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Integrated Lighting Enabler System Using M2M Platforms for Enhancing Energy Efficiency

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Abstract
This paper proposes an integrated lighting enabler system (ILES) based on standard machine-to-machine (M2M) platforms. This system provides common services of end-to-and M2M communication for smart lighting system. It is divided into two sub-systems, namely end-device system and server system. On the server side, the M2M platform OpenMTC is used to receive data from the sensors and send response for activating actuators. At the end-device system, a programmable smart lighting device is connected to the actuators and sensors for communicating their data to the server. Some experiments have been done to prove the system concept. The experiment results show that the proposed integrated lighting enabler system is effective to reduce the power consumption by 25.22% (in average). The proving of significance effect in reducing power consumption is measured by the Wilcoxon method.

Keywords
M2M, Platform, OpenMTC, Sensor and Lighting

1. Introduction

Growth in the use of technological equipment is one of the triggers in the increasing use of electrical energy. One of the major uses of electricity is lighting, both building and road lightings. The use of electricity for lighting mostly could not be controlled accurately which causes waste of electrical energy consumption. In order to use electrical energy more efficiently, a system that could control lighting systems is required.

Internet of Things (IoT) is the tendency of the Future Internet that is rapidly gaining ground in the scenario of connecting various devices to share data and features. Many applications have been proposed on the IoT environment to utilize the shared facilities in order to add new values to existing services. For example, an added value in a home control system is enhancing the convenience in controlling household devices based on information collected from other systems, such as responding accordingly to a received weather status warning. Another example in connected vehicle systems is an added value in navigation, where users could find their way and communicate with other cars in an easier manner.

Enhancing the energy efficiency is becoming a strategic goal worldwide. Different governments are willing to become more energy-independent and have a better perspective on how energy is being used in each of their nations [1]. In addition, saving electric energy consumption should be intensified to reduce other impacts of the power plant. The CO_2 emission, that is pollutant, is another effect of the power plant, which is contributing to global warming or the greenhouse effect. Almost 66.7% of the power plant in the world are using coal and oil as the sources of energy [2], that combustion produces the highest CO_2 emissions [3]. Electric lighting consumes 4% of the total electrical energy consumption worldwide that produce CO_2 emissions [3].

Saving power consumption for lighting is important to reduce the level of world electricity consumption. Various attempts have been made to reduce the use of light for illumination such as changing consumption patterns to outages along with lighting (Earth Hour). Another way is the use of an energy-efficient type of lamp (LED lights) that can save power consumption by 50% [4]. Those efforts are still not enough to significantly reduce electrical energy consumption. Therefore, a system that could massively reduce the use of electrical energy is required.

This paper proposes a smart lighting enabler system to control the electricity usage for building or external lighting. This smart system contains a microprocessor or microcontroller for controlling the connected sensors and actuators. With this sensing capabilities, smart devices "read" the intensity of light around the system, both indoors and outdoors. The actuating capabilities of smart devices can control the power consumed for the lights. The light brightness level is determined by the environment. If the environment is bright, the light turns off, while in the darker the environment, the light turns on with bright level follows the dark level of the environment. In this case, types of lights with dimming capabilities (not shining with maximum potential) are required. At day times when rooms are quite filled with sun ray, the light's intensity will decrease, or even turn-off entirely. By reducing light intensity, the power consumption will also be reduced. In addition, the proposed system consists of pulse width modulations (PWM), Relay, and a wireless communication module. PWM and Relay act as actuators in charge of dimming the lights and turning it off, when brightness in the environment is sufficient. The wireless communication module or Wi-Fi is added to the device as a means of connection to the IoT platform. The IoT Platform utilized here is the OpenMTC platform [5], which is an implementation of the European Telecommunications Standards Institute (ETSI) standard. It provides a horizontal middleware supporting multiple application domains. Having the device connected to OpenMTC, the values of this device can be used by other IoT devices to create larger and comprehensive intelligent system such as smart building and smart city.

The purpose of the research presented in this paper is to prove the performance enhancement of the created integrated lighting enabler system (ILES). The effectiveness of the device is done by comparing two measurements. First, the energy consumption by regular lighting system measurement. The second measurement is the power consumption after the smart lighting device is installed. Each measurement is performed for 24 hours. The significance of efficiency generated by the smart lighting is tested using Wilcoxon method.

2. Related Work

Today, electricity consumption has reached 40% of total global power consumption, while the

increased use of electricity for the residential sector alone has reached to 39% in the previous decade (2000–2010) [3]. The data shows that the energy consumption is remarkable in the development of future technologies. The utilization of energy today remains using non-renewable energy sources that cause pollution.

Various research has been conducted to reduce the growth of electric energy consumption. Development of integrated lights hardware with artificial intelligence [6] was able to reduce the energy usage approximately 23%–43%. The ongoing research toward more efficient usage of energy for highways lighting also successfully demonstrated energy savings up to 35% [7]. In the previous studies [8], the relation between the importance of smart lighting technologies development with the development of smart cities has been acquired. The energy needed for lighting as a consequence of the future smart cities development continues to increase [8].

In the previous studies, the use of machine-to-machine (M2M) platforms was not discussed. M2M platforms support the development of scalable solutions that are also connectable to other solutions to allow convergence in smart systems. The OpenMTC is a standard-based M2M platform that implements the ETSI M2M standard and the OneM2M standard. It provides a middleware developed with the aim to support the development of smart cities [5]. There are some implementation system which use OpenMTC as middleware system such as [9–12].

The OpenMTC platform consisting several layers. OpenMTC supports the RESTful architecture over multiple transport protocols, which are further developed to reduce even more resource consumption required for the communication on this platform.

Growth of the Internet encourages growth of Internet-based smart products, smart building being among them. From the business aspect, smart product has a compound annual growth rate (CAGR) value of 14.2% and in 2016 smart product market is expected to penetrate $1 trillion [13]. This encourages the rapid development of smart research to define products that are already present. Products surveyed defined based on several categories such as Visual Presentation (Present/None), Presentation Channel (Web-Based/Mobile-Based/Desktop-Based/Object-Based), User Interaction (Voice/ Gesture/Touch), Real-Time Archival (Real-Time/Later), Notification Mechanism (Notification/ Action/ Recommendation), Learning Ability (Machine Learning/User Defined), and Notification Execution (Spatial/Temporal/Event-Based). Over 50 Smart Products are involved in the survey, for example, Nest, a smart thermostat, and Mimo, a Smart Baby Monitor.

In the field of building or home energy, there have been studies to reduce Wi-Fi network interference in the smart home system [14]. This research is motivated by the high data-loss in the application of smart home due to Wi-Fi network interference between local area networks and wireless sensor networks. This study offers three things: smart management of the interference, the smart management for lighting with lighting arrangements based on sunlight, and the smart management of home appliances based on usage. The results obtained through simulation calculations say that the proposed system reduces interference and also efficiency in the field of lighting and the use of electrical appliances.

Another study is about a survey on Green IoT [15]. The definition of Green IoT is IoT with lower energy consumption. In this survey, some green terms in IoT are presented such as Green Frequency search, Green WSN, Green Data Center, and M2M Green. As a result of reviews on these fields, this paper describes seven principles in Green IoT, namely:

1. Turn off the device when not in use

2. Send only the data that is needed

3. Minimization of the distance of the data path

4. Minimization of data within a wireless path

5. Swapping processing with communication

6. Advanced communication techniques

7. Usage of renewable resources

In addition, there is an application of detecting the air pollution through M2M system [16].

3. The Integrated Lighting Enabler System

The smart lighting system is designed to be extendable to further features. The extensibility in the hardware part is possible with additional functional boards, so that later the user can put additional components and sensors. An example of extensibility is adding more lights controlled from the hardware module side. From the software side, there is a cloud-based horizontal platform that provides generated application programming interface (API) to facilitate the creation of applications for access needs. Smart lighting framework is an implementation of an embedded-cloud framework proposed as one of the smart city frameworks as well as M2M connectivity framework [17]. The advantages of using cloud embedded framework is making formalized hardware and software development processes among other IoT solution implementations.

3.1 Hardware

Hardware used for controller device (node) consists of two functional boards. Master board as the main part handles the exchange of data with the back-end server, while slave board as the part that handles I/O to the lamp connected to the slave board, using communication standard I2C as shown in Fig. 1. With this type of design, the master board controls multiple slave boards, so that later it could be extended in a room with more lights. On the master-board, the System on Chip (SoC) ESP8266 is used. This is an integrated module that provides Wi-Fi connectivity in ergonomic modules [18]. Other than that, AVR based microcontroller that functions as a master regulator of communication command to access I/O and peripherals on the slave board is used. To support the data from nodes, back-end server that acts as a data collection and logic run platform is required. Fig. 2 shows a detailed illustration of the IOT Device.

A specific SoC will be used for the Wi-Fi module, namely ESP8266EX. As for the microcontroller for sensor and actuator controllers, ATMEGA328PAU is in use. For the light, BH1750 sensor is used. Communication between ESP8266EX with ATMEGA328PAU and BH1750 will use the I2C interface. The relay driver and the PWM driver will be connected to the GPIO of ATMEGA328PAU. To enhance the performance in terms of reducing the price and complexity of the circuitry, a self-designed printed circuit board (PCB) is made. The design can be seen in Fig. 3. It is shown a two layers PCB board.
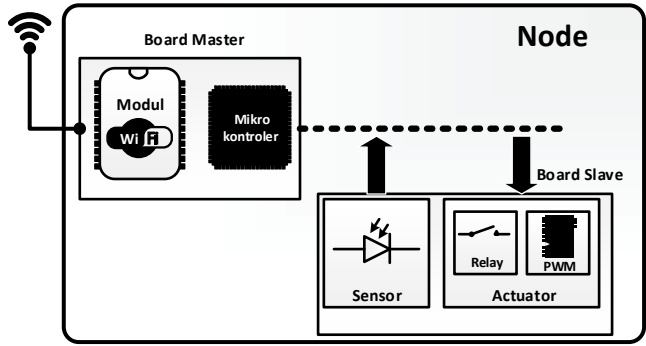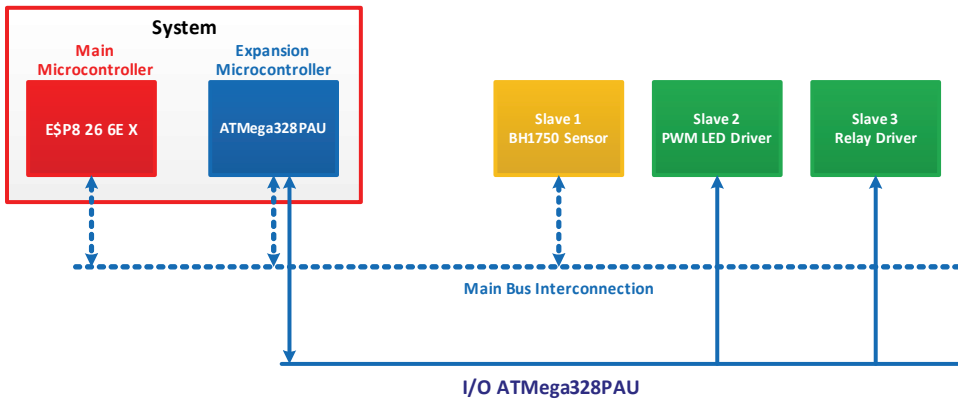
Fig. 1. Smart lighting hardware block diagram.

Fig. 2. Smart lighting hardware specification.

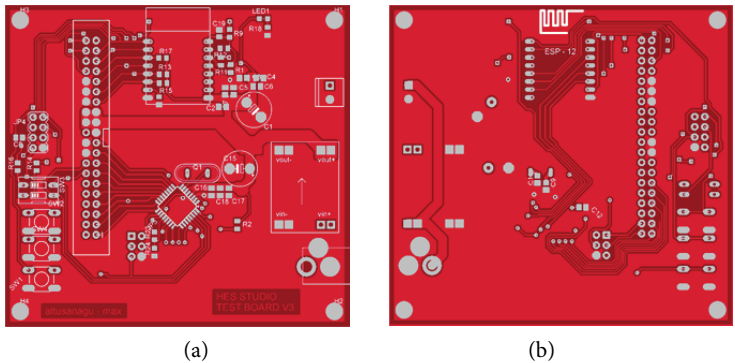(a)   (b)

Fig. 3. Two layers PCB design of smart lighting IoT node: main (a) and expansion (b) board.

3.2 IoT Platform

Mainly, IoT platforms provide a common interaction interface to the varieties of devices and sensors. In our implementation of the Smart lighting system, the OpenMTC platform [19] is used. The main part of OpenMTC is the service capability layer (SCL) that is deployed on the network node (NSCL) and the gateway node (GSCL) as shown in Fig. 4. OpenMTC defined by ETSI (ETSI TS 102 921)

supports a RESTful architecture in client/server system. This system maintains data exchange between applications, gateways and SCLs. Every sub-system in the M2M system can be accessed and manipulated by Create, Read, Update, and Delete verbs. Nodes exchange data over the network using JSON format messages. Network service layer provided by OpenMTC has formerly undertaken applications and sensor registration. Gateway provides a gateway service layer that enables data to be used in other applications, e.g., a UI application that displays data from the node to the user. Gateways are integrated with the OpenMTC platform based on the transport protocol in IP system.

3.3 Software

The software consists of embedded software and the backend platform. Embedded software is installed on the controller device in the master board. Master board has two microcontrollers that have different software. In the SoC, Wi-Fi is an implementation of software that controls the Wi-Fi connection and an implementation of a connection to the platform. In the second microcontroller, software is implemented to control the PWM and relay.

Software block diagram is shown in Fig. 4 describing the smart lighting system that has been implemented. Our descriptions are based on the numbers listed in a white circle. As indicated by Fig. 5, there are three main components, i.e., node, server, and user.

1) (Node) has a main controller (or the controller in the diagram) and an ESP8266 hardware, a microcontroller with an integrated Wi-Fi interface. The Wi-Fi will be used to communicate with the OpenMTC server.
   - When starting the system, the main controller initiates sensors and actuators to connect to the network.
   - After a successfully connection, the system registers to the OpenMTC gateway (GSCL), thus it will be notified when there are new data to the light controls (a subscription with light control container in smartuclab application).
   - The main controller implements an HTTP server as the mld interface. When the OpenMTC is going to send data, the HTTP server will be contacted.
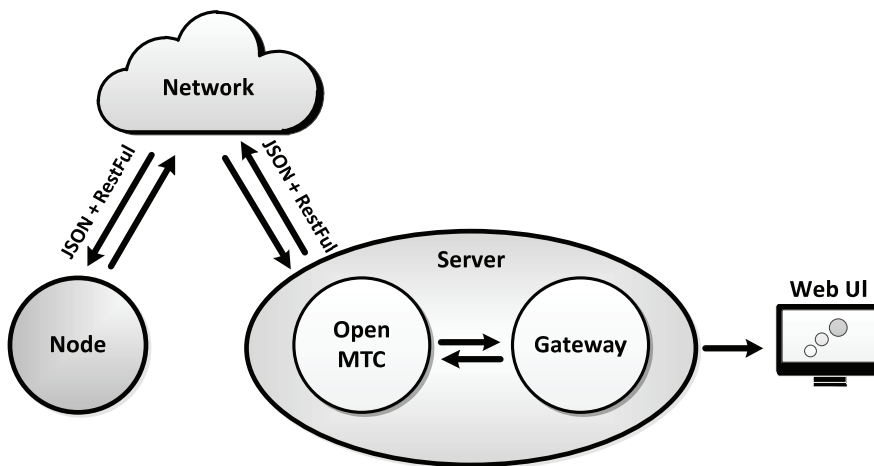

Fig. 4. The system architecture with OpenMTC as M2M platform.

2) (Light Sensor) After receiving notification that the registration was successful, the main controller sends the first light sensor data. Onwards, the main controller checks the light sensor data periodically (every 3 seconds) and sends the data from the light sensor reading. If there is a difference of more than 50 lux of the previous read value, data is sent in the form of content instances to the container in OpenMTC (light sense container in smartuclab application resource).

3) (Light Driver) After simultaneous initiation, the main controller waits for the data of the light controls (light control container) and adjusts the light's brightness based on the data received. The light driver is connected physically via slave controller.

4) Controller implements mId interface, an interface between the device and GSCL. The mId interface uses HTTP RESTful and IP networks where both sides implement server and HTTP client.

5) (Service OpenMTC) provides intermediary facilities of applications and nodes. In explanation of this process, assuming that OpenMTC service is already running before executing the application and the node, so that data can be transferred from node to application and vice versa.

6) (Application) When the application runs, the application registers to OpenMTC and subscribe to get the light sensor data (light sense container) which will be sent by the node (the primary controller) then the application provides the data to be accessed by users via a web control panel. Further, the application checks the lights ignition and shutdown automation, when light data sensor passes a certain threshold, which is also determined by the user via a web control panel.

7) The application also works as a web server to provide web services control panel that is executed by the browser.

8) (Web Control Panel) runs in the browser by the user. Web control panel receives application data using HTTP RESTful and updated periodically by requesting from the application. Web control panel sends automation configuration data, which will then be executed by the application. The main controller in the node executes the following Algorithm 1.
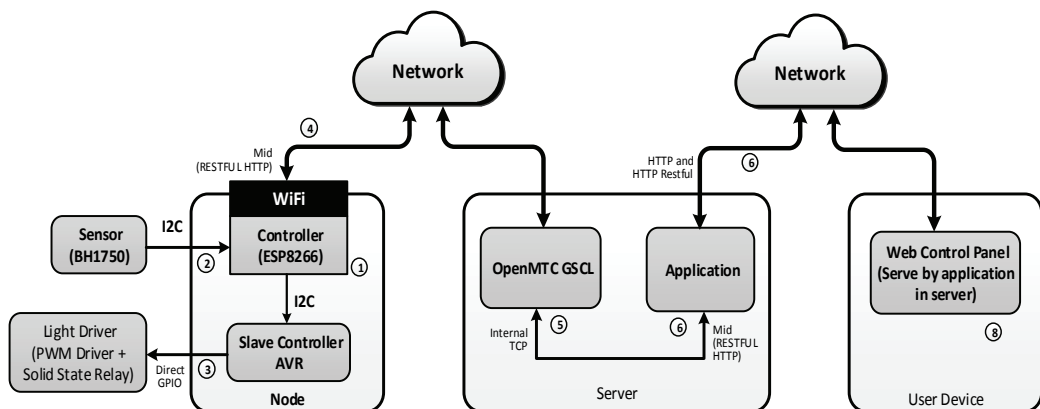

Fig. 5. The smart lighting system architecture.

Algorithm 1

```
Begin
// Sensors and actuators initiation
initiate_sensor_actuator()

//WI-FI connection, wait until the WI-FI is connected
initiate_wifi()

// Register to openMTC data; subscribe to a light control data
reg_openmtc()

//Reading the sensor data and transmit sensor data for the first time
//and send sensor data to openMTC
send_sensor()

// To check whether there is new data in WI-FI. If there is new data,
// Is it an event data from openMTC to control the lights?
while true

//If YES, read the data and change the lights according to the data
if sendsendsensor_timeoutcheck()= true then

// check light sensor data
            new_lightsensor_data ← read_light_sensor()

//Reading the sensor data. Is there any change of more than 50 lux of
//the value from the previous reading? If YES, then send the data to
//openMTC
if|new_lightsensor_data - current_lightsensor_data|>50 then
                    send_sensor()
                    current_lightsensor_data ← new_lightsensor_data
            endif
      endif
if handle_event()= true then
            process_event_data()
            apply_actuator()
      endif
endwhile
end
```

Other than the applications that are placed beside sensors and actuators controlling devices, there is an algorithm which is placed in a server that serves to responds data sent from a sensor and actuator controllers. Here is the algorithm in the server application.

The step of read (event) is executed simultaneously (event driven). If there is data from OpenMTC (via event and not manually reading) on the light sensor data, provide data for web control panel. Then for automation, did the light sensor data pass through the predetermined threshold? If YES then send the light control data to the OpenMTC. If there is data on the web control panel regarding the configuration of the automation, then save the configuration data. If there is data from the web control panel on the lights control data, send the light control data to the OpenMTC.

```
//Initiation and start the server for the web control panel
server <- start();

// Register to openMTC, subscribe to the light sensor data
register_openmtc(sense(u));

// Reading manually light sensor data from openMTC
// for the first time, provide the data to the web
// control panel
if(read(event)){

        foreach(sense(u)){
                web_panel <- u
        }
}
```

4. Testing and Analysis

4.1 Test Bed

The testbed is a limited test environment created to obtain data and insights on the power consumption. The purpose of this testbed is to get an electric power consumption data using both smart lighting system and regular consumption. This testbed used 6 pieces mounted dimmer lights in a laboratory named Unified Communication laboratory. Measurements were carried out for 24 hours with the retrieval of data every minute starting from 23:00 until 22:59. The data taken was electric power consumption by enabling smart lighting systems, and afterward regular data without smart lighting module. The smart lighting module was placed on the wall, as in Fig. 6(a), the room resembles everyday use, with adjustments to the amount of natural light (sunlight) through the window by setting the curtains opened and closed. Fig. 6(b) indicates the position of the lights and light sources. Then the light conditions were taken at various positions to get an estimation the level of lighting when receiving maximum exposure, such as in the scorching daytime. Afterward, the data is taken while the light is on, and when the curtains are closed and when it is fully opened, to get a certain amount of artificial lighting effect produced by LED lamp. Lighting data were taken under the sensor to prevent reciprocal when the lamp is turned on, which will result in the system continuously shifting on and off. Fig. 6(c) shows the position of the sensor. The distance between the lighting level is set up as for the light is on, the reciprocal value of the lighting will not exhibit reverse effect to the level of lighting. Data that has been taken is used to make a decision table of lighting control system that is adaptive to the natural lighting. Table 1 shows the light value mapping.

Fig. 7 shows BH1750 Ambient Light sensor, with a range of 1 to 65535 lux, for a spectral light approach to the human eye. For comparison, blazing sunlight can range from 63300 or more. The sensor itself is an IC that is in the middle of the board, while the other component is a supporting component.

The tools utilized in taking electrical power is a Power and Harmonic Analyzer [20]. This analyzer has ability to measure harmonics and power quality on the device. There are three levels of current measurement. These are 1 A, 10 A, and 100 A. In measurements of smart lighting in Unified

Communication laboratory, the limit of 10 A with a resolution of 0.001 kW is applied. At such resolution, the power reading has an accuracy of +1% +8 W [20]. The reason to apply this resolution is an increase in the peak current, i.e., 2–3 times more than its RMS current, this causes the current exceeding the expected maximum. The use of 1 A of resolution is to anticipate the possibility of data not being properly recorded at a particular time. Measurement in testbed system using both smart lighting system and regular, uses the same current range, which is 10 A.
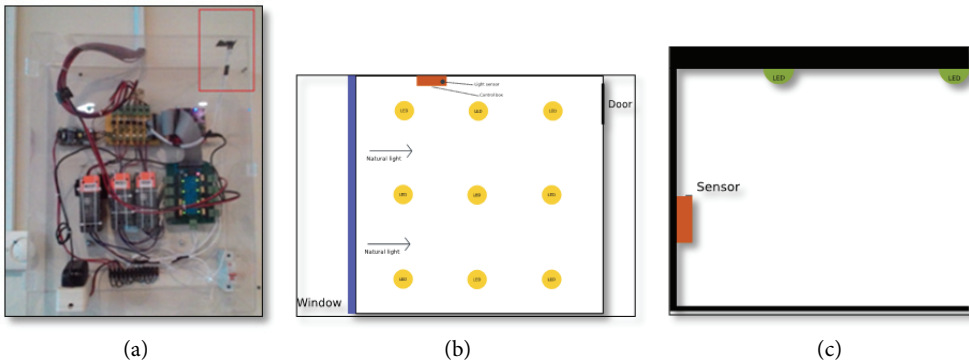

(a)   (b)   (c)

Fig. 6. Test bed of smart lighting indoor module. (a) Module and a sensor, (b) the lights position, and (c) sensor.

Table 1. Mapping of the value of lighting and LED lighting

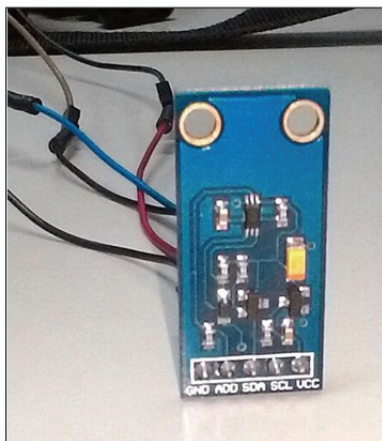| The exposure value (lx)	LED lighting (%)
≤100	100
>100 and ≤150	~80
>150 and ≤200	~72
>200 and ≤250	~41
>250 and ≤300	~25
>300 and ≤350	~9.8
>350	0

Fig. 7. Ambient light sensor BH1750.

The probe is the measuring point of the system to obtain data. The probe is placed between the control box to be measured and the power supply. Fig. 8 shows the spot of probe placement. The number of Probes are three pieces, two pieces for measuring voltage that is arranged in parallel with the phase wires and neutral wires. Meanwhile, the current probe is in clamp shape, mounted on the phase cable.

4.2 Measurement and Data Analysis

Based on the measurements results carried out in one minute duration during 24 hours, measurement of power consumption data with both smart lighting systems as well as regular power consumption is obtained. Fig. 9 shows a diagram of power consumption. Power usage data is retrieved by using the Power Harmonics and Analyzer. Data taken in 1 minute intervals over a span of 24 hours, producing 1,441 pieces of data RMS voltage (V_{RMS}) and the RMS current (I_{RMS}) and its real power. RMS is the Root Mean Square value of voltage or alternating current. V_{RMS} and I_{RMS} are used, since voltage and an alternating current do not have a linear value due to the nature of its sinusoidal. The real power (P) of V_{RMS} (V) and I_{RMS} (I) is expressed as

$$P = \frac{VQ}{t} = VI,$$ (1)

where t is time, and Q is electric charge.

Obtaining the value of current and voltage in the form of RMS is important, particularly for systems working with alternating current (AC) and the nonlinear loads.

Pt is the power (P) measured at time duration t. Measurements were made at intervals of 1 minute. Meaning that the distance from one measurement of Pt to the next Pt measurement is 1 minute.
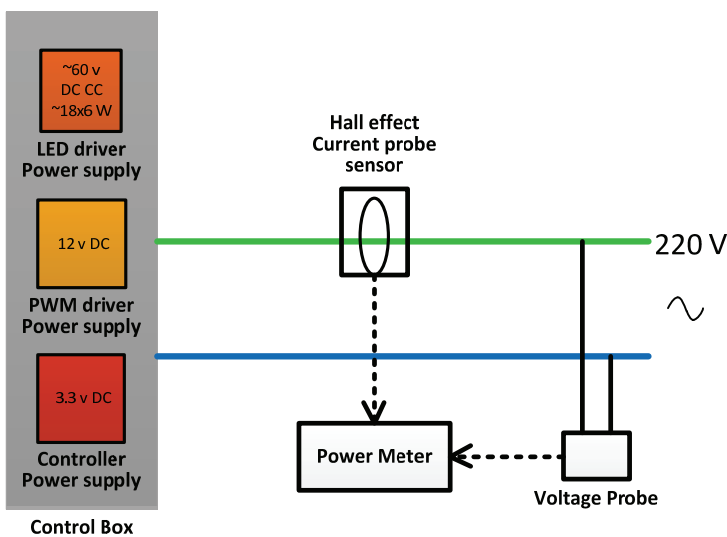

Fig. 8. Placement of probes and power supply.

Attaining Energy

Power (P) is the amount of work per unit of time, which is expressed as

$$P(t) = \frac{E}{\Delta t} \tag{2}$$

where $P(t)$ is power as a function of time, E is energy, and Δt is time interval. From (2), energy (E) is obtained by calculating the integral of power function towards time as

$$E = \int P(t)dt \tag{3}$$

where E is energy, and $P(t)$ is power at time t. To obtain the energy value of a P curve measurement with respect to time, $P(t)$ is unidentified and what is identified is the value of power at each particular interval, Eq. (4) is the limit formula to obtain the value of Energy. Eq. (4) is the integration by summation of Eq. (3).

$$E = \lim_{\Delta t \to 0} \sum_{t=1}^{1440} P_t . \Delta t \tag{4}$$

where E is energy, P_t is power at time t, and Δt is time interval. Limit formula as in Eq. (4) explains that the integral of the power function versus time or $P(t)$ equals to the area or total area under the curve of the function. The size of the area under the curve is obtained by summing the area under every point of measurement. The area under every point of measurement is derived from multiplying the values of Power with an interval of time that the limit of that interval approaches 0 or the Δt. The value of Δt is 1 (in minute) because that is the resolution of the measurement. The result from the calculations is the kilowatt-minutes. To get the value of kilowatt-hour (kWh), the result is to be divided by 60. The general formula of energy to obtain the power utilization per hour is expressed as Eq. (5). Which is derived from Eq. (4) based on the graphic of Fig. 9.

$$E_{total} = \frac{\sum_{n=1}^{1440} P(n)\Delta T}{60} \tag{5}$$

where E_{total} is total energy, $P(n)$ is power at time n, and Δt is time interval. The constant 60 is to convert from minute to hour. From the graphic at Fig. 9, we call the first measurement line P-regular, or the power measurements towards regular lighting system, and we call the second measurement line P-smart lighting, or the power measurements towards the adaptive lighting system.

By inserting Eq. (5) at each measurement, then the result will be E-regular is equal to [E-regular] and E-smart-lighting is equal to [E-smart-lighting].

Eq. (6) shows the calculation for measuring efficiency. Efficiency is the magnitude of the savings gained from the smart lighting system.

$$Efficiency_\% = \frac{E_{regular} - E_{smartlighting}}{E_{regular}} \times 100\% \tag{6}$$
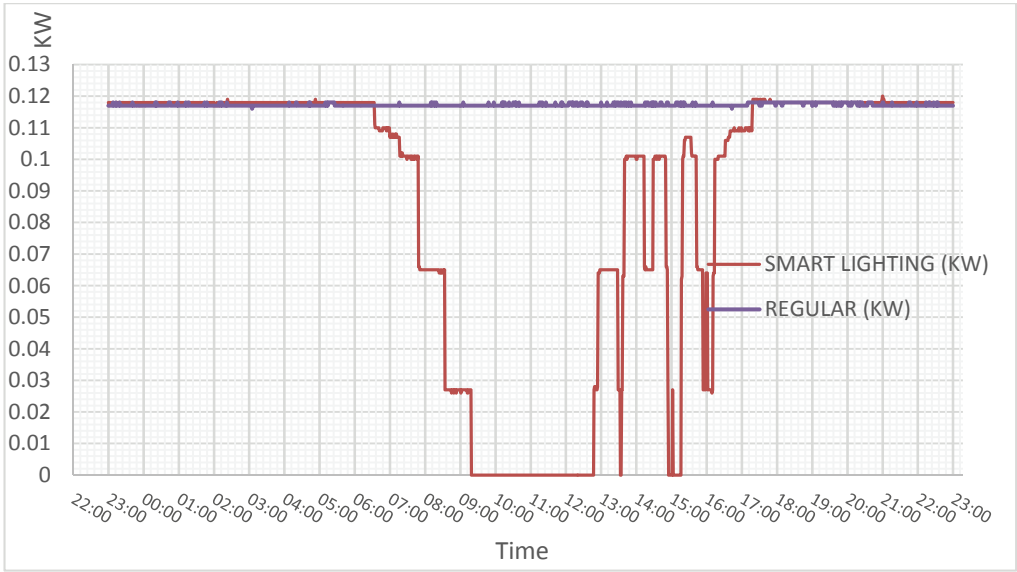
Fig. 9. Regular and smart lighting power consumption measurement data.

where *Efficiency*% is percentage of efficiency, $E_{regular}$ is regular energy consumption, $E_{smartlighting}$ is energy consumption in smart lighting environment. By entering a value E-regular and E-smart-lighting from previous results, the magnitude of the device efficiency adaptive lighting system obtained from measurements on a same light system within 24 hours is obtained.

The total power usage for 24 regular hours was 2,827 kWh while power usage after being given treatment with smart lighting is amounted to 2,114 kWh. Thus, there is a saving as big as 25.22%.

Significance testing of the smart lighting systems influence to energy savings has been carried out by using the Wilcoxon statistical test [21,22]. This test is performed on two data sets that are related to each other. These are electricity usage data before and after the smart lighting systems.

Eq. (7) is used to test the significance of smart lighting systems influence against the reduction of electrical power on the experimental results based on Wilcoxon method [23] as follows:

$$Z = \frac{T - \mu_\gamma}{\delta_\gamma} = \frac{T - \frac{(C+1)C}{4}}{\sqrt{\frac{(C+1)(2C+1)C}{24}}} \tag{7}$$

where Z is score of significance, T is sum of signed rank and C is the number of couples with unequal values, with the following statistical hypothesis:

H0: μ1 = μ2 (No influence of smart lighting systems in to changes of electric power consumption)

H1: μ1 ≠ μ2 (There are influences of smart lighting systems in to changes of electric power consumption)

By applying the two-party test of α/2 = 0.05/2 = 0.025, using the function $f(Z)$, then the curve area of $f(Z) = 0.5 − 0.025 = 0.475$ is obtained. Hypothesis rejection H0 is less than -1.96 or more than 1.96. With

the value of Z = -30.23, then the Z position is identified, that is within the H0 rejection area. This test shows that H0 is rejected, so that H1 is being an acceptable alternative. The null hypothesis (H0) is the hypothesis that states the similarities results between the data before and after the treatment. This hypothesis proves that "there is no influence of smart lighting systems to changes in power consumption" while the alternative hypothesis (H1) proves that "there is influences of smart lighting systems against the changes in power consumption". The test results above indicate a rejection of H0 and acceptance of H1. Thus, it can be clarified that the utilization of smart lighting is influential towards power consumption. The effect is shown by the reduction in power consumption.

5. Conclusions

We have proposed ILES as an enabler to connect smart lighting applications to various sensors and actuators environment. This proposed system simplifies complexity on developing silo smart lighting applications. We perform some experiments for proving this concept. The results show that the total power consumption of regular system is amounted to 2,827 kWh while using smart lighting system the amount of power consumption is 2,114 kWh. There is a reduction in electric power consumption by an average of 25.22%. Based on a significance test using Wilcoxon method for the changes in power consumption, the Z values obtained under the table, -30.23 and -1.96. It indicates the rejection of H0 and the acceptance of H1. Thus, it is concluded that there are significant influences of proposed system for decreasing power consumption.

Acknowledgement

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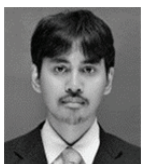
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