Determining the usage feasibility of battery for disaster mitigation devices using Fuzzy Inference with Tsukamoto

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Abstract. Batteries have become an electrochemical device that plays an essential role in human life. Lately, batteries have also been used in disaster research, especially volcanic disaster mitigation in Indonesia. In addition, some electronic devices require a high amount of batteries thus these devices can remain alive for the continuation of mitigation research. Therefore, we research the fuzzy inference system to determine the usage feasibility of battery in Mount Merapi. The system is used for the simulation of the application of battery monitoring which is done periodically. As a result, users can monitor and evaluate the use of a high amount of batteries at several installation points easily and cost-effectively. Moreover, from the results of the test cases using the fuzzy inference system and fuzzy manual calculations, it can be concluded that both calculations produce the same output of fuzzy value for two test cases with a different dataset.

1. Introduction
Batteries have become an electrochemical device that plays an essential role in human life, almost all electronic and transportation devices use the battery as a device that can continue to conduct electricity. Lately, the battery has also been used in disaster research, especially volcanic disaster mitigation in Indonesia. Battery plays a role in supplying electricity to electronic equipment used by BPPTKG (Geological Disaster Technology Research and Development Agency) in monitoring the condition of Mount Merapi in Indonesia. Besides, some electronic devices require a high amount of batteries thus these devices can remain alive for the continuation of mitigation research.

Battery power will decrease until it runs out if used continuously. Therefore, the battery needs to recharge to maintain power in the normal ranges. This process can damage the battery if cannot be used properly. Cell components in the battery cannot last long in temperatures that are too high or temperatures that are too low. Also, some factors may affect the downgrade of battery usage feasibility such as voltage or current that is incompatible with the initial length or the charging time that is above or below the normal time required.

Correspondingly to prevent the use of batteries in vain, we conduct a study to determine the feasibility status of battery usage using the fuzzy inference method. Also, to make it easier to monitor, an expert system will be developed which has the functions to monitor several battery points installed around disaster mitigation areas. Therefore, the data of battery condition in the form of temperature, voltage, current and charging time will be read over when the charging process occurs and transmitted after the charging process is complete. However, in this study the problem is constrained to the implementation of methods to determine the feasibility status of battery use and the development of a prototype system for monitoring thus we use the simulated data in the process. Hence, this study is used
to provide a concept of maintaining the continuity of batteries condition thus it is not easily damaged and it is suitable for reuse.

2. Literature Review
The research on monitoring and determining the battery conditions has been carried out by several studies. Agustian [1] tried to design a tool based on the internet of things to monitor the condition of dry batteries in motor vehicles in the form of temperature, voltage, and current. The lowest recommended voltage level is a minimum of 10.5 volts. While for batteries that are in good condition, the battery voltage will range from 12.3 - 12.6 volts. For battery temperature, it takes 30 degrees Celsius as a maximum value when the battery is in charging or the battery condition is being used. Furthermore, the warning will occur when battery conditions are not within normal limits. Although the tool can read and maintain the conditions of battery usage, it has not been embedded with a fuzzy inference system to determine the usage feasibility of battery so that its use is still limited to current data reading and more depends on the subjectivity of the user.

In another study, Novia [2] developed a tool that can monitor battery conditions and can prevent the battery from overheating due to overcharging by using a fan that has been controlled by a fuzzy logic system. This tool is designed based on fuzzy logic, based on 3 sensors that will detect the conditions of temperature, current, and battery voltage. Although the tool is already embedded with fuzzy logic and can prevent overheating due to the fan feature, it has not yet determined the usage feasibility for the future use of the battery. Moreover, using the fuzzy logic to control the state of charge (SOC) is also studied by Dwiono and Taufiq [3] which research the fuzzy performance controller for battery charging. This study also explains the results of the design and testing of acid battery charging using a fixed current with the fuzzy controller which is then compared to the PID controller. The state of charge ratio is calculated using a fuzzy logic system with input variables are temperature and battery voltage, then the fuzzy controller is used using two input variables namely the error and integral error variables and one output variable in the form of a duty cycle weight. The results stated that the fuzzy controller gain less error than the PID. One in common to previous studies is that the fuzzy system to determine the usage feasibility of the battery has not yet been developed.

Lately, the study to determine the feasibility of an electronic device, especially the usage feasibility of battery is quite in demand. For example, in 2019, Wang et al conducted a study that estimates the State of Function (SOF) of power lithium-ion batteries [4]. In that study, 3 fuzzy variables are used such as battery status when charging (SOC), battery health status (SOH) and Maximum C-rate (charge and discharge Rate) using the Fuzzy c-Means Clustering algorithm method (FCM). The results obtained from that study aim to estimate the magnitude of the percentage or the feasibility of using lithium-ion batteries before being marketed or leaving the factory.

As the development of the Internet of Things (IoT) architecture is increasing, several studies including the previous which have been explained have suggested the real-time monitoring system on battery conditions. While others enhanced the system or tools by adding embedded fuzzy logic to control and maintain the state of charge to normal conditions. However, the expert system which uses fuzzy inference to determine the usage feasibility of battery and also provides monitoring of many batteries at the same time has not yet been developed in regards to mitigation researches. Therefore, we developed a system that was used to facilitate the monitoring of several batteries and determine its condition at several points in the Merapi volcano region. The final result of this research is to provide a simulation or prototype of a monitoring system that embedding the fuzzy inference to determine the usage feasibility of the battery periodically.

3. Methods

3.1. Fuzzy Inference with Tsukamoto
Tsukamoto is a vague conclusion drawing method where each consequent to IF-THEN rules needs to be represented by a vague set with a monotonous membership function. As a result, the inference results
from each rule are given explicitly (crisp) based on $\alpha$-predicate (fire strength). The final result is obtained by using a weighted average [5]. Tsukamoto is easy to implement yet still powerful thus makes it usually suitable for simple problems and calculations that are not too complicated. While Mamdani is suitable for intuitive problems and Sugeno is suitable for problems that handle control. As for the flow of inference process with Tsukamoto can be seen in Figure 1 below.

![Figure 1. The flow of inference process with Tsukamoto](image)

The design process in the Tsukamoto fuzzy inference method has ease compared to other methods such as Mamdani and Sugeno. This is based on the implications and aggregation process that does not exist. In addition to its simplicity, several studies can prove the superiority of the Tsukamoto method compared to other methods as in [6] and [7].

### 3.2. Fuzzy Variables and Fuzzy Sets

In this study, we use 4 fuzzy variables as input which taken from an expert in volcanic disaster mitigation at BPPTKG. Those variables are temperature, voltage, current, and charging time which used to determine the usage feasibility of a battery. Each of the variables consists of several fuzzy sets in the specified domain. Meanwhile, detailed information about these fuzzy variables with respectively corresponding fuzzy sets can be seen in Table 1 below.

| Fuzzy Variable   | Fuzzy Sets          | Explanation                                    |
|------------------|---------------------|------------------------------------------------|
| Temperature      | COLD, NORMAL, WARM  | The battery temperature on charging            |
| Voltage          | LOW, NORMAL, HIGH   | The battery voltage on charging                |
| Current          | POOR, STRONG        | The current power on charging                  |
| Charging Time    | QUICK, SLOW         | The time needed until the charging process is complete |

### 3.3. Membership Functions

The membership function is used to map inputs to the degree of membership which symbolized with $\mu(x)$. In this study, the membership function used is a combination of a triangle shape curve and a
shoulder shape curve. There are 5 membership functions which consist of 4 membership functions to map the input in the form of crisp to the degree of the membership and a membership function on the feasibility variable to map the degree of membership into the output in the form of crisp.

3.3.1. The Input of temperature. The first curve of the membership function is a function of the temperature fuzzy variable in °C consisting of three sets with their respective domains namely COLD [0, 22], NORMAL [20, 30], and WARM [28, 35]. The membership functions for the temperature fuzzy variable can be seen in Figure 2 below.

![Figure 2. Membership functions for temperature fuzzy variable](image)

3.3.2. The Input of voltage. The second curve of the membership function is a function of the voltage fuzzy variable consisting of three sets with their respective domains namely LOW [0, 12.2], NORMAL [12, 13], and HIGH [12.8, 13.8]. The membership functions for the voltage fuzzy variable can be seen in Figure 3 below.

![Figure 3. Membership functions for voltage fuzzy variable](image)

3.3.3. The Input of current. The third curve of the membership function is a function of the current fuzzy variable consisting only two sets with their respective domains namely POOR [0, 12] and STRONG [8, 24]. The membership functions for the current fuzzy variable can be seen in Figure 4 below.

3.3.4. The Input of charge time. The fourth curve of the membership function is a function of the charge time fuzzy variable in hour consisting only two sets with their respective domains namely QUICK [0, 2.5] and SLOW [1.6, 10]. The membership functions for the charge time fuzzy variable can be seen in Figure 5 below.

3.3.5. The Output of usage feasibility. The last curve of the membership function is a function of the usage feasibility fuzzy variable in percent consisting only two sets with their respective domains namely NOT FEASIBLE [0, 50] and FEASIBLE [25, 100]. The membership functions for the usage feasibility fuzzy variable can be seen in Figure 6 below.
3.4. Fuzzy Rules.
There are several fuzzy rules compiled based on the result of an interview with the expert on volcanic disaster mitigation. In this study, there are 4 fuzzy variables which consist of 3 temperature sets, 3 voltage sets, 2 current sets, and 2 charge time sets respectively. Each variable gets one allotment of occurrences in one rule with the fuzzy operator used is an intersection in which order does not matter. From this definition, there are 36 combinations of rules that allowed to use in the inference process. However, in this study only used 6 rules that can be seen in Table 2 below.

3.5. Defuzzification
Defuzzification is the calculation process to get the crisp output value of the fuzzy value symbolized by \( z \). Defuzzification on Tsukamoto is usually obtained using a weighted average function where there is \( z_i \) which is a result of defuzzification of fuzzy values obtained from the inference process for each rule (\( \alpha \)-predicate). Therefore the value of \( z \) is a weighted average obtained from one or more rules that can be formulated in equation (1) below.
Meanwhile, to get the value $\alpha_i$, the intersection operator is used. If the result of the intersection is symbolized as $\mu_{A\cap B}$, $\alpha_i$ can be obtained by equation (2) below.

$$\alpha_i = \min(\mu_A[x], \mu_B[y])$$

(2)

| Symbol | Rule |
|--------|------|
| R1     | IF Temperature is NORMAL AND Voltage is NORMAL AND Charge Time is SLOW AND Current is STRONG THEN Usage Feasibility is FEASIBLE |
| R2     | IF Temperature is COLD AND Voltage is NORMAL AND Charge Time is SLOW AND Current is STRONG THEN Usage Feasibility is NOT FEASIBLE |
| R3     | IF Temperature is NORMAL AND Voltage is NORMAL AND Charge Time is QUICK AND Current is POOR THEN Usage Feasibility is NOT FEASIBLE |
| R4     | IF Temperature is WARM AND Voltage is NORMAL AND Charge Time is SLOW AND Current is POOR THEN Usage Feasibility is FEASIBLE |
| R5     | IF Temperature is WARM AND Voltage is NORMAL AND Charge Time is SLOW AND Current is STRONG THEN Usage Feasibility is NOT FEASIBLE |
| R6     | IF Temperature is COLD AND Voltage is NORMAL AND Charge Time is QUICK AND Current is STRONG THEN Usage Feasibility is FEASIBLE |

Afterward, the value of $z_i$ which is defuzzification will be determined based on the membership function of usage feasibility. Mapping $\alpha_i$ to $z_i$ is done based on consequent in certain rules. If consequent is FEASIBLE, the function used can be seen as in equation (3), but if it is NOT FEASIBLE then the function used can be seen as in equation (4). In the equations below, a is prefer to the left side of the domain and b is prefer to the right side of the domain.

$$z_i = (b-a) \times \alpha_i + a$$

(3)

$$z_i = b - \alpha_i \times (b-a)$$

(4)

3.6. System Design

A web-based system will be created to provide an interface for users, especially the BPPTKG, who want to monitor the condition of battery usage easily. This system is designed with the PHP 7 programming language and MySQL DBMS. The features contained in this system include rule management, membership function management, installed battery condition monitoring, and battery data input form. In addition, the data manipulated in the system is not real-time so it is still a simulation. In this case, the data is still inputted and updated manually by the user to test the reliability of the fuzzy inference system. Meanwhile, database implementation can be seen in Figure 7 below.
4. Result and Discussion

4.1. Testing stage
At this testing stage, calculation using fuzzy inference is done manually and used validated data from an expert who knows the characteristics of the battery. After that, the fuzzy inference system is coded and executed to compare the results with manual calculation. Moreover, the data used is also data that is relevant to the level of influence of the battery condition on the indicators that are the variables of the system calculation process. Two test cases are used as shown in Table 3.

Table 3. Test case

| Name               | Temperature (°C) | Voltage | Current | Charge time |
|--------------------|------------------|---------|---------|-------------|
| Test case 1 (TC1) | 35               | 12.4    | 20      | 10          |
| Test case 2 (TC2) | 26               | 12.4    | 12      | 2           |

To get the output value feasibility in the form of crisp \( z_i \), it is necessary to map the degree of inference result members \( \alpha_i \) into the usage feasibility membership function. After that, a weighted average is calculated to get the final value of usage feasibility \( Z \). The \( Z \) value is used to determine the degree of membership of FEASIBLE and NOT FEASIBLE as shown in Table 4.

4.2. Result Stage
From the results of testing the data above, it can be seen the status of the battery's usage feasibility. Meanwhile, the results of calculations using the fuzzy inference system can be seen in Figure 8 below.

Figure 7. Database implementation of web-based fuzzy inference system
Table 4. Inferences Results

| Test Cases | Usage Feasibility (Crisp) | Z (Weighted Average) | Degree of Membership |
|------------|---------------------------|----------------------|----------------------|
|            | Z1 | Z2 | Z3 | Z4 | Z5 | Z6 | FEASIBLE | NOT FEASIBLE |
| TC1        | 25.00 | 50.00 | 50.00 | 25.00 | 23.75 | 25.00 | 23.75 | 0.00 | 0.75 |
| TC2        | 43.75 | 50.00 | 50.00 | 25.00 | 25.00 | 25.00 | 43.75 | 0.25 | 0.18 |

In this study, the test cases are done twice using data on different battery conditions which in this case is TC1 and TC2. From Figure 8 above, it can be seen that the tests that done manually by tabulating and the tests that done by generating the values on the system have the same output of fuzzy value. As shown by the results, the first battery (TC1) is not suitable for the use of mitigation research while the second battery (TC2) is suitable for the use of mitigation research. Moreover, the weighted average value obtained is 23,750 for TC1 and 43,750 for TC2. After the conversion to the degree of usage feasibility is done, it showed that TC1 gets a membership degree of 0.00 for the FEASIBLE set and 0.75 for the NOT FEASIBLE set while TC2 obtains a membership degree of 0.25 for the FEASIBLE set and 0.18 for the NOT FEASIBLE set. Although this research can provide a good simulation to determine the usage feasibility of batteries with a fuzzy inference system, this research is far from appropriate to be applied in the real environment because real-time monitoring has not yet been developed.

This research can be further developed by adding a control system with fuzzy inference and automatic charging that implanted in the battery so that it can make decisions directly. In this way, the control system can automatically check the battery voltage when charging which then processes the reading results in the control system where the fuzzy inference program is coded. In addition, these control systems can also be used to record the length of time of charging and the time of battery usage which will be used as a variable to determine the feasibility of using a battery. The control system calculation results will then be reported to the system interface owned by BPPTKG, and BPPTKG as the decision-maker will follow up on the use of the battery.

5. Conclusion
The system created using Tsukamoto's fuzzy method is useful to assist the Yogyakarta Geological Disaster Technology Research and Development Agency (BPPTKG) in determining the usage feasibility status of batteries as energy suppliers for electronic disaster mitigation equipment at Mount...
Merapi. This study uses 4 variables including temperature, voltage, charging time, and current strength with 2 expected outputs that are feasible to use and not feasible to use. In addition, there are 6 rules used in this fuzzy system based on interviews with experts. From the results of the test cases using the fuzzy inference system and fuzzy manual calculations, it can be concluded that both calculations produce the same output of fuzzy value for two test cases with a different dataset.

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