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Design and Application of Monitoring System for Electrical Energy based-on Internet of Things

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Abstract
The system was designed for electrical energy usage data that be obtained through detection device can be accessed and processed from an application on a user's smartphone. The detection device can notice electrical energy in the power cord of the electronic device. It has a different function with power as 18 watts up to 77 watts. Detection of device and application in the system are well integrated because of status in application displays the same result as the LED indicator on the detection device. The system has an accuracy of 1 Wh with an uncertainty of 0.5 Wh. The result shows that monitoring duration for 60 minutes in accordance with the specification of the electronic device being monitored.

Keywords
Internet of Things, Electrical Energy, Detection Device, Application.

Introduction
Electrical energy is the easiest energy converted into other energy. Therefore almost all human activities require electricity [1]. The development of technology makes the demand for electrical energy is increasing every day [2]. The electrification ratio in Indonesia at the end of 2018 is 98.30%. However, natural resources producing energy are still limited. Technology for renewable energy is still not effective so it is required to remain wise in the use of energy. Therefore, the Indonesian government issued several regulations related to energy conservation. Generally, a collection of electrical energy usage data was conducted using simple measuring devices and writing data manually. This makes monitoring of electrical energy can not be done at any time and it takes a long time to get the results [3]. Based on these facts, the research aims to design systems that can help users to carry out monitoring of electricity usage, where the system can provide an estimation of the amount of electricity used in an electronic device so users can adjust their habits based on these data [4].
Various methods have been used to design a monitoring system for the use of electrical energy, but it is still relatively expensive and has a complex structure [5]. Therefore, the system is designed to build using electric energy detector, which is the application of Faraday's Electromagnetic Induction Law based on Internet of Things (IoT). The data obtained through the detection of electrical energy will be uploaded to the internet so that data can be accessed and processed through applications that can be downloaded on the user's smartphone [6]. With the application of the IoT concept, users can carry out the process of monitoring energy usage continuously and in real-time [7].
This research focuses on the detection of electrical energy by placing the electronic devices' power cables in the available slots. The monitored electronic devices are light bulb, fan, laptop charger and rice cooker. Monitoring usage of electrical energy is conducted for 15 minutes, 30 minutes and 60 minutes.
Energy management is an incorporated activity to manage energy consumption in order to obtain efficient and effective utilization in producing the maximum output [8]. Internet of things (IoT) can be stated as a dynamic global network infrastructure equipped with self-configuration and communication networks that can be operated, as shown in Figure 1a [9]. More simply, IoT is a concept for making all objects around it connected to the internet and have intelligence.

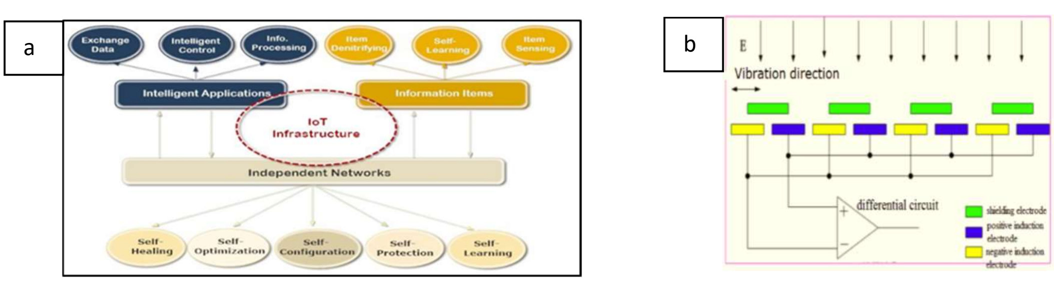


Figure 1: (a) IoT Concept [9] and (b) Working Principle of Electric Energy Detector [10]

The method of detecting electrical energy uses the principle of Faraday's Electromagnetic Induction Law [10]. In this design, electrical energy acts as a magnet and copper coil acts as a detector of electrical energy as shown in Figure 1b.

Materials and Methods

The design process was needed in making a system aims to produce excellent system performance. The system design is displayed in Figure 2 in the form of a block diagram system.

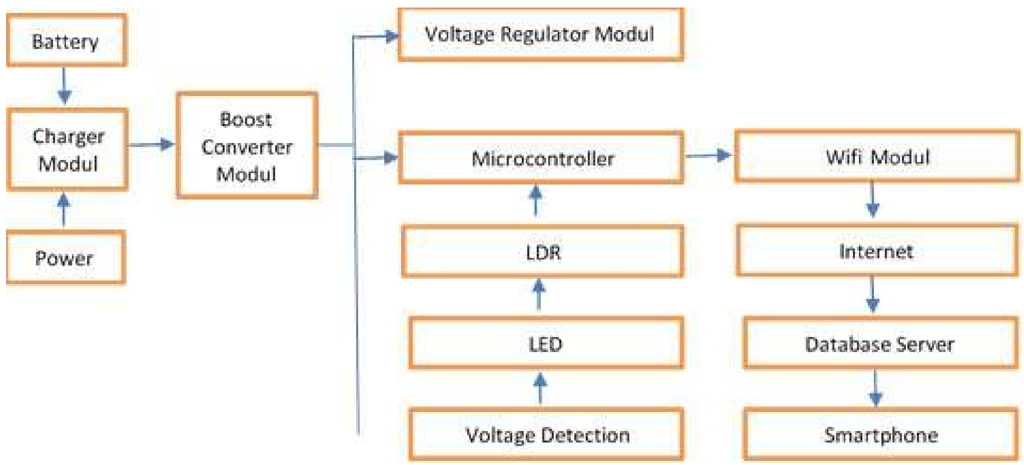


Figure 2: Block Diagram System

The hardware in this IoT-based monitoring system, in the form of an electric energy detector, can upload data to the database server by internet network. The design of the detector can be shown in the form of a circuit diagram in Figure 3a.

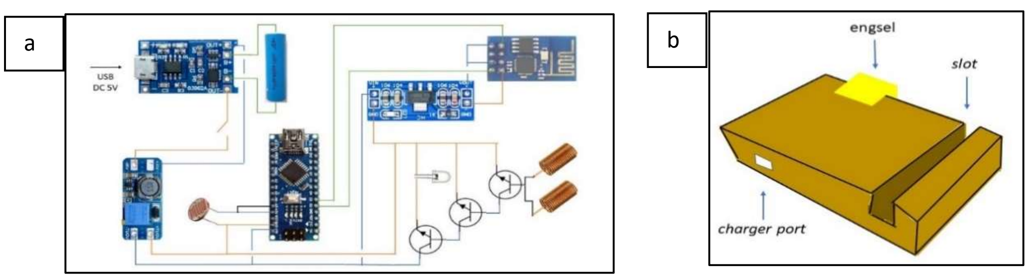


Figure 3: (a) Hardware Circuit Diagram and (b) Display of Detection Tool

The detector is equipped with a slot that aims to be used as a place to put the power cable from the electronic device to be monitored. The casing is made from MDF. On the casing, a plastic hinge is installed therefore, it can be opened to activate the detector. Display detector that has been built is shown in Figure 3b.

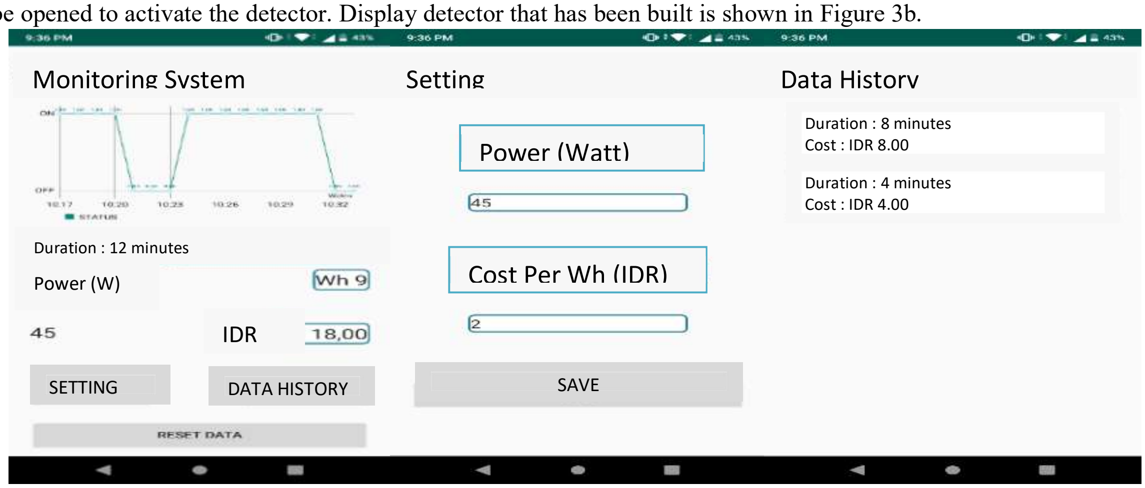


Figure 4: Application Display

The software was programmed in the form of applications that can be downloaded to smartphones with the Android operating system. The main page of the application displays a graph of monitoring device condition versus time, in the ON condition or the OFF condition. It also displays time data in minutes, the power of electronic devices monitored in watts (W), estimated total electricity usage in watt-hours (Wh) and estimated costs incurred in IDR. Data were accepted from the detector for every 60 seconds. There are 3 buttons on the main page. The first button is Monitoring System, the second button is Setting to input electronic device power and energy cost per Wh, the third button is Data History to display historical usage electronic devices duration being monitored. Reset data is used to reset data resulting from the monitoring of electronic devices. The application display is shown in Figure 4.
Electronic devices which are the object of research are suggested to have different usage functions and power values. The specifications of the research object are shown in Table 1.

Table 1: Research Object Specifications

Device Type	Power (Watt)
Light bulb	18
Fan	45
Laptop charger	65
Rice cooker	400 (cook) 77 (heating)

Data retrieval from light bulb needs cables in fitting components, while for fan device, we must set the speed at maximum value. For laptop charger device, it is connected to a laptop without a battery, and rice cooker device used as a heater.
Two types of data will be taken, system and calculation data. System data was resulted by an application that has been uploaded on a smartphone, while calculation data was resulted of manual calculations using basic electronic energy as shown in Equation (1) accompanied by monitoring of the energy meter at the research site.

$$Electrical\ energy\ consumption\ (Wh) = Power\ (W)\ .\ time\ (hour) \quad (1)$$

The first step in collecting research data is to disconnect electronic devices from electrical energy in addition to the research object being monitored. Second, put the electronic device power cable into an available slot on the detector. The power cord is in a stable condition. At the same time, monitoring is carried out on the energy meter at the study site. Data were taken in the form of time required for the energy meter to decrease in value every 0.01 kWh or 10.00 Wh. The conditioned energy meter has an exact value of 13.40 kWh or 13,400 Wh. This value is obtained by recharging the previously used energy meter as IDR 21,500. Data collection on electricity usage is carried out with variations, data of electricity usage is taken every minute for 15 minutes, data on electricity usage is taken every two minutes for 30 minutes and data on electricity usage is taken every four minutes for 60 minutes. The data collection scheme is shown in Figure 5.

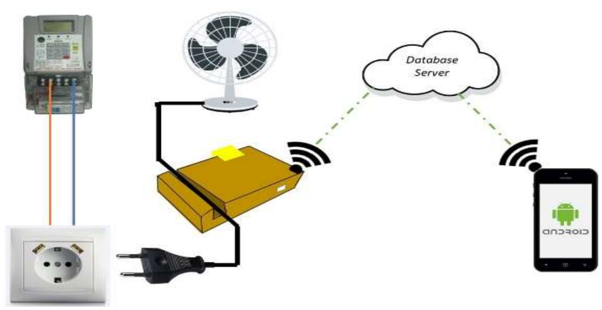


Figure 5: Data Collection Scheme

Results and Discussion

Testing is intended to determine whether the hardware and software in the system, has met the design criteria. The design criterion in this research is detector detects the electrical energy through an LED indicator on the detector, upload data to the database server, the application can download and processing data from the database server shown in the main view of the application. The results of system testing are shown in the following Table 2.

Table 2: System Testing

Device Type	LED indicator	Application Status
Light bulb	ON	ON
Fan	ON	ON
Laptop charger	ON	ON
Rice cooker	ON	ON

Based on Table 2, the IoT-based electrical energy monitoring system tested, has met the design criteria and shows excellent quality. Detectors can respond well to various electronic devices even with different usage functions and power values. This means that the components of the detector are working well. The detection tool upload data to the database server every 60 seconds. The detector and the application have also been well integrated because the status in the application displays the same results as the LED indicator on the detector. The database server used in this system is the free user version 000Webhost, so the database server does not operate for 24 hours. Access to the database server will be closed from 12 pm to 3 am every day. Beyond this time, the database server works well and is sufficient to meet the design criteria of this research.
The error percentage value in the calculation data determines suitability estimation electrical energy usage by the application. The error percentage value based on monitoring results on the energy meter at the research site. The results of monitoring on the energy meter include the time was taken for the energy meter to decrease value every 0.01 kWh or 10.00 Wh. The calculation data becomes feasible if it has a small error percentage below 10%. Percentage of calculation data error values used Equation (2).

$$Percentage\ of\ calculation\ data\ error = \frac{calculation\ data - monitoring\ data}{monitoring\ data} \quad (2)$$

When monitoring manually, the energy meter for each object of research, the energy meter is conditioned at an initial value of 13.40 kWh or 13400.00 Wh and certainly, no other electronic devices are connected to electrical energy other than the research object being monitored. For light bulbs monitored to a value of 0.02 kWh or 20.00 Wh in the energy meter, fan up to 0.05 kWh or 50.00 Wh, for laptop chargers up to 0.07 kWh or 70.00 Wh and for rice coockers up to 0.08 kWh or 80 kWh. The calculation results of the percentage error data calculation values are shown in the following Table 3.

Table 3: Percentage of Error Data

Object of research	Monitoring		Calculation		Error (%)
	Time (min)	Decreased value of the energy meter (Wh)	Time (min)	The use of electrical energy (Wh)	
Light bulb	34	10.00	34	10.20	2.00
	67	20.00	67	20.10	0.50
Fan	14	10.00	14	10.50	5.00
	27	20.00	27	20.25	1.25
	40	30.00	40	30.00	0.00
	54	40.00	54	40.50	1.25
	67	50.00	67	50.25	0.50
Charger laptop	10	10.00	10	10.83	8.30
	19	20.00	19	20.58	2.90
	28	30.00	28	30.33	1.10
	37	40.00	37	40.08	0.20
	47	50.00	47	50.92	1.84
	56	60.00	56	60.67	1.12
	65	70.00	65	70.42	0.60
Rice cooker	8	10.00	8	10.26	2.60
	16	20.00	16	20.53	2.65
	24	30.00	24	30.80	2.67
	32	40.00	32	41.07	2.68
	39	50.00	39	50.05	0.10
	47	60.00	47	60.32	0.53
	55	70.00	55	70.58	0.83
	63	80.00	63	80.85	1.06

Based on Table 3, the calculation data in this study is feasible to be used as a basis in determining the value of the percentage error in the estimation of the use of electrical energy by the application. The calculation data has a

small error percentage value below 10%. The average error percentage value calculation data is only 1.80 % with a range of error percentage values are 0 - 8.30 %. The error value in the calculation data is because the energy meter at the study site has the smallest scale of 0.01 kWh or 10.00 Wh. The error value in the calculation data is because the energy meter at the study site has the smallest scale of 0.01 kWh or 10.00 Wh.
Retrieval of research data for each research object carried out with three different monitoring durations, 15 minutes, 30 minutes and 60 minutes. Data were taken in the form of electrical energy usage by the object of research in units of Wh. Before the research data was collected, it was confirmed that there were no other electronic devices connected to electrical energy at the study site other than the research object being monitored. Retrieval of data on only one research object at a time. The power cable of the research object and which is being monitored is placed in a slot available on the detector and the cable is in a stable position. If the position of the power cord is unstable, it will interfere with the reading results of the electric energy detector.
Percentage of error in the estimation of electrical energy usage by the application based on the results of calculations that are accompanied by manually monitoring the energy meter at the research site. Determining the percentage of estimated error in the electrical energy usage by an application use Equation (3).

$$Percentage\ of\ estimated\ data\ error = \frac{estimation\ data - calcula \quad data}{calculation\ data} \tag{3}$$

The value of the percentage of error in the estimation of electrical energy usage by the application to quantitatively indicate the error at each monitoring duration. The results of the calculation of the estimated percentage of error in the use of electrical energy are shown in the following Table 4.

Table 4: Percentage Error Estimated from Electric Energy Usage

Object of research	**Monitoring Duration**	**Calculation Data (Wh)**	**Estimated Data (Wh)**	***Error* (%)**
Light bulb	15 minute	4.50	4.00	11.11
	30 minute	9.00	9.00	0.00
	60 minute	18.00	18.00	0.00
Fan	15 minute	11.25	11.00	2.22
	30 minute	22.50	22.00	2.22
	60 minute	45.00	45.00	0.00
Charger laptop	15 minute	16.25	16.00	1.54
	30 minute	32.50	32.00	1.54
	60 minute	65.00	65.00	0.00
Rice cooker	15 minute	19.25	19.00	1.30
	30 minute	38.50	38.00	1.30
	60 minute	77.00	77.00	0.00

At a monitoring duration of 15 minutes, the error value will be higher if the power of the electronic device being monitored is getting smaller. At the monitoring duration of 30 minutes, for the value of power in the form of odd numbers, an error value equal to the value of the monitoring duration of 15 minutes is obtained, while for power in the form of even numbers, an error value of 0% is obtained. This happen because the application displays data in integers, while the results of calculations in decimal numbers. The results of the system data and calculation data are in accordance with the power consumption specifications of the electronic device being monitored. This is indicated by the monitoring duration of 60 minutes, where each research object has an error percentage value of 0%.
In addition to the percentage of error in estimating of electrical energy usage by the application, the results of data processing in this research are graphs of electrical energy usage for each object of research in Wh units for each duration of monitoring in minutes. This graph shows visually the difference in values obtained from the estimation of electrical energy usage with values obtained from the calculation data.
This research using single measurement so that with one direct measurement, the measurement results are obtained and if repeated measurements are carried out the results remain the same. Accuracy is the ability of a measuring instrument to provide an indication of the approach to the actual price of the object being measured. This system has an accuracy of up to 1Wh with an uncertainty of 0.5 Wh. The following is a graph of the use of electrical energy at each monitoring duration for the research object in the form of Philips LED light bulbs with 18 Watt power as shown in Figure 6.

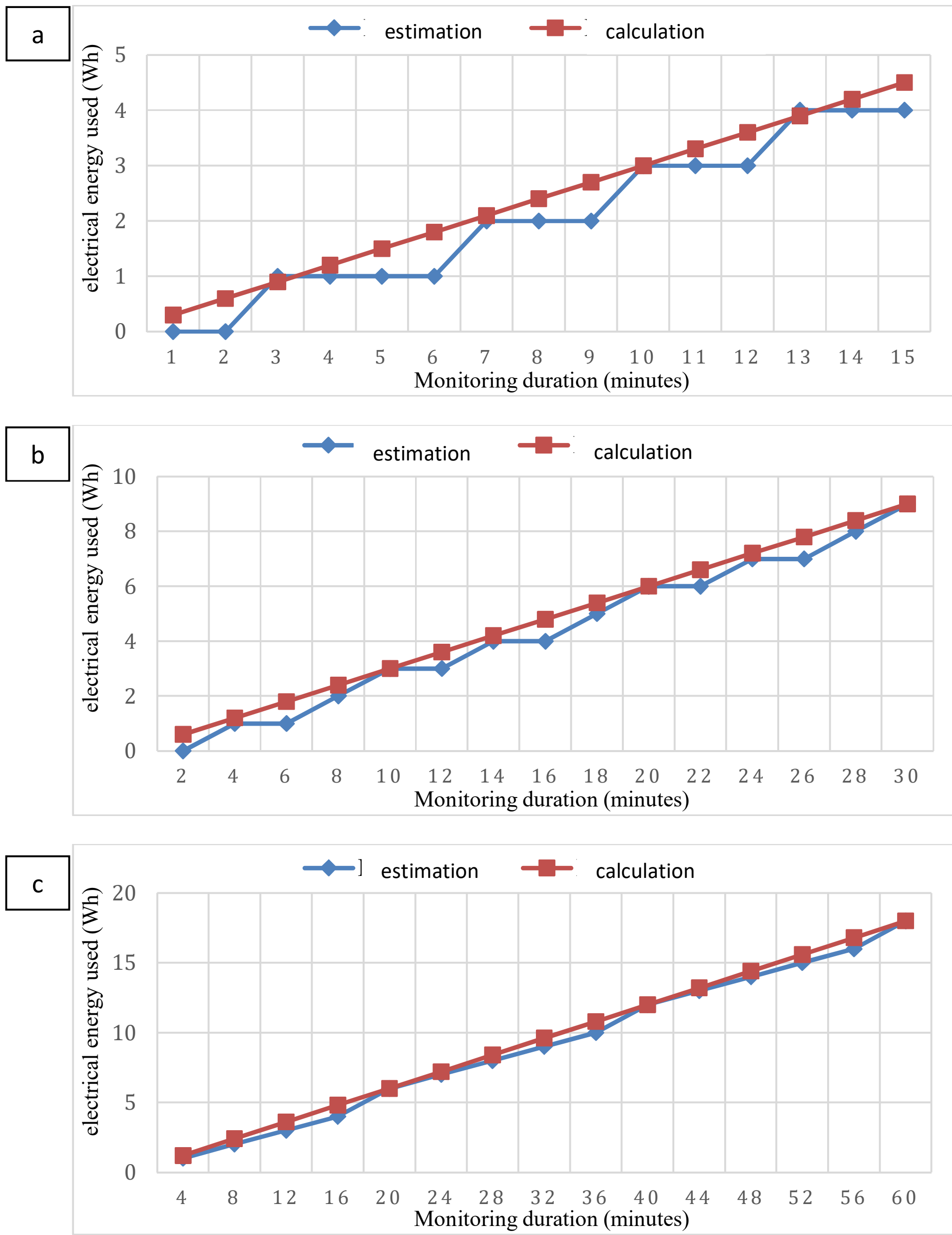
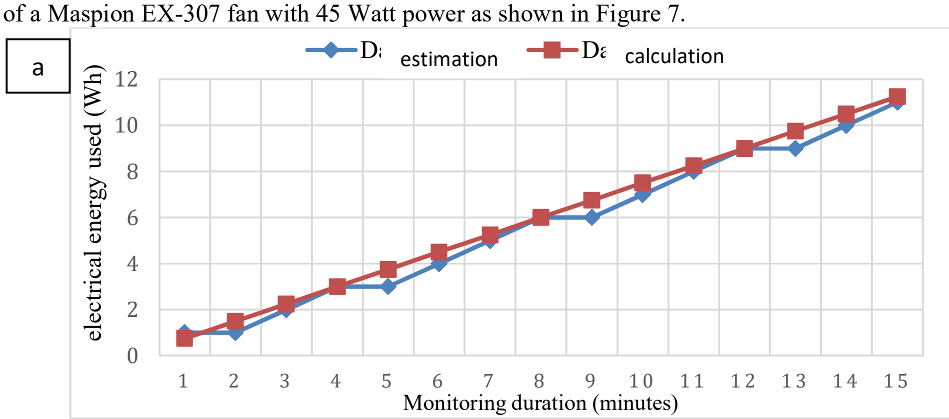


Figure 6: Electric Energy usage of Light Bulb for (a) 15, (b) 30, (c) 60 minutes

The following is a graph of the use of electrical energy at each monitoring duration for the research object in the form of a Maspion EX-307 fan with 45 Watt power as shown in Figure 7.



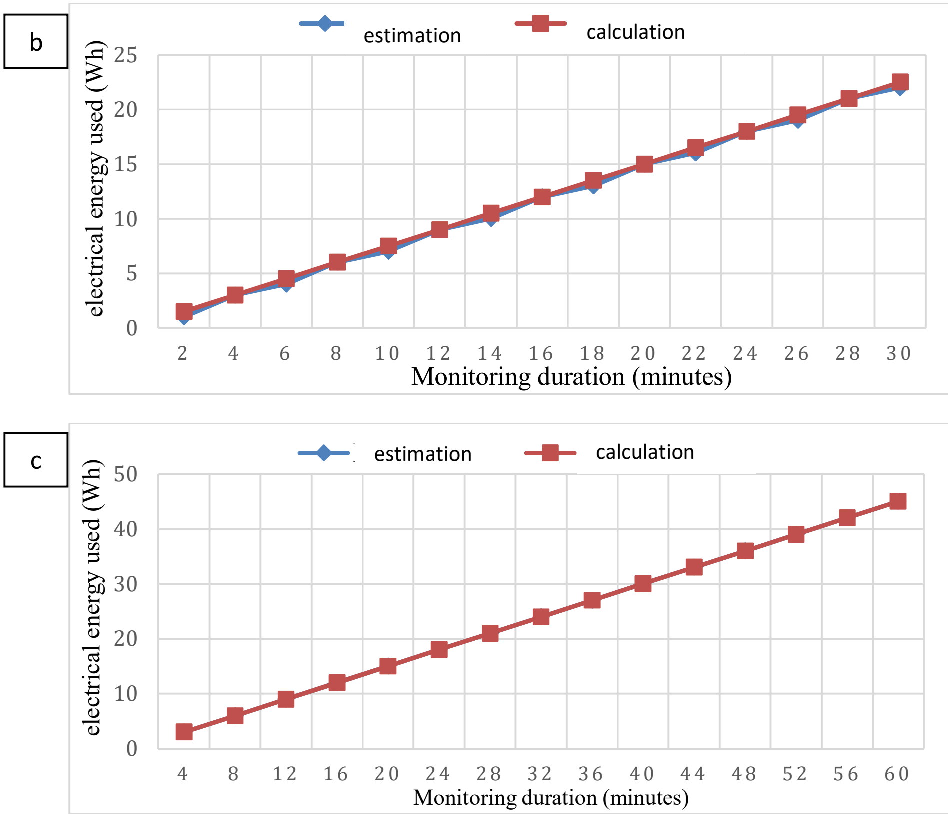
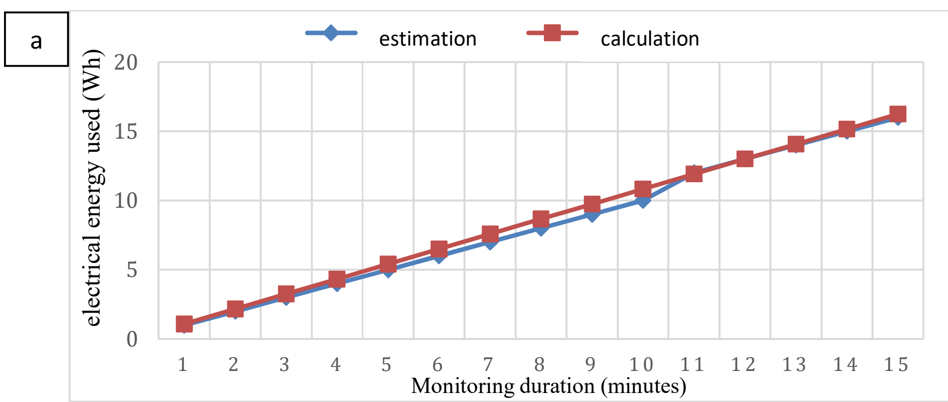


Figure 7: Electric Energy Usage of Fan for (a) 15, (b) 30, and (c) 60 minutes

The following is a graph of the use of electrical energy at each monitoring duration for the research object in the form of an Acer Aspire laptop charger with 65 Watt power as shown in Figure 8.



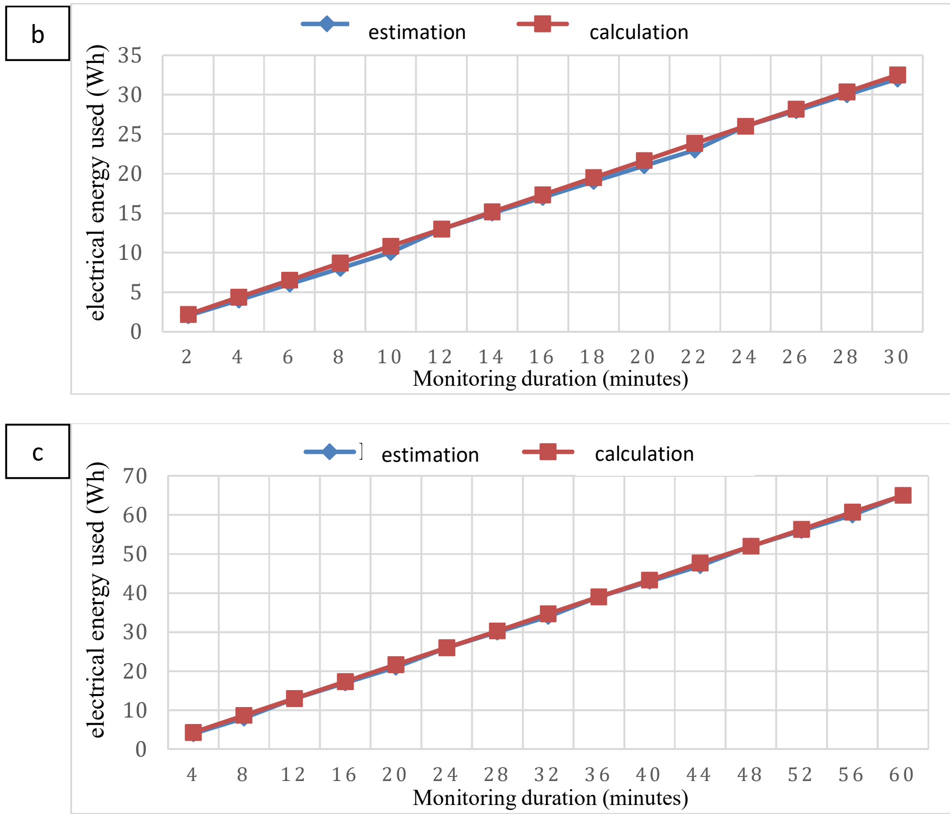
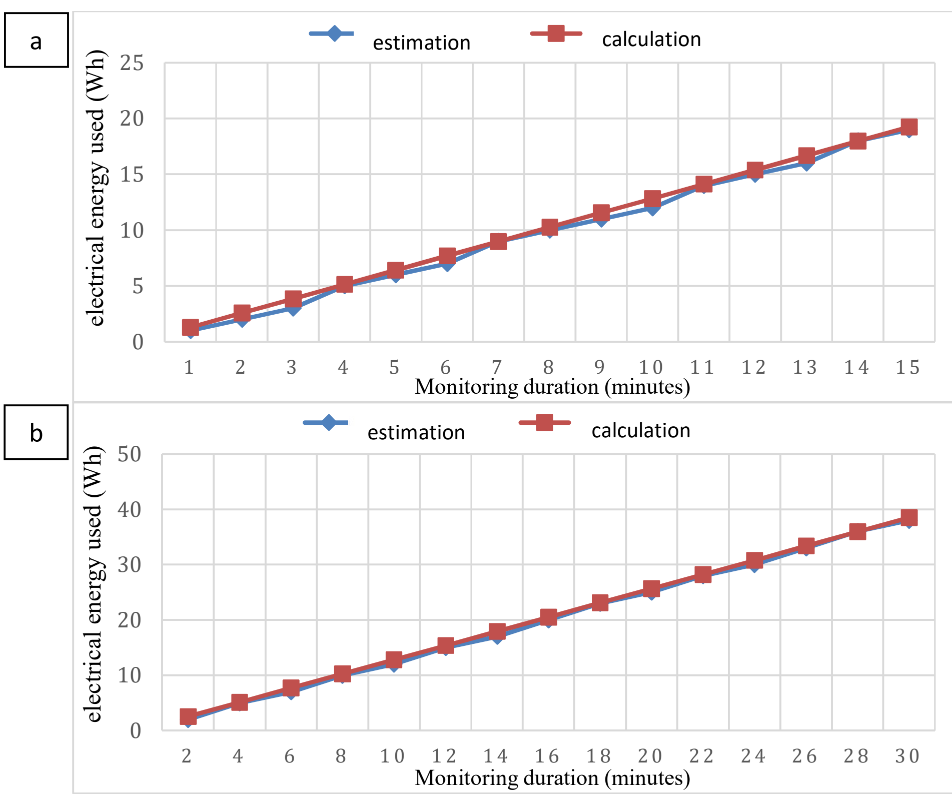


Figure 8: Electric Energy Usage of Laptop Charger for (a) 15, (b) 30, (c) 60 minutes

The following is a graph of the use of electrical energy at each monitoring duration for the research object in the form of Miyako MCM507 Rice Cooker under heating conditions (77 Watt) as shown in Figure 9.



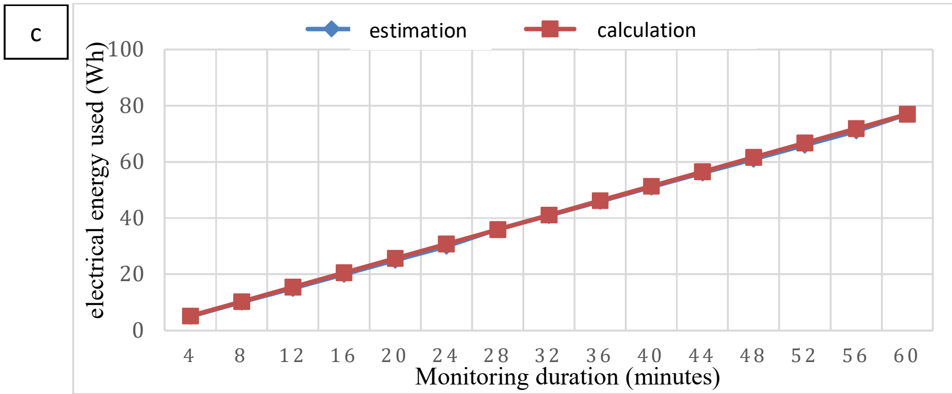


Figure 9: Electric Energy Usage of Rice Cooker for (a) 15, (b) 30, (c) 60 minutes

Based on the graph above, obtained optimal results from the estimation of the use of electrical energy by the application, the duration of monitoring for 60 minutes. At the duration of monitoring for 60 minutes, data collection is done every 4 minutes and the graph shows the results in the form of a straight line. This means that the value obtained from the estimation of the use of electrical energy by the application is the same or almost close to the results of the calculation data.

Conclusions

It has been designed and tested and tested to detect electrical energy which is the application of Faraday's Electromagnetic Induction Law. The tool can detect electrical energy in the power cables of electronic devices that have different usage functions with a range of power values from 18 W to 77 W. The IoT-based monitoring system for electrical energy has an accuracy of 1 Wh with an uncertainty of 0.5 Wh. The IoT-based monitoring system for electrical energy which was designed and tested in this study is still limited to only monitoring one electronic device at a time. Future studies are expected to be able to design and build systems that can monitor several electronic devices simultaneously.

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