1. First submission through the on-line system (9-1-2019)
2. Request concerning the progress (12-5-2019)
3. Reviewers assigned to proceed to reviewing (14-5-2019)
4. Revision send to the editor (23-5-2019)
    - Amends
    - Corrected paper
5. Revision received additional revision required (23-5-2019)
6. Paper accepted (24-5-2019)
7. Paper transferred to publication (3-6-2019)
8. Corrected proof received (5-6-2019)
9. Paper available online (10-6-2019)

1. First submission through the on-line system (9-1-2019)

Dear Suryono Suryono,

Thank you for your submission. Please see the details below.

Submission ID	**199599720**
Manuscript Title	**A Fuzzy Rule-based Fog-Cloud Computing for Solar Panel Disturbance Investigation**
Journal	**Cogent Engineering**

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2. Request concerning the progress (12-5-2019)

webmail FISIKA universitas diponegoro

Suryono Sur <suryono@fisika.undip.ac.id>

Submission Id: 199599720

1 message

Suryono <suryono@fisika.undip.ac.id> 12 May 2019 at 19:46

To: engineering@cogentoa.com

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Diponegoro University-Indonesia

3. Reviewers assigned to proceed to reviewing (14-5-2019)

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1 message

engineering@cogentoa.com <engineering@cogentoa.com> 14 May 2019 at 07:16
To: suryono@fisika.undip.ac.id

Dear Dr. Suryono,

Thank you for your email.

I can see that your paper (**199599720, A Fuzzy Rule-based Fog-Cloud Computing for Solar Panel Disturbance Investigation**) has received the minimum number of reviews required for a decision to be made.

The editor has been informed that they can made their decision now, provided that these completed reviews are sufficient to make a decision.

We hope to get this to you as soon as possible.

Should you need further assistance, kindly let me know.

Best regards,

Lesny Hernandez - Journal Editorial Office
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Sincerely yours
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Diponegoro University-Indonesia

4. Revision send to the editor (23-5-2019)

- **Amends**
- **Corrected paper**

REVIEWER A	
Comments	Author Responses
1. The paper does not provide sufficient information on the reasoning as why the model is proposed, please elaborate. In the results section, it should be proven whether the designed system's contribution is significant.	• Additional explanation of the reasons why this model is proposed has been added in the introduction section (Page 2, paragraph 3, highlighted in yellow) • The difference in performance from the implemented system has been described in the discussion (Page 17, Paragraph 2, highlighted in yellow)
2. The paper focuses on the topic of Fuzzy-Rule-Based-function. The basic theories and formulations of which are poorly explained in this work. The literature on this issue is limited, please add more supporting references to the list.	• In this paper the fuzzy-rule-based formulation has been added and the method section also describes the procedure for how the fuzzy rule base algorithm works (Page 5, highlighted in yellow) • Additional literature has been added, as following Albert, M., Gors, M., & Schilling, K. (2015). Telemedical Applications with Rule based Decision – and Information-Systems (TARDIS). *IFAC-Papers Online*, 48, 007–011. Zhang, S., Wang, T., Li, C., Zhang, J., & Wang, Y. (2016). Maximum power point tracking control of solar power generation systems based on type-2 fuzzy logic. 2016 *12th World Congress on Intelligent Control and Automation* (WCICA), 770 – 774
3. Figure 6 is very blur, and provides limited information. Please replace this figure with better, more comprehensive illustrations including flowcharts and sensor details. Please explain the descriptive of the program coding	• Figure 6 (Shift to figure 7) has been changed which is oriented to the state of the sensor readings and the action results that are family as program information (Page 10, Paragraph 2, highlighted in yellow). • This section also explains program code as a description of the programming logic used (Page 10, Paragraph 2, highlighted in yellow).
4. The detailed specifications of the sensors used in the experiment, should be outlined in this paper. Explain how the sensor-network connection is carried out,	• In this paper, we describe in detail the specifications of the sensors used and are shown in Table 1 (Page 7 paragraph 3, highlighted in yellow).

since this is a paramount part of the system. Please clarify!	• The sensor-network connection diagram is carried out via the SOC Wifi MIcrocontroler and has been added to Figure 4 (Page 8, highlighted in yellow).
5. The disparities between the utilization of the proposed network models is unclear, the contribution of the developed system needs to be explained through these differences to strengthen its necessity.	• A discussion of differences in network performance has been added to the explanation in page 16, paragraph 1 and 2 (highlighted in yellow).

REVIEWER B	
1. The correlation between the introduction and conclusion are not interconnected. Please pay attention to the formulation in its content.	• This paper has been synchronized and matched between the introduction and conclusion. Some important sentences have been added conclusion (highlighted in yellow).
2. The effectiveness of this system is not clear, and the general contribution of this work should be mentioned in greater detail.	• A description of work efficiency has been added to the discussion section on the page 16 paragraph 2 (highlighted in yellow).
3. Use the word "show" should be used instead of "given" for all declaration of figures. "Given" is not customary used in this context.	• In this paper, we have re-checked the use of appropriate words.
4. The factors affecting solar panel efficiency using the rule-based system is analysed correctly. The results however, should be supported theoretically based on the literature.	• This paper has added a rule-based understanding that is associated with the literature (page 16, paragraph 1 and 2).

A Fuzzy Rule-based Fog-Cloud Computing for Real-time Solar Panel Disturbance Investigation

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Abstract

The electrical energy produced by solar panel depends on the light intensity falling on the panel but this process is prone to disturbances from external factors. Unfortunately, models of online solar panel disturbance diagnosis have not been widely developed. This research proposes a model of fog computing using fuzzy rule-based algorithm is capable of automatic monitoring and diagnosing factors affecting solar panel efficiency. Data from physical parameter of sensors are acquired by the System on Chip (SoC) Wi-Fi microcontroller and sent to the fog server via a Wi-Fi gateway. The fuzzy rule-based algorithm consists of investigation rules showing the relationships among efficiency, light intensity, output electrical power, temperature, and humidity. Output of fog network computing is sent to the cloud server and serves as information for users of this investigation system. The fog network system is able to improve cloud performance, in terms of the transmission time has increased performance from 246.1 ms to 27.9 ms. In general, this system is able to improve relative efficiency of solar panel by 2.1%, compared to solar panels not equipped with this instrument. In order to obtain accurate investigation results, detailed conditions of all possible events in the field are required.

Keywords: Solar Panel, Disturbance, Wireless Sensor System, Fuzzy Rule-based, Efficiency

I. Introduction

Energy crisis is a serious problem faced by almost all countries [1]. The use of fossil fuels to generate electrical energy comes with the side effect of environmental pollution [2]. Another issue that stems from the use of non-environmentally friendly energy sources is the greenhouse effect. Therefore, efforts have been carried out to find new and renewable energy sources [3]. Solar energy is one of the most abundant energy sources with great prospect of further development [4]. In tropical regions, solar energy can be obtained almost every day with long duration each time. Photovoltaic panel (PV) is a semiconductor instrument that can alter solar radiation energy into electrical energy [5].

The use of solar energy for electricity has the benefit of economic efficiency in terms of power transmission [6]. Electrical energy can be provided in dwelling areas without the need for a complex power transmission infrastructure [7]. This is possible as for the power transmission system, PV panels do not require step-up transformers for short distance transmission. Moreover, the use of PV panel also supports the green technology campaign. Unlike fossil fuel for power generation, PV panel technology does not produce toxic exhaust gases that cause pollution and endanger people’s health [8]. The process of energy conversion from solar power to electricity itself is photonic that results in no greenhouse gases are released [9]. One disadvantage of PV panel electricity power generation system is the high initial capital. The price of solar panels is categorically still very expensive. This is due to the fact that they are made of silicon which requires high technology and large investment for its purification [10]. Therefore, there needs to be improvement in the efficiency of solar panel use in order to produce electrical energy continuously. Energy management by designing scenario on sources of energy generation can improve the efficiency [11].

Improvement of solar panel efficiency has been made in terms of material and panel condition in the field. In Australia, electrical energy production from solar panels is affected by environmental conditions and there is a difference in energy productivity between winter and summer [12, 13]. Monitoring for PV panel disturbance is generally carried out by comparing PV input (light intensity) against the power produced [14]. Nonetheless, there are many factors affecting the efficiency of PV panel. Dust is one of the substances that can block sunlight from properly fall onto the panel. The other things that may prevent this sunlight exposure to PV panel are snow, leaves, rainwater, and the likes. Disturbance caused by dust can be mechanically handled using a brush-disk [15] and the electrostatic method, so that solar panel efficiency is restored [16]. A proper solution for disturbance of PV panel in the field can definitely be beneficial for its high productivity.

Physically, diagnosis for solar panel disturbance is carried out by comparing conditions of illumination against the electrical power a solar panel produces. Direct field measurement on light intensity and electrical power produced by a solar panel can easily provide simple investigation results [17, 18]. However, this direct method is disadvantageous in terms of efficiency and speed as a solution for PV panel maintenance. Therefore, the use of information technology in electronically monitoring solar panels can be of high economic value. Performance of solar panels can be monitored from the electrical energy they produce. Daily energy monitoring for a period of 3 years reveals lower efficiency of the solar panel [19]. The important variables in monitoring PV panel are light intensity and temperature. These two units can be acquired in the field using special sensor chips that are integrated in a microcontroller that will allow further analyses in order to figure the condition of solar panels [20].

This research proposes a PV panel investigation system using wireless sensor system with fog network model. This model is capable of performing local computing, so that it eases burden in the cloud network. It also provides speedy information with higher network efficiency [21]. It comprises sensors of temperature, humidity, light intensity, and electrical power. The System on Chip (SOC) Wi-Fi microcontroller, which is a combination of microcontroller for data acquisition and Wi-Fi radio for data communication, is used in this system. The use of this system is very effective because of its small size and low cost production [22]. The model proposed here is expected to tackle spatial issues associated with PV panels as they are located in wide areas. This system is integrated in a fog server data base as to allow continuous data history storage. Online data acquisition system is very effective as no weather issues are of concern and it can work in real-time as well [23]. The use of artificial intelligence in diagnosing PV panels is based on a dedicated input sensor used for speedy maintenance in order to ensure productivity and uninterrupted electrical energy supply.

II. Related Works

The era of innovation disruption brings about digital revolution that results in inter-connected digital devices that make up complex networks [1-8 in 1]. The impact of these is growing demand for both digital hardware and software capable for data analysis, system diagnosis, and industrial activity prediction. The whole industry has since set off from being offline into cyber systems that perform processes online and in real-time [18-19 in 1]. This situation requires fog-based computing to solve issues at the local level as to support the cloud-based computing system. An architecture of fog network that connects sensors to a cloud server is shown in Figure 1.

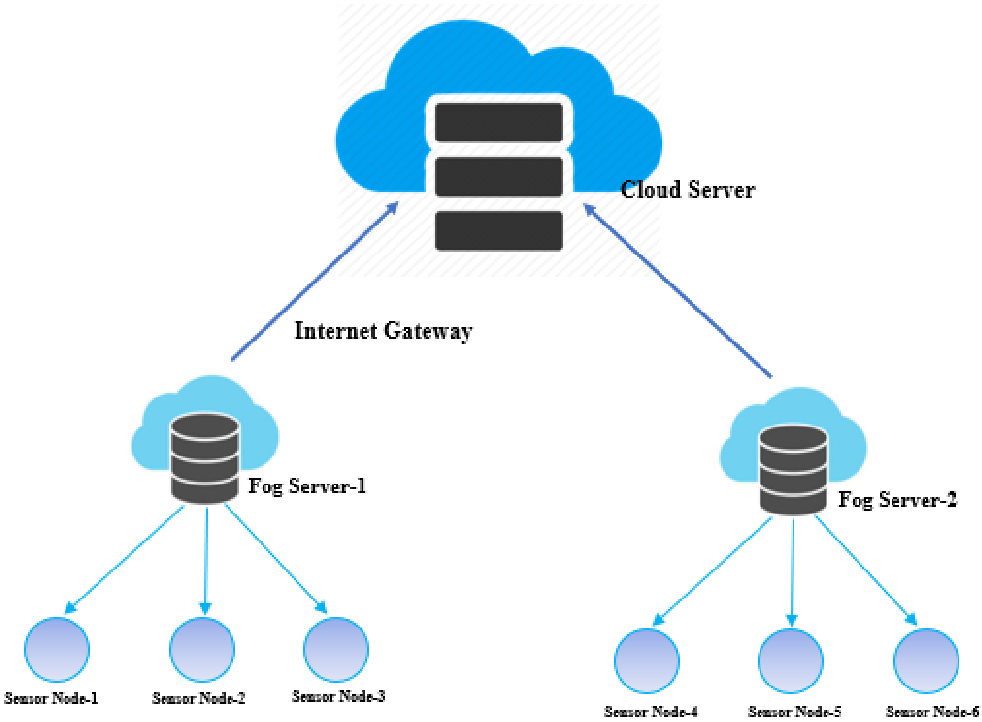

Figure 1. Architecture of a fog network connecting node sensors to a cloud server

Fog networking is physically capable of connecting sensors on the ground level attached to objects to the cloud. This type of network reduces latency as it transfers computation from the cloud to the local network. It is also able to access more local parameters that allows more data computation and analysis to be carried out in real-time. This network is suitable for diagnostic models of numerous parameters as it will solve the issue of busy networks. The use of local gateway in local data storage network within the fog network makes it even more safe and economical [26-28 in 1].

Integration of sensors to the fog network that is connected to the cloud has successfully been developed and this in turn, has been integrated to machine learning capable of producing diagnostic instruments in many industries. This kind of system has proven to be able to collect data from all sorts of parameters into one local server and analyze them accordingly in real-time [23-25 in 1]. In order to produce information, a system is constructed at the local server to compute and learn the object(s) being investigated. Fog computing is part of the calculation process in that local server that is aimed at generating values that serve as information for certain purposes. Diagnosis and prediction are two examples of fog computing output [1].

The Internet of Thing (IoT) has proven to provide effective service as it eliminates spatial and temporal issues. The main components of IoT include a network of sensors that are in direct contact with objects, a gateway to send sensor data, and a cloud to record, store, and process those data. This paper proposes a diagnosis method using IoT components of:

- A sensor system to acquire data from parameters related to condition and productivity of solar panels.

- A data communication model using Wi-Fi gateway that connects solar panels to a local gateway server which represents fog networking for optimized system diagnosis.
- A fog computing system in the local network to perform diagnosis of solar panels and connects data to the cloud, so that internet network in the cloud is not overloaded, that may otherwise cause failure in information generation.

In the fuzzy system, sensor data from certain measurements are physical values that can be categorized linguistically, in terms of membership. The function of Fuzzy Logic Membership from sensors in the solar panels is to calculate degree of membership in a fuzzy group. Each linguistic term is associated with a fuzzy set that has specifically defined membership function. In turn, membership function from sensor reading shows mapping of data input points for membership values. Within this fog computing system, each sensor is taken as a definite number of 0 or 1, but in the interval instead [0,1]. Mathematical definition of membership A in the universal number U is written as:

$$\mu_A: \mathrm{U} \rightarrow [0,1] \tag{1}$$

Membership function of fuzzy number from the sensor in the solar panels, among others, can be stated in the following equations:

a. Ascending linear curve:

$$\mu[x,a,b] = \begin{cases} 0; & x \leq a \\ (x-a)/(b-a); & a \leq x \leq b \\ 1; & x \geq b \end{cases} \tag{2}$$

b. Descending linear curve:

$$\mu[x,a,b] = \begin{cases} 0; \quad (b-x) / (b-a); & a \leq x \\ 1; & x \geq b \end{cases} \tag{3}$$

c. Triangular function (combination of ascending and descending linear curves):

$$\mu[x,a,b] = \begin{cases} 0, & x \leq a \text{ or } x \geq c \\ \frac{x-a}{b-a} & a \leq x \leq b \\ \frac{c-x}{c-b} & b \leq x \leq c \end{cases} \tag{4}$$

If sensor values are a combination of membership numbers A and B, then this combination is stated as:

$$\mu(A \cap B)\ (x) = \min\ [\mu_A(x), \mu_B(x)],\ \forall x \in X\ \mu \tag{5}$$

An example of fuzzy membership number function from readings of solar panel temperature sensors is shown in Figure 2. Each membership does not have a definite value, but it comes with a membership degree [0,1].

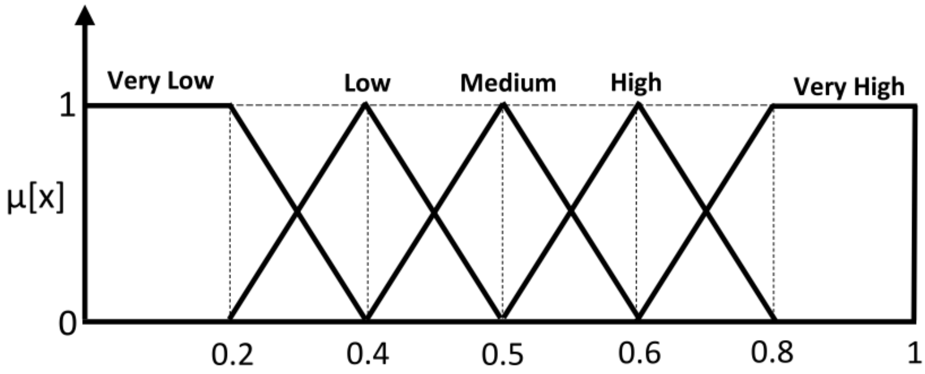

Figure 2. Fuzzy membership function according to sensor readings

Values of sensor output can be transformed into fuzzy membership function and classified as required. Classification using fuzzy method puts data into certain classes based on probability level of each datum. Classification output is represented in a fuzzy set that depends on the value of x:

$$\overline{y}(x) = \frac{y_1(x)}{c_1} + \ldots . + \frac{y_k(x)}{c_k}, \qquad (6)$$

Where $\frac{y_k(x)}{c_k}$ is c_k element of fuzzy set y (X) of membership $\hat{y}_k$(x).

In the fuzzy rule-based system, output data from fuzzy classification has to undergo rule-based operation. It is known in mathematics as the p set rule:

$$if\,(x)^{(1)} is\overline{F}^{(1)}_{(\rho)} \quad and/or \ldots and/or\, x^{(n)} is\overline{F}^{(n)}_{(\rho)} \quad then \quad y \quad is\overline{C}_{(\rho)} \qquad (7)$$

A combination of rules r (m_1, m_2.......m_n) can be written as:

$$r\,(m_1, m_2 \ldots\ldots m_n) \begin{cases} if\,(x)^{(1)} is\overline{F}_1^{(1)} \quad and/or \ldots and/or \quad x^{(n)} is\overline{F}^{(n)}_{(1)} \quad then \quad y \quad is\overline{C}_{\{1..1\}} \\ \\ if\,(x)^{(1)} is\overline{F}_{M_1}^{(1)} \quad and/or \ldots and/or \quad x^{(n)} is\overline{F}^{(n)}_{M_n} \quad then \quad y \quad is\overline{C}_{\{M_1..M_n\}} \end{cases} \qquad (8)$$

III. Method

2.1 The fog network system developed

The system built in this research is a wireless sensor system consisting of a Remote Terminal Unit (RTU) attached on a PV panel. The RTU itself contains sensors used and a Wi-Fi microcontroller to communicate the data acquired. The other part is the Control Terminal Unit (CTU) consisting of a Wi-Fi receiver and a computer. Diagram for RTU and CTU communication system is shown in Figure 3. The SoC Wi-Fi microcontroller used in the RTU has short communication range between 30 – 100 m in open space. In order to send data from each node, a Wi-Fi gateway is required to function as a data multiplexer from each node.

The Wi-Fi gateway attached on the RTU is capable of connecting up to 256 nodes and sends data over tens of kilometers. The gateway of this system works at 2.4 GHz IEEE 802.11b/g frequency with data transmission speed of up to 54Mbps. Wi-Fi microcontroller ESP8266 functions as the sensor for data acquisition system and as the data interface to the computer via Wi-Fi network. Each Wi-Fi microcontroller on the node is set at 11,680 BPS speeds and at different IP Addresses of the same class. This arrangement is carried out with chip programming on the computer using C language, which is then uploaded on ESP8266 chips.

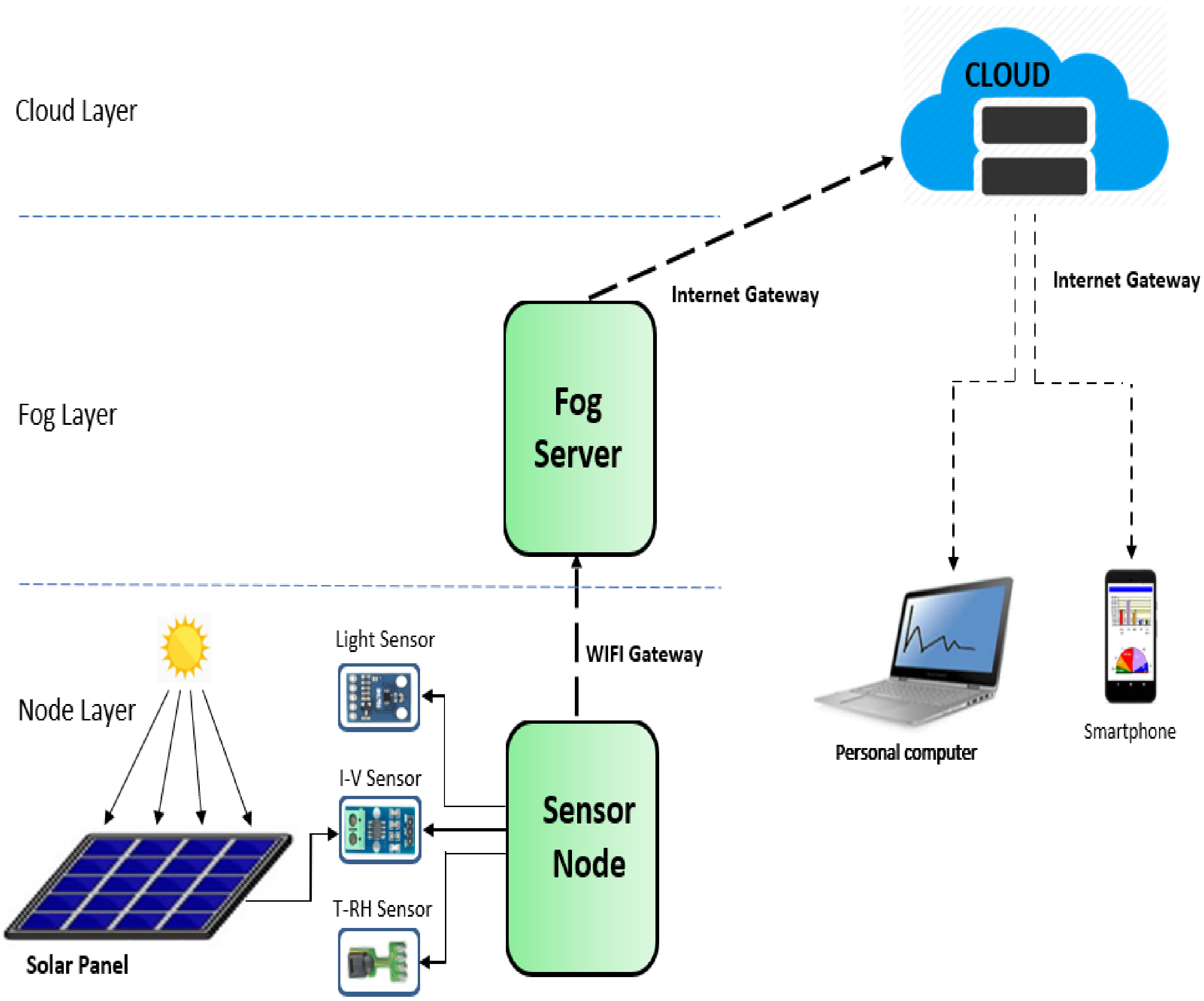

Figure 3. Diagram of a fog network communication system

2.2 Solar Panel Sensor Data Acquisition System

Solar Panel is a device of high value as it is capable of turning solar energy, which is abundant in nature, into electrical energy that can be stored and used for daily energy needs. The electrical energy produced by PV panels is DC electricity, the power of which is comparable to the light intensity gained by the PV panels. The most important part of a PV panel is the semiconductor material that undergoes photoelectric effect upon being hit by photons from solar radiation. Nowadays, the semiconductor material found in PV panels is made from silicon that can either be monocrystalline, polycrystalline, or amorphous) [6].

A diagram showing the sensor communication system circuit with the SoC Wi-Fi microcontroller ESP8266 is shown in Fig. 4. Ideally, the amount of solar radiation that is turned into PV panel power output can be measured with a circuit of ampere and volt meters. However, it not possible for all of the solar radiation to be turned into electrical energy. PV panel efficiency value (η) is calculated using the following formula:

$$\eta = \frac{P_{max}}{E.A} \tag{9}$$

In this equation, P_{max} is the electrical power output, which is a multiplication of current and output voltage, E is the solar radiation input, and A is the PV panel area. The unit for electrical power P_{max} is in Watt, while the solar radiation input is in Watt/m2, which in lux is equal to 1 Watt/cm^2 = 6.83 x 106 lux [20].

Smart sensor technology for physical environment detection has speedily developed with its integration into microprocessors and microcontrollers for data processing prior to being made into input for devices. A system for PV panel monitoring requires sensors of temperature, humidity, light intensity, current, and voltage. Specifications of the sensors used in this system are shown in Table 1.

Table 1. Sensor specification for solar panel monitoring

Type	Physical Unit	Unit	Resolution	Protocol
Voltage	Volt	Analog	-	TWI
BH1750	Light Intensity	Lux	16 bit	I2C
ACS172	Current	Ampere	Analog	-
Voltage divider	-	-	-	-

The sensor used in this system consists of two smart sensors (SHT11 and BH1750), an analog sensor (AC172), and a PV Panel voltage sensor, made of two resistors, as voltage divider. SHT11 is a smart sensor for temperature and humidity that uses the two wire interface (TWI) protocol to read both units. BH1750 sensor is a light intensity sensor. It takes an Inter Integrated Circuit-protocol (I2C) to read this sensor. ACS172 is a current sensor and has output of analog signals. Hence, an Analog to Digital Converter (ADC) is required to read the current passing through this sensor.

The voltage sensor is built from voltage dividing sensors, and as in the current sensor, an Analog to Digital Converter (ADC) is needed to read its output. In the Wi-Fi-microcontroller ESP8266, there is 1 ADC channel ADC, while the system actually requires 2 ADCs. Hence, a multiplexer is constructed using a relay to acquire both current and voltage form the solar panel.

A microcontroller is needed to read both the smart sensors and the analog sensors. This research employs the System on Chip (SoC) Wi-Fi microcontroller ESP8266 that can be programmed to generate TWI and I2C protocols and turn analog signals into digital signals via the ADC input on the chip [21].

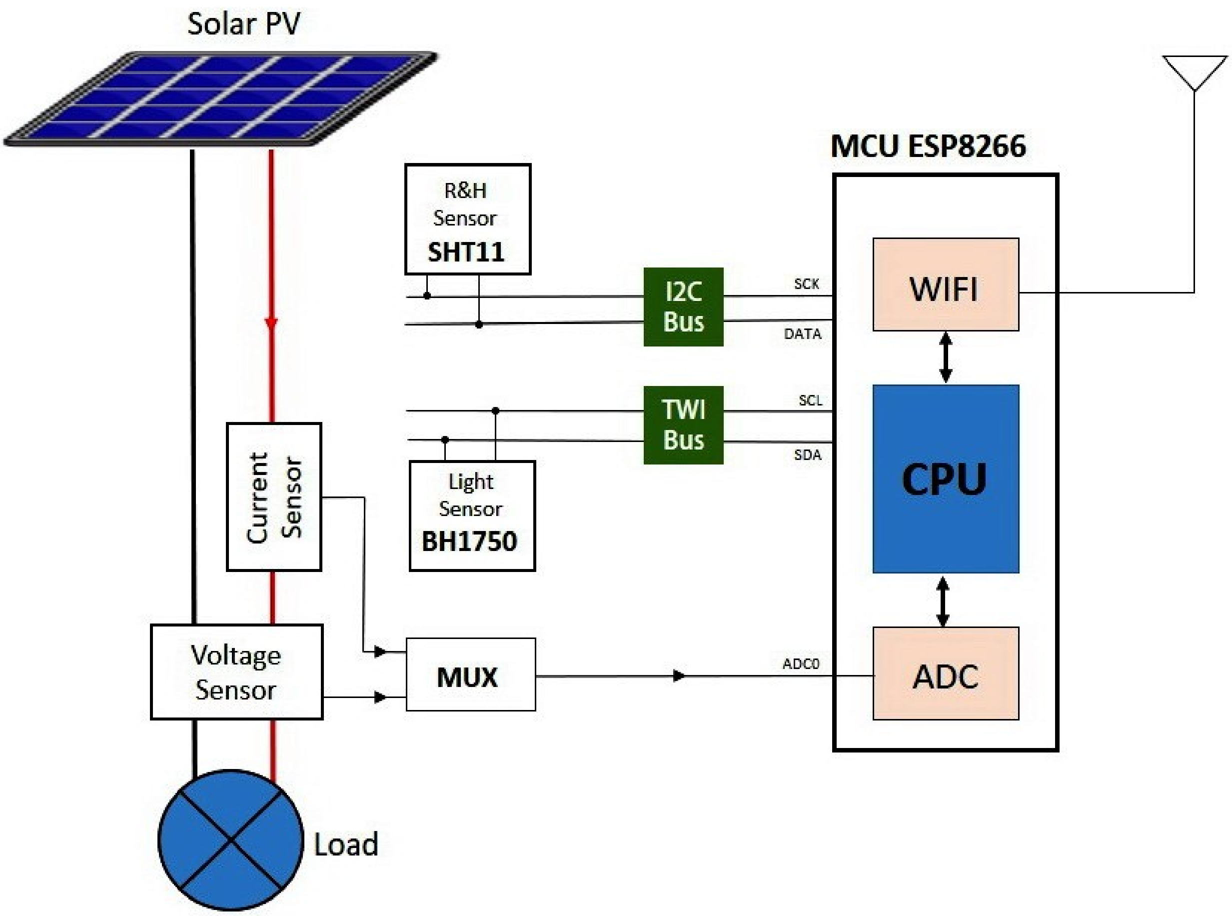

Figure 4. Diagram of sensor communication system circuit with SoC Wi-Fi microcontroller ESP8266

2.3 Fuzzy Rule-Based System

Computation process in a fog server consists of fuzzyfication of sensor input and rule development on the solar panel to state a disturbance. Fuzzyfication is performed against data of illuminance, efficiency, temperature, and humidity. The four variables are then categorized into membership functions of very low, low, medium, and high. The span classification is based on real conditions in the field. That means clustering tailored to the needs oriented to the system's ability to distinguishing the disturbance conditions in the field. For example, the develop of a range of light intensity conditions in solar panels has been divided into 4 levels namely very low, low, medium and high. The range of values of very low and low is very different, very low is on range $I < 100$ lux, while the low is at $100 \leq I \leq 2000$ lux. The value of the intensity range is based in experimental circumstances that aim to distinguish between the night ($I < 100$ lux lux), and overcast ($100 \leq I \leq 2000$ lux). Graphs of membership function are shown in Figure 5.

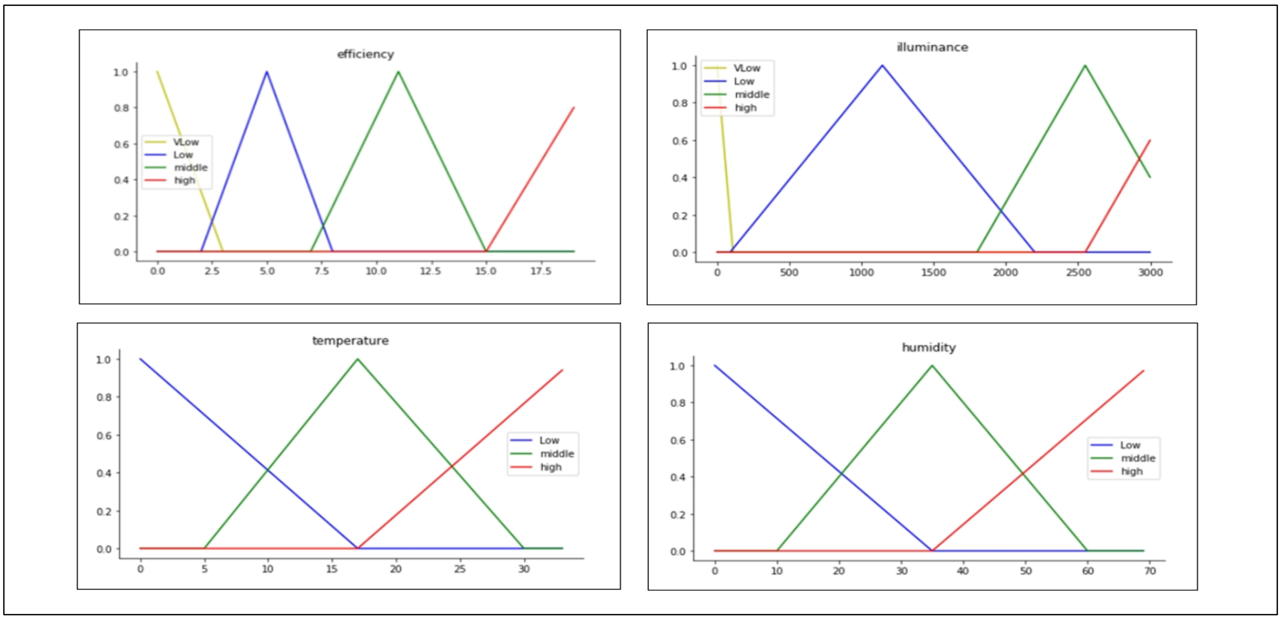

Figure 5. Graphs of membership function of sensor readings on the solar panel

Output of fuzzy logic system computation is then used as input of the rule-based system developed to determine disturbance on solar panels. Rule-based system is one example of artificial intelligent with the principle of knowledge manipulation to gather more useful information. The rule-based system in this solar panel diagnosis can automatically run inferences that is determines conditions swiftly and then stores it in the data base. Data history is kept for decision support system in optimizing output power of PV panels. Rule-based system employs rules set by people and automatically executed by the computer. This system is suitable for non-complex regulation systems, with more accurate and speedy results [22].

Rules set in the rule-based system for solar panel is based on input facts from sensor data base to execute an action. These rules make use of AND or OR logics to connect facts. Architecture of the rule-based system for solar panel diagnosis is shown in Fig. 6. Condition represents premises or facts, and *conclusion* represents actions for those premises or facts. *Condition* can either a premise or a group of premises connected to *AND & OR logical operators*. Meanwhile, conclusion can be an action taken or a conclusion based on a shown premise.

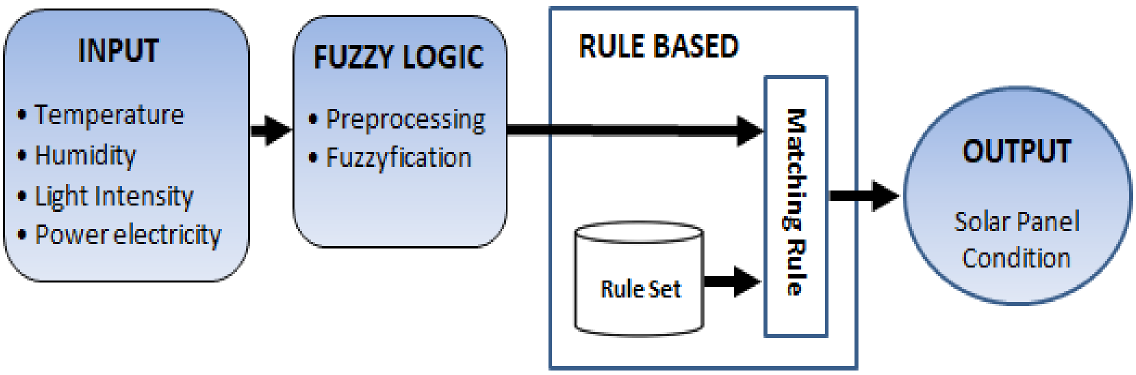

Figure 6. Architecture of the rule-based system for solar panel diagnosis

Rule is a general knowledge of application domain. It maintains originality, modularity, and ease in explanation as it is used as it is, as if it were stated by an expert. The drawback of this rule is that it is not easy to gain a complete and perfect set of knowledge on a complex domain, as there may not be any expert who can reveal his/her knowledge or there may not be enough experts on the domain concerned. Diagram of rule-based system flow is shown in Fig. 7.

The programming script for this rule-based system is written with the CTU computer that stores the data base of solar panel sensors in the field. The program is written independently as is not connected to the data acquisition system and sensor data recording to the data base, as to prevent data traffic congestion during execution. Procedure for rule-based system programming starts with sensor data loading from the data base, which is then matched with the rule conditions set. Each input condition probability will result in a matching statement. Diagnosis of all solar panels includes conditions of intensity, efficiency, temperature and humidity. Proportion is classified by experiment and are categorized into very low, low, medium, high and very high. If a sensor condition does not come with a rule, then the loop in considered closed, and the condition recorded in the computer is taken as the same to the prior condition and then the last data base is taken.

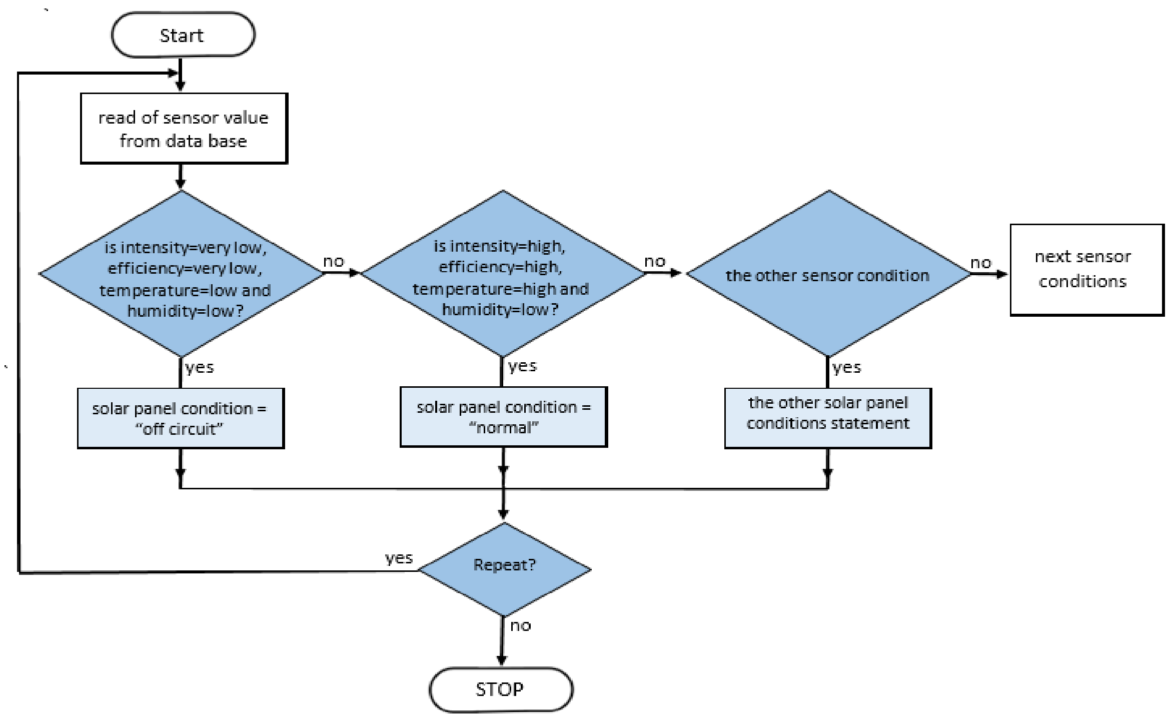

Figure 7. Diagram of rule-based system flow

The input is called promise, which is the initial condition of rule based. Through computer programming that has been built then has obtained the output of diagnostic results called conclusion. In computer programming both are often expressed in commands: IF… THEN …. An Example of such programming is:

IF (illuminance = 'High') and (efficiency ='High')
AND
(temperature ='High') and (humidity ='Low')
THEN

begin
conclusion: ='Normal'
END

IV. Result and Discussion

An instrument for photovoltaic panel online and real-time monitoring and investigation using the rule-based artificial intelligent system has been successfully realized with multi-node wireless sensor configuration. In this research, discussion for one of the nodes of the data base from one photovoltaic panel is taken as a sample in the CTU computer. The main input parameters of the rule-based is efficiency (η), which is calculated from output electrical power reading (P) from the photovoltaic panel compared to light intensity (I) that falls upon the photovoltaic panel. This system also takes temperature (T) and humidity (H) as additional parameters. The rule-based system for photovoltaic panel diagnosis is a set of rules of cause and effect from each input parameter from sensor readings. Hence, testing for the sensor built is important in order to produce an accurate monitoring and investigation system. Sensor calibration is carried out by comparing readings in the CTU database to those from standard instrument readings in the RTU. Results of testing for each sensor are shown in Fig. 8.

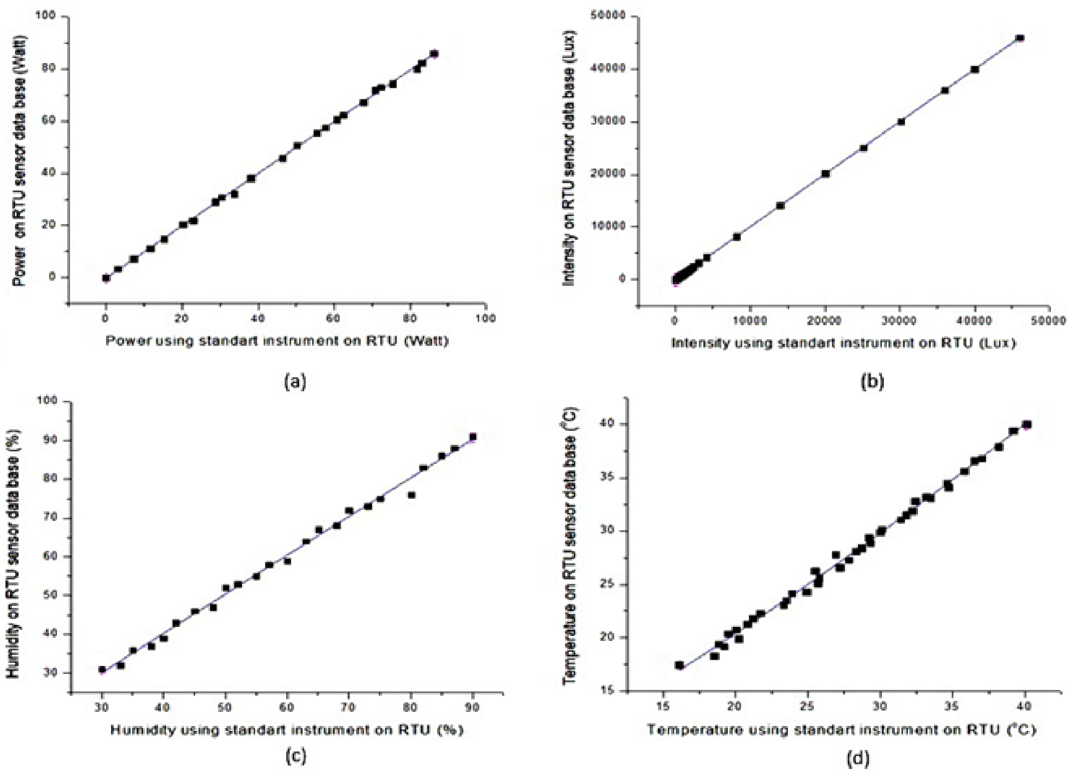

Figure 8. Results of sensor testing for electrical power (P), light intensity (I), temperature (T) and humidity (H)

Results of sensor calibration show linear relationships between the sensor being tested and the standard measurement instrument used as comparison (calibrator). Error values are used to quantify differences in values between tested and standard sensors. The less the error value, the more accurate the sensor system developed is. Calibration results of the sensor system developed are shown in Table 2.

Table 2. Calibration results of the sensor system developed.

Quantity	Average Error	Unit	Percentage Error (%)
Light intensity	8.36	Lux	0.02
Power	0.52	Watt	0.61
Temperature	0.39	Celsius degree	0.96
Humidity	0.96	Percent	1.05

Results of sensor testing show small error values of less than 1.05% of percentage error. This means that the sensor system developed is capable of monitoring and investigation of photovoltaic panel efficiency in the field. In order to analyze input data against electric power output of the photovoltaic panel, graphs are used and shown on the computer monitor. Other than showing sensor readings, the graphs also show values of photovoltaic panel efficiency calculated using equation (1). In this calculation, input of light intensity is turned into units of Watt/cm^2 before being compared to the electric power output of the photovoltaic panel.

Empirically, investigation for photovoltaic panel can be carried out by figuring out efficiency values compared to light intensity. However, this method is not capable of diagnosing the cause of efficiency reduction. Literature studies reveal that efficiency is reduced by sun radiation itself, dust, dirt, rain, snow, and the likes. In tropical regions, diagnosis is based on the most common causes; dust, dirt, and rain. Data on these impurities serve as foundation for the rule-based system for photovoltaic panel investigation. Graphs showing variation of photovoltaic panel conditions due to external disturbances in tropical areas are shown in Fig. 9.

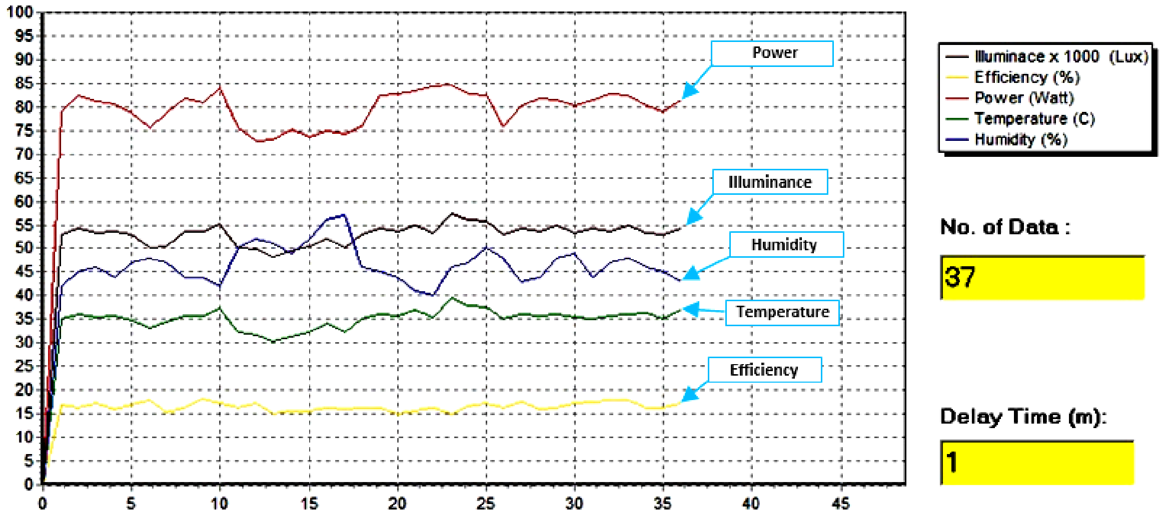

Figure 9. Graphs of various photovoltaic panel conditions due to external disturbances commonly found tropical areas, photovoltaic panel in normal condition.

Figure 9 is a graph showing photovoltaic panel in normal condition in which it has the highest efficiency as the sensor reads high light intensity. This means that no significant disturbance is experienced by the panel and it has 18.20% efficiency. The photovoltaic panel condition at night when it experiences the lowest efficiency as light intensity is almost none (≅0), accompanied with low temperature, and high humidity. The photovoltaic panel of low efficiency despite high light intensity, high temperature, and low humidity. This condition differs from the condition at night in that reading for light intensity is high. This means that there is disturbance caused by external natural factors commonly found in literature studies. Analyses of data in the field reveal that this disturbance is caused by falling leaves on the photovoltaic panel. The effect of disturbance by leaves and dust in this research is found to be slightly differs, with the leaves resulting in the lowest efficiency. Meanwhile, reduction in efficiency due to dust does not reach the extreme low value. If one sensor condition is not found in one of the rules, then sensor reading is conducted again and the status of photovoltaic panel condition is taken as the same at it was earlier.

In this system, the fuzzy rule-based algorithm has been built separately with the main program on the server. Re-reading was set at 5-minute intervals and can be customized a required. Data that has been read by the program from the server is displayed on the 'sensor input' section, then clustered according to the rule and the results are displayed on the 'linguistic input' section. Table 3 shows examples of fuzzification testing results based on degree of membership between 0-1. This value range is then used to determine sensor condition in linguistic terms.

Table 3 : Results of sensor fuzzification

Intensity (lx)	Degree				Status
	very low	low	middle	high	
0	1.00	0.00	0.00	0.00	very low
24	0.76	0.00	0.00	0.00	very low
80	0.20	0.00	0.00	0.00	very low
124	0.00	0.03	0.00	0.00	low
252	0.00	0.16	0.00	0.00	low
303	0.00	0.21	0.00	0.00	low
492	0.00	0.41	0.00	0.00	low
522	0.00	0.44	0.00	0.00	low
693	0.00	0.62	0.00	0.00	low
721	0.00	0.65	0.00	0.00	low
811	0.00	0.75	0.00	0.00	low
955	0.00	0.90	0.00	0.00	low
1007	0.00	0.95	0.00	0.00	low
1922	0.00	0.08	0.00	0.00	low
2100	0.00	0.00	0.03	0.00	medium
4200	0.00	0.00	0.55	0.00	medium
8100	0.00	0.00	0.48	0.00	medium
20000	0.00	0.00	0.00	0.25	high
30100	0.00	0.00	0.00	0.50	high
46000	0.00	0.00	0.00	0.90	high

Intensity (lx)	Degree				Status
	very low	low	middle	high	
0	1.00	0.00	0.00	0.00	very low
24	0.76	0.00	0.00	0.00	very low
80	0.20	0.00	0.00	0.00	very low
124	0.00	0.03	0.00	0.00	low
252	0.00	0.16	0.00	0.00	low
303	0.00	0.21	0.00	0.00	low
492	0.00	0.41	0.00	0.00	low
522	0.00	0.44	0.00	0.00	low
693	0.00	0.62	0.00	0.00	low
721	0.00	0.65	0.00	0.00	low
811	0.00	0.75	0.00	0.00	low
955	0.00	0.90	0.00	0.00	low
1007	0.00	0.95	0.00	0.00	low
1922	0.00	0.08	0.00	0.00	low
2100	0.00	0.00	0.03	0.00	medium
4200	0.00	0.00	0.55	0.00	medium
8100	0.00	0.00	0.48	0.00	medium
20000	0.00	0.00	0.00	0.25	high
30100	0.00	0.00	0.00	0.50	high
46000	0.00	0.00	0.00	0.90	high

Temperature (°c)	Degree			Status
	low	middle	high	
16.10	0.36	0.00	0.00	low
18.80	0.25	0.00	0.00	low
19.20	0.23	0.00	0.00	low
20.20	0.19	0.00	0.00	low
21.20	0.15	0.00	0.00	low
23.30	0.07	0.00	0.00	low
24.90	0.00	0.00	0.00	low
25.70	0.00	0.23	0.00	medium
26.90	0.00	0.63	0.00	medium
27.80	0.00	0.93	0.00	medium
29.30	0.00	0.67	0.00	medium
31.40	0.00	0.15	0.00	medium
32.20	0.00	0.00	0.01	high
33.50	0.00	0.00	0.08	high
34.60	0.00	0.00	0.14	high
35.80	0.00	0.00	0.21	high
37.00	0.00	0.00	0.28	high
38.20	0.00	0.00	0.34	high
39.20	0.00	0.00	0.40	high
40.10	0.00	0.00	0.45	high

Humidity (%)	Degree			Status
	low	middle	high	
33	0.34	0.00	0.00	low
35	0.30	0.00	0.00	low
38	0.24	0.00	0.00	low
40	0.20	0.00	0.00	low
42	0.16	0.00	0.00	low
45	0.10	0.00	0.00	low
48	0.04	0.00	0.00	low
50	0.00	0.00	0.00	low
55	0.00	0.50	0.00	medium
57	0.00	0.70	0.00	medium
60	0.00	1.00	0.00	medium
63	0.00	0.70	0.00	medium
68	0.00	0.20	0.00	medium
70	0.00	0.00	0.00	medium
73	0.00	0.00	0.10	high
75	0.00	0.00	0.17	high
80	0.00	0.00	0.33	high
85	0.00	0.00	0.50	high
87	0.00	0.00	0.57	high
90	0.00	0.00	0.67	high

Output of linguistic status changes at membership borders [36]. The table shows borders of changes in output values from fuzzification process, and that they vary in line with the fuzzy set developed [37]. In agreement to the discussion of this paper, the method of solar panel diagnosis that is developed based on of fuzzy rule-based system performs fuzzification of output data using the rule-based algorithm execution of rule-based system in the program has been displayed in the 'condition statement' as a conclusion statement that indicates the condition of the solar panel.

Table 4 serves as justification for testing of the rule-based system developed that is used to diagnose photovoltaic panel. It can be seen in the table that almost all parts of the rule are TRUE. However, there are times when the rule-based system conducts processes that do not fit conditions in the field. For example, in a condition of high light intensity, but with low temperature and humidity. In this condition, the electric power a photovoltaic panel produced is low, that the system understands the condition as Night. This may happen as the rule-based system in the computer does not state specific conditions that may tell differences between two similar conditions [38]. In this case, the addition of sensors to obtain parameters that can help differentiate two similar conditions seems to be a good solution. The addition of specific sensors can explain facts in the field in more detail that the rule-based system is capable of representing a wider range of conditions [39].

Table 4. Rules on the computer used to determine the solar panel condition based on the sensor input

Number of Rules	Promise				Conclusion
	Intensity	Efficiency	Temperature	Humidity	
1	Very Low	Very Low	Low	Low	Off Circuit
2	High	High	High	Low	Normal
3	High	High	Medium	Low	Normal
4	Very Low	Very Low	Low	High	Night
5	Very Low	Very Low	Medium	High	Night
6	Very Low	Very Low	Low	Medium	Night
7	Very Low	Very Low	Low	High	Night
8	Very Low	Very Low	Low	Medium	Night
9	Very Low	Very Low	Medium	Medium	Night
10	Low	Very Low	Low	Medium	Rain
11	Low	Very Low	Low	High	Rain
12	Low	Low	Low	Medium	Rain
13	Low	Low	Low	High	Rain
14	High	Medium	High	Low	Dust
15	High	Medium	High	Medium	Dust
16	Medium	Low	Low	Medium	Dust
17	Medium	Low	Medium	High	Dust
18	High	Very low	High	Medium	Leaves
19	High	Very low	High	Low	Leaves
20	Medium	Very low	Medium	Medium	Leaves
21	Medium	Very low	Medium	Low	Leaves
22	Medium	Very low	Low	Medium	Leaves
23	Medium	Very low	Low	Low	Leaves

This research has tested different effectiveness between a cloud network supported by fog network and that a cloud network only. The important parameters proposed for performance test for both models are data transmission time/network communication delay. The test was carried out for 14 days with a measurement interval of 1 hour. The results of testing these parameters is shown in Figure 10. Then the measurement results are averaged to get the difference values from the drivers using the fog-cloud network model. In general, the data transmission time has changed at any time. This relates to cellular activities that use broadband internet network [40]. During the day, transmission quality is reduced and this time of day shows lower transmission time. This means that the use of fog networking plays a crucial part in the utilization of cloud network. It can be seen in Figure 10 that network performance increases with the use of fog-cloud networking, compared to only using cloud networking alone. The fog-cloud networking has been able to improve data transmission time from 246.1 ms to 27.9 ms.

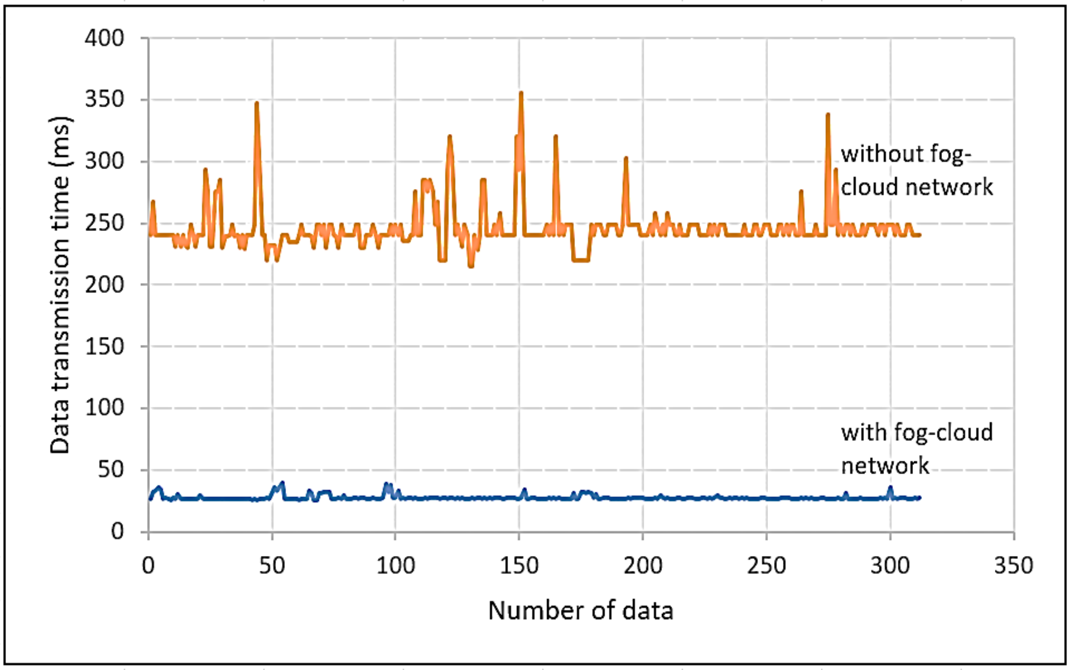

Figure 10. Graph of the results of testing the data transmission time parameters for performance using fog.

This research has successfully investigated the performance of fuzzy rule-base fog-cloud computing for real-time solar panel disturbance investigation. Testing of solar panel productivity with the use and non-use of investigated instrument has been carried out. Testing data were taken from the server in everyday for a period of 1 months. These represent average efficiency value of each solar panel. Results of sensor readings for solar panel efficiency are shown in Figure 11. The graph shows that efficiency of both solar panels lowers after a few days of measurement. The solar panel that is equipped with the fog-cloud network immediately provides a notification so that it returns to normal after several notifications and hence, corrective steps.

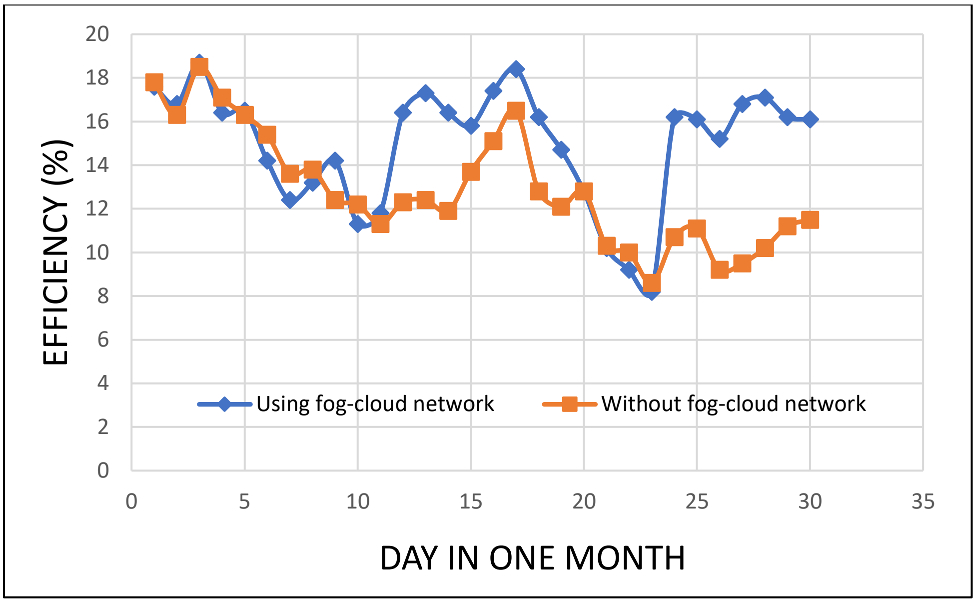

Figure 11. Graph of results of sensor readings for solar panel efficiency

In normal conditions, the solar panels in this research have average efficiency of 17.2%, while when dust is present, their efficiency drop to 7.6%. Early notification system can therefore restore a 9.6% efficiency gain in that sort of event. When disruptions from leaves are detected, solar panel efficiency may drop to as low as 1.6%. From the results of this study it has been obtained an average efficiency increase of 14.9% while if without using the fog-cloud network the efficiency is obtained by an average of 12.8%. Hence, the diagnosis system developed here is capable of improving efficiency by up to 2.1% when such a disruption takes place. Sustainability of electricity supply is vital for either industry or emergency installations such as hospitals, farms, and fisheries. The server computer calculates average solar panel efficiency for conditions of either no disturbance or when disruptions due to rain, leaves, and dust take place.

There two main advantages of this research in improving solar panel performance; efficiency and sustainability [41]. The use of artificial intelligence both online and in real-time allows for speedy diagnosis that solar panels can readily be conditioned to optimum efficiency. It also guarantees adequate electric energy supply from solar panels as based on environmental condition. The wireless sensor technology here helps solar panel technicians by relieving them from the arduous work of going to the field with measuring instruments to check solar panel conditions and manually draw conclusion from the data found. This system relies on the essence of artificial intelligent in which notification can directly informed by computers. A speedy notification of solar panel condition has economic repercussions as it concerns with the sustainability of electricity supply.

5. Conclusion

The online fuzzy rule-based system using System on Chip (SoC) Wi-Fi microcontroller has proven to be effective in monitoring the efficiency and diagnosing the condition of photovoltaic panel with the help of sensors for physical parameters input and electrical power output on solar panels. In general, the conditions resulting from diagnosis are based on the correlation of light intensity, temperature, and humidity parameters with electric power output of photovoltaic panel. The system developed here is capable of continuously monitoring photovoltaic panel efficiency and disturbances found in the field. Rules are set based on conditions in the field from observations and supported by data taken by sensors that are stored in the data base of the RTU computer. There are discrepancies in the result of rule-based truth table test. This shows that there are some undefined rule-based values in the computer system developed. This means that in order to build a rule-based system, detailed conditions of all possibilities in the field are required. Additional sensors may be needed to perfect results of photovoltaic panel diagnosis against abnormalities. The purpose of this research has been achieved by referring to the improvement of solar panel efficiency from the maintenance side. The use of online rule-based diagnostic system can speed up the handling of interference so that the total efficiency and continuity of electricity production in solar panels can be improved.

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