoT system to be more detail. The wiring system is designed with the aim that the IoT system can switch on and off automatically when already installed to the vehicle without having to use other tools such as electricity from other source or anything else. The wiring scheme can be seen in Fig. 6. Based on the wiring scheme, the following is a schematic diagram to make it easier in assembling IoT devices as follows in Fig. 7.

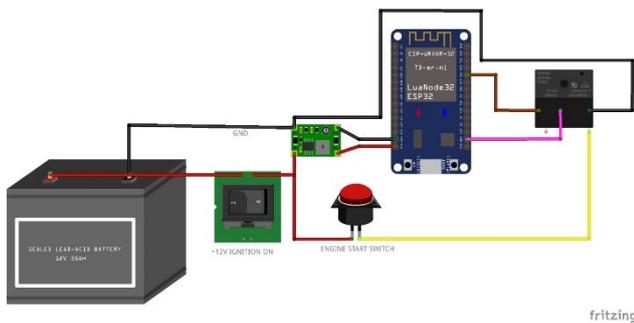


Fig. 6. The Wiring Scheme for the IoT System

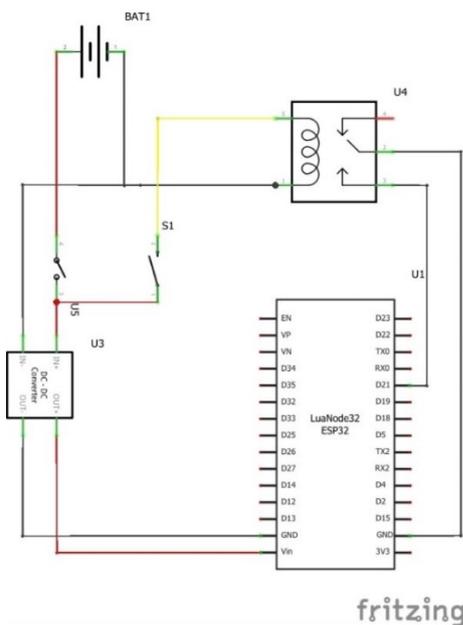


Fig. 7. The Schematic Diagram for The IoT System Based on the Wiring Scheme

According to the design in Fig. 6 and Fig. 7, here are some hardware and software that needed in the proposed IoT System to develop a complete system as shown in Table I and Table II.

TABLE I. HARDWARE NEEDED FOR IOT DEVICE

No	Hardware	Function
1	ESP32	Connect to ELM327, request the data, and post it to Thingspeak
2	ELM327	Read the data, connect to ESP32, and send the feedback
3	Relay	Control the digital output when ignition in "start" mode
4	Dc to dc converter	To lower a voltage from 12 volt to 5 volt (regulator step down)

TABLE II. SOFTWARE NEEDED FOR IOT SYSTEM

No	Software	Function
1	Arduino IDE	Code the IoT Program
2	IoT Platform (Thingspeak)	Store the data from IoT Device

C. Data Processing with Fuzzy Logic Tsukamoto

After the system successfully collects and uploads all the data to Thingspeak, the authors uses a Mini-PC (Raspberry Pi 3b) to run the AI program. The AI program will GET data from Thingspeak and store it temporarily for the next process. The next process is to run the Fuzzy Logic Tsukamoto program to find the results of a vehicle health diagnosis. The AI program will be running in Mini-PC as shown in the block diagram and flowchart abin Fig. 8, and Fig. 9.

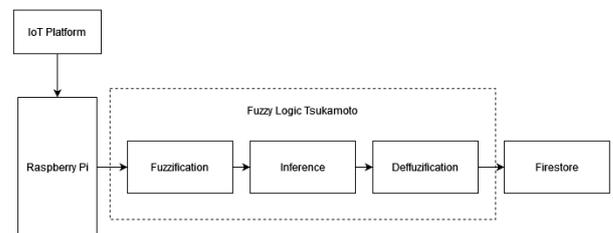


Fig. 8. The Block Diagram of AI Fuzzy Logic Tsukamoto

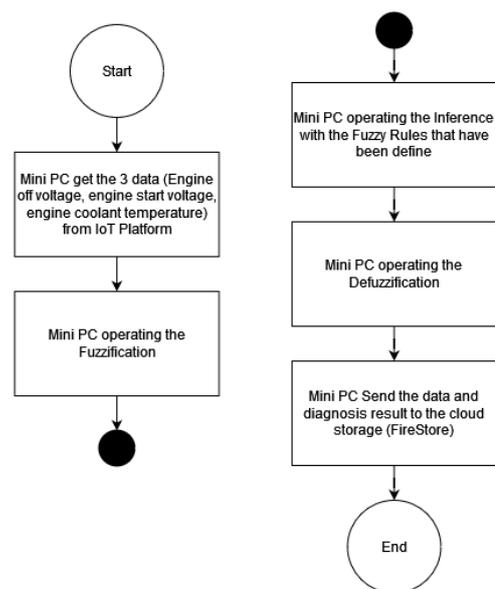


Fig. 9. The Flowchart of AI Fuzzy Logic Tsukamoto as General

There are limitations in every data that the author wants to use. The first one is for the battery voltage for the engine off; the threshold can be seen in the Table III threshold that the author uses are based on [85], [86].

TABLE III. THE THRESHOLD OF "BATTERY VOLTAGE ENGINE OFF" PARAMETERS

Battery Voltage Engine Off	Indication
<10.8V	Bad (Very weak)
10.8V ~ 11.8V	Warning (Weak)
11.8V ~ 12.8V	Good (Normal)

The second one is the threshold for battery voltage for the engine start, in the Table IV.

TABLE IV. THE THRESHOLD OF "BATTERY VOLTAGE ENGINE START" PARAMETERS

Battery Voltage Engine Start	Indication
<8.7V	Bad (Very weak)
8.7V ~ 9.2V	Warning (Weak)
9.2V ~ 10V	Good (Normal)

The last one is the threshold for the engine coolant temperature. The threshold that the author uses is based on [81], the author from that research said that the danger limits from engine coolant are around 220°F or 104°C, and it's shown in the Table V.

TABLE V. THE THRESHOLD OF "ENGINE COOLANT TEMPERATURE" PARAMETERS

Engine Coolant temperature	Indication
104 ~ 110°C	Bad (High)
101 ~ 107°C	Warning (Quite High)
97 ~ 104°C	Good (Normal)

From the threshold that already assign, the authors can finally design the Fuzzy Logic with Tsukamoto Algorithms. According to the previous section on Fuzzy Logic Theory, there are four main steps that must be design, which are:

- *Fuzzification*

In this step, the authors use the threshold that already assign in Tables III, IV, V to make the membership degree. By following the rules of fuzzification, here are the membership degree of each parameter:

- Battery Voltage Engine Off

The membership function plot of the battery voltage engine off, shown in the Fig. 5.

Good:

$$\mu(x) \begin{cases} 1: x \geq 12.8 \\ \frac{12.8 - x}{12.8 - 11.8}: 11.8 < x < 12.8 \\ 0: x \leq 11.8 \end{cases} \quad (6)$$

Warning:

$$\mu(x) \begin{cases} 0: x \leq 11.3 \text{ OR } x \geq 12.3 \\ \frac{x - 11.3}{11.8 - 11.3}: 11.3 < x < 11.8 \\ \frac{12.3 - x}{12.3 - 11.8}: 11.8 < x < 12.3 \end{cases} \quad (7)$$

Bad:

$$\mu(x) \begin{cases} 1: x \leq 10.8 \\ \frac{x - 10.8}{11.8 - 10.8}: 10.8 < x < 11.8 \\ 0: x \geq 11.8 \end{cases} \quad (8)$$

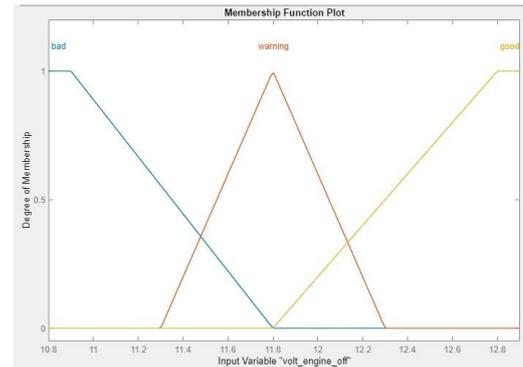


Fig 10. The membership function plot for "Battery Voltage Engine Off"

- Battery Voltage Engine Start

The membership function plot of the battery voltage engine start, shown in the Fig. 6.

Good:

$$\mu(x) \begin{cases} 1: x \geq 10 \\ \frac{10 - x}{10 - 9}: 9 < x < 10 \\ 0: x \leq 9 \end{cases} \quad (9)$$

Warning:

$$\mu(x) \begin{cases} 0: x \leq 8.8 \text{ OR } x \geq 9.2 \\ \frac{x - 8.8}{9 - 8.8}: 8.8 < x < 9 \\ \frac{9.2 - x}{9.2 - 9}: 9 < x < 9.2 \end{cases} \quad (10)$$

Bad:

$$\mu(x) \begin{cases} 1: x \leq 8.7 \\ \frac{x - 8.7}{9 - 8.7}: 8.7 < x < 9 \\ 0: x \geq 9 \end{cases} \quad (11)$$

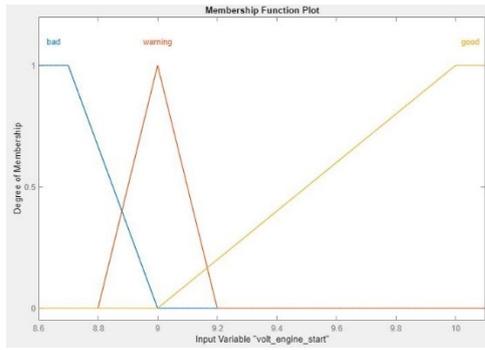


Fig. 11. The membership function plot for “Battery Voltage Engine Start”

#### - Engine Coolant Temperature

The membership function plot of the engine coolant temperature, shown in the Fig. 7.

Good:

$$\mu(x) \begin{cases} 1: x \leq 97 \\ \frac{x - 97}{104 - 97}: 97 < x < 104 \\ 0: x \geq 104 \end{cases} \quad (12)$$

Warning:

$$\mu(x) \begin{cases} 0: x \leq 101 \text{ OR } x \geq 107 \\ \frac{x - 101}{104 - 101}: 101 < x < 104 \\ \frac{107 - x}{107 - 104}: 104 < x < 107 \end{cases} \quad (13)$$

Bad:

$$\mu(x) \begin{cases} 1: x \geq 110 \\ \frac{110 - x}{110 - 104}: 104 < x < 110 \\ 0: x \leq 104 \end{cases} \quad (14)$$

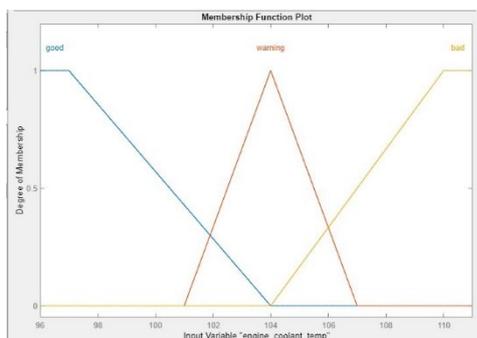


Fig. 12. The membership function plot for “Engine Coolant temperature”

#### - Diagnosis (Results)

The Result membership degree will use the scale on 1 to 10, but for the final results, the authors convert to a scale of 0 (very bad) to 100 (very good/safe). For the membership degree, there will be divided into three sections, there are good, warning, and bad. The membership function plot of the diagnosis, shown in the Fig. 8.

Good:

$$\mu(x) \begin{cases} 1: x \leq 1 \\ \frac{x - 1}{5.5 - 1}: 1 < x < 5.5 \\ 0: x \geq 5.5 \end{cases} \quad (15)$$

Warning:

$$\mu(x) \begin{cases} 0: x \leq 3 \text{ OR } x \geq 8 \\ \frac{x - 3}{5.5 - 3}: 3 < x < 5.5 \\ \frac{8 - x}{8 - 5}: 5 < x < 8 \end{cases} \quad (16)$$

Bad:

$$\mu(x) \begin{cases} 1: x \geq 10 \\ \frac{10 - x}{10 - 5.5}: 5.5 < x < 10 \\ 0: x \leq 5.5 \end{cases} \quad (17)$$

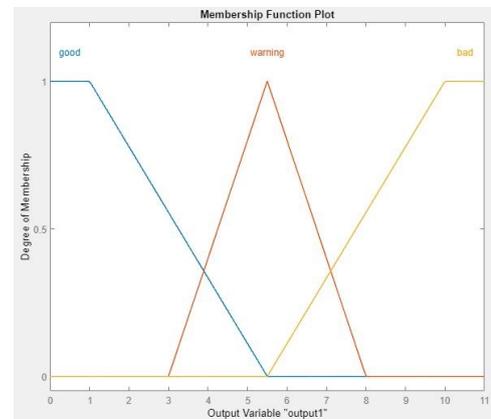


Fig. 13. The membership function plot for “Diagnosis” or output

#### • Fuzzy Rules

This research uses three parameters where it is one of the most important aspects of the motorized vehicle, by the reason of that, wherever one of the parameters is on the “bad” condition, the system will automatically diagnose the vehicle as “bad”. Therefore, in the Fuzzy rules, the authors agree to use the conjunction “AND” to find the minimum of alpha-predicate in the inference step.

As for the total of the Fuzzy rules is  $3^3 = 27$ , because the authors use three parameters and wants to include all the possibilities. The Fuzzy rules are:

1. IF engineOff good AND engineStart good AND Temperature good THEN good
2. IF engineOff good AND engineStart good AND Temperature warning THEN warning
3. IF engineOff good AND engineStart good AND Temperature bad THEN bad
4. IF engineOff good AND engineStart warning AND Temperature good THEN warning
5. IF engineOff good AND engineStart warning AND Temperature warning THEN warning

6. IF engineOff good AND engineStart warning AND Temperature bad THEN bad
7. IF engineOff good AND engineStart bad AND Temperature good THEN bad
8. IF engineOff good AND engineStart bad AND Temperature warning THEN bad
9. IF engineOff good AND engineStart bad AND Temperature bad THEN bad
10. IF engineOff warning AND engineStart good AND Temperature good THEN warning
11. IF engineOff warning AND engineStart good AND Temperature warning THEN warning
12. IF engineOff warning AND engineStart good AND Temperature bad THEN bad
13. IF engineOff warning AND engineStart warning AND Temperature good THEN warning
14. IF engineOff warning AND engineStart warning AND Temperature warning THEN warning
15. IF engineOff warning AND engineStart warning AND Temperature bad THEN bad
16. IF engineOff warning AND engineStart bad AND Temperature good THEN bad
17. IF engineOff warning AND engineStart bad AND Temperature warning THEN bad
18. IF engineOff warning AND engineStart bad AND Temperature bad THEN bad
19. IF engineOff bad AND engineStart good AND Temperature good THEN bad
20. IF engineOff bad AND engineStart good AND Temperature warning THEN bad
21. IF engineOff bad AND engineStart good AND Temperature bad THEN bad
22. IF engineOff bad AND engineStart warning AND Temperature good THEN bad
23. IF engineOff bad AND engineStart warning AND Temperature warning THEN bad
24. IF engineOff bad AND engineStart warning AND Temperature bad THEN bad
25. IF engineOff bad AND engineStart bad AND Temperature good THEN bad
26. IF engineOff bad AND engineStart bad AND Temperature warning THEN bad
27. IF engineOff bad AND engineStart bad AND Temperature bad THEN bad

- *Inference*

In the inference step, the main purpose is to find the alpha predicate and the inference value. To find the alpha-predicate, the system will using the Fuzzy rules to find the minimum value. After that, there are

three conditions based on the minimum alpha-predicate that have been found, there are good, warning, and bad. To find the inference, the formula is based on the “diagnosis” membership degree (on the formula 15, 16, and 17).

- *Deffuzification*

The last step is defuzzification, and this step will be using the formula from number 3.

After the system has finished diagnosing the health of the vehicle, the results and data will be posted by the Raspberry pi to the database.

There is some software and hardware that needed in the AI system as we already proposed before, it shown in Table VI and Table VII.

TABLE VI. HARDWARE NEEDED FOR RUNNING THE FUZZY LOGIC

No	Hardware	Function
1	Mini-PC (Raspberry Pi 3B)	Run the AI program, get the data from Thingspeak and post the data to Firebase

TABLE VII. SOFTWARE NEEDED FOR DEVELOP FUZZY LOGIC

No	Software	Function
1	PyCharm / Python	Code the AI Program

#### D. Data Show

Data that has been previously processed using a Fuzzy algorithm is displayed on Firebase Storage (Firestore Database). In the Firestore storage, general vehicle information and diagnostic results are displayed.

## IV. RESULT

In testing, the data that authors have collected is 50 data, and from 3 motorized vehicles. In this sections, we conclude in to 3

#### A. Collecting Data with IoT

In IoT system, the testing will take the data from ECU with help of OBD-II. Here are the results shown in Fig. 9, and the proof, that the IoT system that the authors already design is working as it proposed.



Fig. 14. IoT Device that proposed in this work



Fig. 15. Example of The IoT System that is Already Installed

By using the IoT system shown in Fig. 14, the system can retrieve data after we install the tool into the vehicle, shown in the Fig. 15. After the data has been retrieved, the IoT system will automatically send the data to the IoT platform in the form of ThingSpeak. The following is an example of proof that data has been successfully sent by the IoT system and received by the IoT platform.

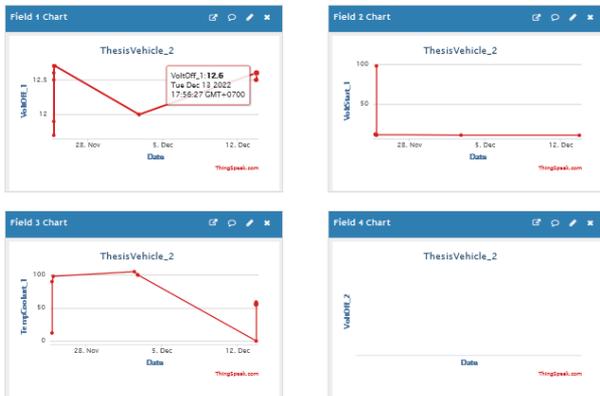


Fig. 16. Example of Data from IoT System to ThingSpeak

After that, to convince that the proposed system is already accurate, the testing for IoT system will also use the MAPE methods for two parameters: the voltage of engine off, and the voltage of engine start or cranking. The authors agree to use the Avometer to get the current voltage, whether it in the off state or start/cranking state. The purpose from that is to get the predicted value for MAPE. Here are the results shown in Table VIII, IX.

TABLE VIII. DATA COLLECTION WITH ERROR RATE FOR IoT SYSTEM

No	Voltage Off System (V)	Voltage Start System (V)	Voltage Off Avometer (V)	Voltage Start Avometer (V)	Error rate Voltage Off (%)	Error rate Voltage Start (%)
1	12.7	9.5	12.7	10.8	0	13.68421053
2	12.7	9.9	12.7	10.11	0	2.121212121
3	12.7	10.5	12.7	9.93	0	5.428571429
4	12.7	9.7	12.7	10.41	0	7.319587629
5	12.7	10.5	12.7	10.75	0	2.380952381
6	12.7	10.2	12.7	10.63	0	4.215686275

No	Voltage Off System (V)	Voltage Start System (V)	Voltage Off Avometer (V)	Voltage Start Avometer (V)	Error rate Voltage Off (%)	Error rate Voltage Start (%)
7	12.7	10.3	12.7	9.96	0	3.300970874
8	12.7	10	12.7	10.32	0	3.2
9	12.7	9.9	12.7	9.79	0	1.111111111
10	12.7	9.3	12.7	9.78	0	5.161290323
11	12.5	11.3	12.5	11.4	0	0.8849557522
12	12.5	11.1	12.5	11.3	0	1.801801802
13	12.6	11.1	12.5	11.58	0.7936507937	4.324324324
14	12.6	11	12.5	11.3	0.7936507937	2.727272727
15	12.6	10.3	12.5	11.45	0.7936507937	11.16504854
16	12.7	11.1	12.5	11.35	1.57480315	2.252252252
17	12.6	11.2	12.5	11.6	0.7936507937	3.571428571
18	12.6	11.2	12.5	11.64	0.7936507937	3.928571429
19	12.6	11.1	12.5	11.2	0.7936507937	0.9009090909
20	12.7	11.1	12.5	11.4	1.57480315	2.702702703
21	12.6	10.7	12.6	11.07	0	3.457943925
22	12.6	10.5	12.6	11	0	4.761904762
23	12.5	10.4	12.6	10.96	0.8	5.384615385
24	12.6	10.6	12.6	10.98	0	3.58490566
25	12.6	10.4	12.6	10.78	0	3.653846154
26	12.5	10.3	12.6	10.89	0.8	5.72815534
27	12.5	10.5	12.6	11	0.8	4.761904762
28	12.6	10.5	12.6	10.49	0	0.09523809524
29	12.6	10.5	12.6	10.84	0	3.238095238
30	12.7	10.5	12.6	10.75	0.7874015748	2.380952381
31	12.5	10.3	12.7	10.73	1.6	4.174757282
32	12.5	10.2	12.69	10.63	1.52	4.215686275
33	12.5	10.2	12.69	10.9	1.52	6.862745098
34	12.3	10.8	12.7	10.48	3.25203252	2.962962963
35	12.3	10.2	12.7	10.8	3.25203252	5.882352941
36	12.3	10.6	12.71	10.68	3.333333333	0.7547169811
37	12.3	10.8	12.71	11.03	3.333333333	2.12962963
38	12.3	10.9	12.7	11.1	3.25203252	1.834862385
39	11.9	11	12.7	11.16	6.722689076	1.454545455
40	11.9	10.9	12.69	10.96	6.638655462	0.5504587156
41	9.7	7.3	9.6	7.5	1.030927835	2.739726027



successfully retrieved the data, the AI system that is already running will process every data on each vehicle that has been registered. The following is an example of evidence when the AI system runs to retrieve data to carry out the diagnosis process for each vehicle and send it to the storage using Firestore.

```

d:\raspberrypi1:~/skripsi/fuzzy_main_program $ sudo python3 Main.py
Vehicle0001:
INFO: _main_:Vehicle0001:
Volt_off: 12.2
Volt_start: 12.2
coolant: 24.0
63.5
Warning
INFO: _main_:Fuzzy Result Vehicle 0001 : 63.5, Warning
Vehicle0002:
INFO: _main_:Vehicle0002:
Volt_off: 12.7
Volt_start: 9.4
coolant: 110.0
14.5
Bad
INFO: _main_:Fuzzy Result Vehicle 0002 : 14.5, Bad
Vehicle0003:
INFO: _main_:Vehicle0003:
Volt_off: 12.5
Volt_start: 10.8
coolant: 59.0
86.5
Good
INFO: _main_:Fuzzy Result Vehicle 0003 : 86.5, Good
    
```

Fig. 17. The AI System in Mini-PC

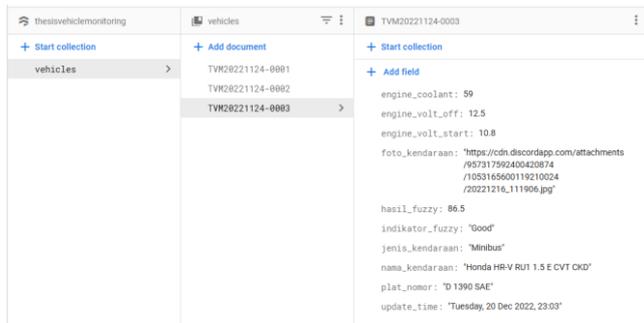


Fig. 18. The Firestore Storage

As in the IoT testing, the authors used the same data set that was already collected. In this case, the authors use Fuzzy Logic Toolbox using the Mamdani algorithm to find the expected results and calculate the MAPE value. Here are the tables that shows the Fuzzy value that the authors already design and the Fuzzy value from Fuzzy Logic Toolbox:

TABLE X. Data collection with Error Rate for AI system

No	Voltage Off System (V)	Voltage Start System (V)	Temperature Coolant (°C)	Fuzzy Main Program (%)	Fuzzy Toolbox Mamdani(%)	Error Rate
1	12.7	9.5	84	95.5	87.9	7.958115183
2	12.7	9.9	85	95.5	91	4.712041885
3	12.7	10.5	87	95.5	91	4.712041885
4	12.7	9.7	85	95.5	89.6	6.178010471
5	12.7	10.5	86	95.5	91	4.712041885
6	12.7	10.2	86	95.5	91	4.712041885
7	12.7	10.3	87	95.5	91	4.712041885
8	12.7	10	88	95.5	91	4.712041885

No	Voltage Off System (V)	Voltage Start System (V)	Temperature Coolant (°C)	Fuzzy Main Program (%)	Fuzzy Toolbox Mamdani(%)	Error Rate
9	12.7	9.9	91	95.5	91	4.712041885
10	12.7	9.3	93	95.5	86	9.947643979
11	12.5	11.3	84	86.5	89.6	3.583815029
12	12.5	11.1	85	86.5	89.6	3.583815029
13	12.6	11.1	85	91	90.3	0.7692307692
14	12.6	11	87	91	90.3	0.7692307692
15	12.6	10.3	85	91	90.3	0.7692307692
16	12.7	11.1	87	95.5	91	4.712041885
17	12.6	11.2	87	91	90.3	0.7692307692
18	12.6	11.2	88	91	90.3	0.7692307692
19	12.6	11.1	89	91	90.3	0.7692307692
20	12.7	11.1	88	95.5	91	4.712041885
21	12.6	10.7	89	91	90.3	0.7692307692
22	12.6	10.5	88	91	90.3	0.7692307692
23	12.5	10.4	89	91	90.3	0.7692307692
24	12.6	10.6	90	91	90.3	0.7692307692
25	12.6	10.4	92	91	90.3	0.7692307692
26	12.5	10.3	93	86.5	89.6	3.583815029
27	12.5	10.5	92	91	90.3	0.7692307692
28	12.6	10.5	91	91	90.3	0.7692307692
29	12.6	10.5	92	91	90.3	0.7692307692
30	12.7	10.5	94	95.5	91	4.712041885
31	12.5	10.3	81	86.5	89.6	3.583815029
32	12.5	10.2	83	86.5	89.6	3.583815029
33	12.5	10.2	83	86.5	89.6	3.583815029
34	12.3	10.8	83	77.5	87.9	13.41935484
35	12.3	10.2	81	77.5	87.9	13.41935484
36	12.3	10.6	82	77.5	87.9	13.41935484
37	12.3	10.8	82	77.5	87.9	13.41935484
38	12.3	10.9	83	77.5	87.9	13.41935484
39	11.9	11	82	55.03	59.6	8.304561148
40	11.9	10.9	83	55.03	59.6	8.304561148
41	9.7	7.3	26	10	18.5	85
42	9.7	7.2	26	10	18.5	85
43	9.7	7.4	26	10	18.5	85
44	9.8	7.4	26	10	18.5	85

No	Voltage Off System (V)	Voltage Start System (V)	Temperature Coolant (°C)	Fuzzy Main Program (%)	Fuzzy Toolbox Mamdani (%)	Error Rate
45	10	7.5	26	10	18.5	85
46	10	7.3	26	10	18.5	85
47	9.8	7.5	26	10	18.5	85
48	9.7	7.6	26	10	18.5	85
49	9.7	7.5	26	10	18.5	85
50	9.5	7.8	26	10	18.5	85
					Error Rate	1037.182206 %

TABLE XI. MAPE and Validity Percentage for Fuzzy Logic

	Fuzzy System (%)
MAPE	20.74364412
Validity Percentage	79.25635588

Also, for the example of how the authors calculate the error rate and the MAPE for this testing (only for the data number 1):

$$e_1 = \left( \frac{|95.5 - 87.9|}{95.5} \right) \times 100\%$$

$$= \left( \frac{7.6}{95.5} \right) \times 100\%$$

$$= (0.07958115183) \times 100\%$$

$$= 7.958115183\%$$

$$MAPE = \frac{1}{50} \sum_{i=1}^{50} [7.958115183 + 4.712041885 + 4.712041885 + 6.178010471 + 4.712041885 + 4.712041885 + 4.712041885 + 4.712041885 + 9.947643979 + 3.583815029 + 3.583815029 + 0.7692307692 + 0.7692307692 + 0.7692307692 + 4.712041885 + 0.7692307692 + 0.7692307692 + 0.7692307692 + 4.712041885 + 0.7692307692 + 0.7692307692 + 0.7692307692 + 0.7692307692 + 3.583815029 + 0.7692307692 + 0.7692307692 + 0.7692307692 + 4.712041885 + 3.583815029 + 3.583815029 + 3.583815029 + 13.41935484 + 13.41935484 + 13.41935484 + 13.41935484 + 8.304561148 + 8.304561148 + 85 + 85 + 85 + 85 + 85 + 85 + 85 + 85 + 85]$$

$$MAPE = \frac{1}{50} [1037.182206]$$

$$MAPE (Fuzzy Result) = 20.74364412 \%$$

C. Discussion

The proposed IoT and AI system has already been tested in 3 motorized vehicles. The main purpose of this is to find the accuracy of the proposed system that has been designed.

By using the MAPE methods, we can see the results of the proposed system, whether it is already accurate or not.

In this case, the results of IoT testing for 2 parameters namely Engine Off Battery Voltage and Engine Start Battery Voltage, are very good. By comparing the system with Avometer, the MAPE for Engine Off Battery Voltage is 0.9510789847% and Engine Start Battery Voltage is 3.136217503%, which is very low. That also means the validity percentage of the data that the author’s system gets and the Avometer is quite high as shown in the Table IX.

After the IoT system, according to Table XI, the MAPE for the Fuzzy Logic with Tsukamoto that the authors design is quite high, shown by 20.74364412%. This result indicates that the system with Fuzzy Logic Tsukamoto in this system is quite inaccurate compared to the Fuzzy Logic Toolbox using the Mamdani algorithm. Therefore, the validity of this system is 79.25635588%.

To end this discussion, the difference between our work and previous work is mainly in the “Approach used”, as shown in Table XII. The main strength of this work that if we want to implement this system, the cost for the IoT system will decrease because we use ESP32 to collect 3 data from vehicle. To complete the diagnosis, we also use Fuzzy Logic Tsukamoto to make a diagnosis vehicle health by using the 3 collected data

TABLE XII. COMPARISON RESULTS

Paper	Focus	Approach used
Srinivasan, 2018 [14]	Making a monitoring vehicle health by using Raspberry Pi to collect data and running Machine Learning.	K-Nearest Neighbor and Naïve Bayesian Algorithm
Adhisuwignyo et al, 2016 [17], Rodríguez Rodríguez et al, 2018 [38]	Making an user interface for OBD-II based on Arduino Uno.	IoT
Randis et al, 2018[37]	Making an IoT system to monitor engine temperature to prevent over heat at the mining district.	IoT
Our work	Making an IoT system to collect data using ESP32, and AI system using Fuzzy Logic Tsukamoto algorithm in the mini-PC to diagnose the vehicle health.	IoT, Fuzzy Logic Tsukamoto

V. CONCLUSION

This work has shown how to get the data with the proposed IoT device, from ECU’s vehicles, using a device called OBD-II and with a help of AI in the form of Fuzzy Logic Tsukamoto to diagnose the vehicle’s health. As shown in Table, the proposed IoT system is already working well and accurately with the low MAPE value 9. While the proposed AI system is working quite well. Compared with the Fuzzy Logic Toolbox using Mamdani, the proposed AI (Fuzzy Logic with Tsukamoto) get a quite big MAPE value as shown in Table XI. The system designed by the authors already works fine. Although the data reported here only used three data from vehicles, this work shows that it is possible to make a diagnosis for vehicles from the ECU in real-time

situations. Future works can try to obtain more parameters or data from ECU to expand the scope. For example the resistance of the battery for more accurate battery State of Health (SoH), tyre pressure, etc. In the same way, AI decision-making for diagnosing the vehicle can also be tried by different methods, like Fuzzy Logic with Mamdani, Sugeno, or any kind of decision-making to gain more accurate results. There are some suggestions for software development to develop an application to facilitate the end user. This software can use the concept of the fleet management system to make a complete monitoring vehicle.

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