Electric Load Forecasting for Internet of Things Smart Home Using Hybrid PCA and ARIMA Algorithm

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***Abstract*—Many types of research have been conducted for the development of Internet of Things (IoT) devices and energy consumption forecasting. In this research, the electric load forecasting is designed with the development of microcontrollers, sensors, and actuators, added with cameras, Liquid Crystal Display (LCD) touch screen, and minicomputers, to improve the IoT smart home system. Using the Python program, Principal Component Analysis (PCA) and Autoregressive Integrated Moving Average (ARIMA) algorithms are integrated into the website interface for electric load forecasting. As provisions for forecasting, a monthly dataset is needed which consists of electric current variables, number of individuals living in the house, room light intensity, weather conditions in terms of temperature, humidity, and wind speed. The main hardware parts are ESP32, ACS712, electromechanical relay, Raspberry Pi, RPi Camera, infrared Light Emitting Diode (LED), Light Dependent Resistor (LDR) sensor, and LCD touch screen. While the main software applications are Arduino Interactive Development Environment (IDE), Visual Studio Code, and Raspberry Pi OS, added with many libraries for Python 3 IDE. The experimental results provided the fact that PCA and ARIMA can predict short-term household electric load accurately. Furthermore, by using Amazon Web Services (AWS) cloud computing server, the IoT smart home system has excellent data package performances.**

***Index Terms*—Hybrid algorithm, internet of things, load forecasting, python IDE, remote control, smart home**

I. INTRODUCTION

The electric load pattern for households is very stochastic, changes frequently, and differs significantly between customers [1]. Household electric load depends on the number of electrical appliances used, the number of individuals living in the house, light intensity, weather, and etcetera [2]. In addition, occupant characteristics also affect the amount of electric load consumed [3]. In a broader context, failure to predict aggregated system load accurately has the potential to cause several impacts (such as the occurrence of transmission congestion phenomena) [4]. Such transmission congestion can create power market inefficiency that should be avoided [5].

Hence, the variety of ways to save electricity is something that needs to be researched using the latest technology developments [6]. One of them is by adding an electric load forecasting feature in the Internet of Things (IoT) smart home system. Turning a residential house into a smart home is a great way to save energy, money, increase work efficiency, automation and security. From the research point of view, investigating the hardware and software integration to predict electric load has been widely conducted. While in engineering practice, there are various ways to develop hardware, algorithms, programming languages, software, and internet platforms as the forming components for IoT smart home systems.

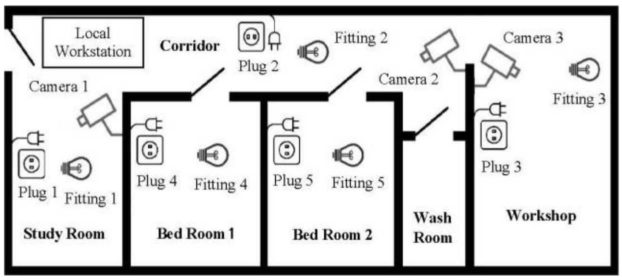

Fig. 1. IoT devices installation based on the residential house plan.

II. LOAD FORECASTING DESIGN

Variables reviewed in this study are the real-time electric current, room light intensity, number of individuals living in the house, weather conditions in terms of temperature, humidity, and wind speed, obtained from https://openweathermap.org. After that, the developed IoT system was tested in a residential house for a month, with the device installation layout carried out as shown in Fig. 1.

Meanwhile, the main IoT hardware components are as follows:

- IoT receptacles and fittings; ESP32 as a low-powered affordable microcontroller [7], ACS712 current sensor, and SSR electromechanical switch.

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- IoT cameras; Raspberry Pi (Raspi) 3 Model B, 5 megapixels RPi Camera (E) with night vision infrared Light Emitting Diode (LED) and Light Dependent Resistor (LDR) sensor.
- Local workstation; Raspi 4 Model B, XPT2046 10.1 Inch Liquid Crystal Display (LCD) touchscreen and keyboard with an integrated touchpad.

The additional software and libraries in this design include:

- Arduino Interactive Development Environment (IDE) for ESP32 microcontroller. One of the options for programming is by connecting the computer via a mini USB data cable [7].
- Visual Studio Code (VSCode) as Python program and interface developer on the local workstation and internet website. The program can be developed with mouse-driven and is highly efficient to create program helper objects and internet applications, programs testing or debugging, and to produce ready-to-use programs.
- Raspberry Pi OS as Debian GNU or Linux-based Raspi operating system. One of the options for OS operation on the Raspi controller is by connecting the computer via Ethernet (LAN) cable [8].
- Python 3 IDE as Python-based applications developer on the Raspberry Pi OS. The user can choose two approaches to carry out the programming process [9]. The first approach is by using a text editor for scripting and executing. Then the second one is by using interactive prompts such as IDLE, IPython, and Thonny.
- Open Sources Computer Vision (OpenCV) 4, TensorFlow (for numerical computation using data flow graphs [9]), and Yolov3-Tiny as Python libraries for real-time image processing [10].
- Scikit-Learn (Sklearn) and Pmdarima as Python libraries to facilitate electric load forecast calculations.
- Matplotlib as Python library for numerical data visualizations in two dimensions (cartesian), three dimensions, or categories-based charts.

In addition, the internet platforms used in this research include:

- GitHub as a shared web service for software development using Git version control system and data storage service (hosting). This application is very popular and widely used by large companies such as Facebook, Google, and Twitter.
- Amazon Web Services (AWS) as permanent data storage on the internet server, content delivery, and other functionality based on cloud computing.

Meanwhile, from the forecasting point of view, various algorithms can be used [11]. Among them are Principal Component Analysis (PCA) and Autoregressive Integrated Moving Average (ARIMA). PCA is a technique to simplify data using linear transformation to form a new coordinate system with maximum variance. PCA is used for simplification without significantly reducing the data's characteristics, thereby making it easier for interpretation [12], while ARIMA is a non-stationary model [13]. The use of ARIMA in short-term forecasting is very precise and accurate, but the accuracy for long-term forecasting is poor [14].

Mathematically, ARIMA consists of three elements combined into one, namely Autoregressive (AR), Moving Average (MA), and Integrated (I). The general form of this method is ARIMA (p, d, q), where p, d, and q denote the AR process degree, order of integrated differentiation, and MA process degree, respectively. The ARIMA model consists of three basic steps, namely the identification stage, the assessment and testing stage, and the diagnostic examination [15]. It is expected that the PCA and ARIMA hybridization provides calculation results that combine the superior properties of the two methods.

III. System Development

IoT is a concept in which an electronic object can transfer data over a network without requiring human-to-human or human-to-computer interaction [16]. While a smart home is a house whose electronic devices are connected to the IoT network to enable all household functions to be controlled wirelessly [16]. Fig. 2 shows the IoT system design developed in this research.

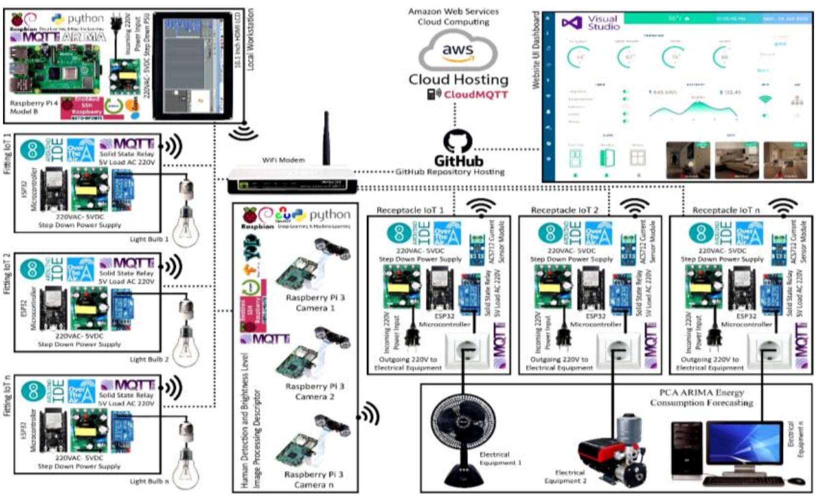

Fig. 2. IoT system design.

The hybrid PCA and ARIMA algorithm programmed in the cloud server and local workstation illustrated in Fig. 3. Fig. 4 shows the IoT camera algorithm. Having interconnected the Raspi 3 Model B with infrared LED, the camera will work both in bright and dark conditions. Added with OpenCV 4, TensorFlow, and Yolov3-Tiny, the cameras will acquire real-time datasets of light intensity and the number of humans detected. Furthermore, Fig. 5 shows the IoT receptacle algorithm. Not only used for on and off command, but the receptacle also can acquire real-time datasets of electric current using ACS712 sensor. While Fig. 6 shows the IoT fitting algorithm. Users can command the lightbulb to turn on and off remotely and watch the light intensity changing via IoT camera video. But there is no ACS712 sensor installed since the lightbulb is considered to consume a low electric load.

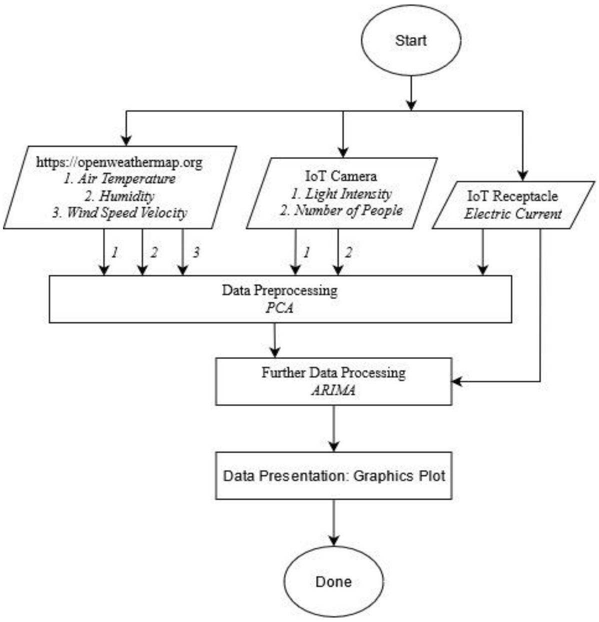

Fig. 3. Hybrid PCA and ARIMA algorithm.

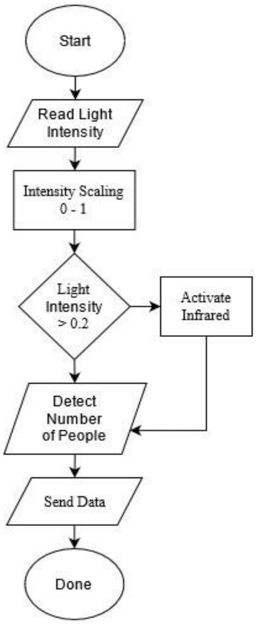

Fig. 4. IoT camera algorithm.

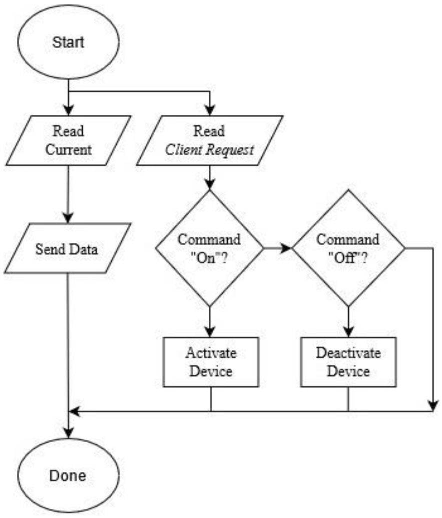

Fig. 5. IoT receptacle algorithm.

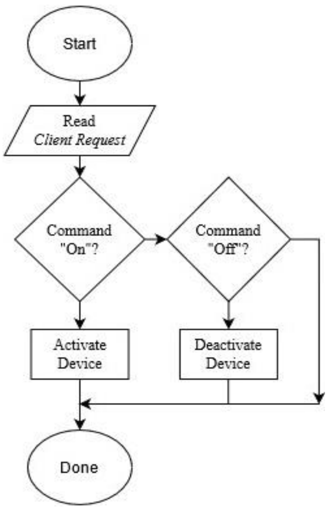

Fig. 6. IoT fitting algorithm.

And for hardware development, Fig. 7 shows the local workstation prototype. When the IoT function fails, the local workstation will act as the cloud computing and website interface backup via a private intranet network. Furthermore, Fig. 8 shows the IoT camera prototype. The Rpi camera (E) connected to Raspi 3 Model B using Camera Serial Interface (CSI) 22 pin ribbon cable. And the LDR sensor is connected via a General Purpose Input/Output (GPIO) pin.

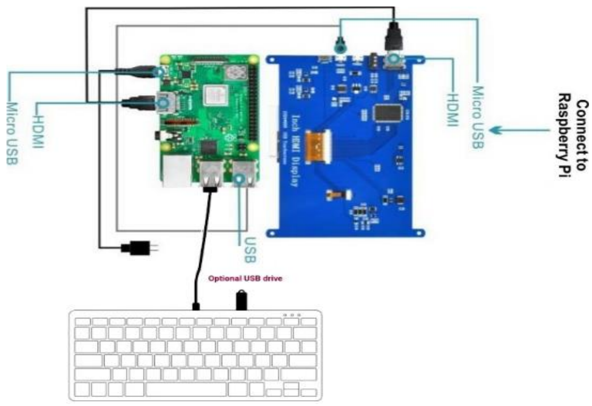

Fig. 7. Local workstation prototype.

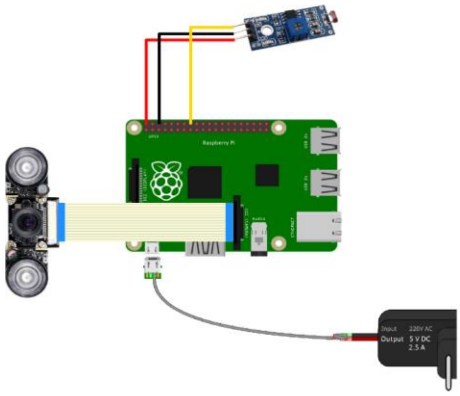

Fig. 8. IoT camera prototype.

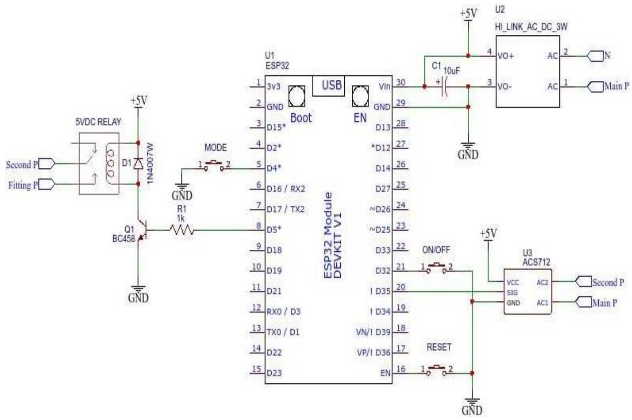

Fig. 9. IoT receptacle prototype.

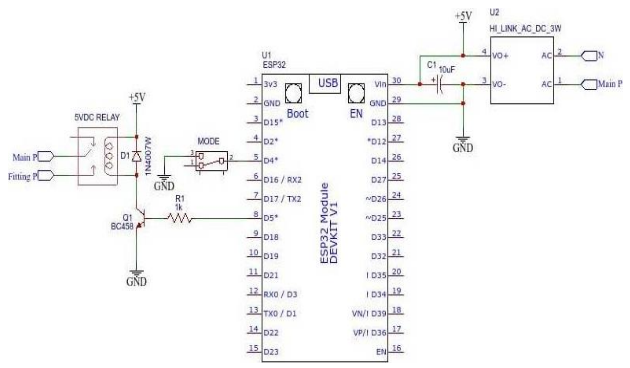

Fig. 10. IoT fitting prototype.

Moreover, Fig. 9 shows the IoT receptacle prototype. The receptacle is connected to 220 voltage sources. While the other end is connected to the male plug of household electric appliances that want to be monitored and controlled via the internet. Additionally, Fig. 10 shows us IoT fitting prototype. The lightbulb monitor and control is integrated through the website interface and its activation affects the number of light intensity variables as one of the electric load forecast datasets.

To facilitate remote revision, Over The Air (OTA) and Secure Shell (SSH) features are used on all types of hardware for updating, reconfiguring, and distributing programs over the internet. Then to optimize the data exchange efficiently, reduce the size of the data packet as small as possible, minimize the storage and machine-to-machine (M2M) computing processes; and the Message Queue Telemetry Transport (MQTT) protocol is used [17].

Fig. 11. Website interface development.

The interface information displayed on the landing page as per Fig. 11 include:

- Selection button that contains hardware list for each room
- Numeric column that shows weather condition around the residential house
- Amount and type of all hardware installed
- The total amount of the electric load
- Image frame of real-time video broadcasts recorded
- Number of people and average light intensity detected
- Table column that shows event history of all hardware over the last 24 hours
- Graphics pop-up click button that shows total people detected and average light intensity over the last 24 hours
- Graphics pop-up click button that shows weather condition around the residential house over the last 24 hours
- The numeric column that shows performance results of the IoT system
- Graphics pop-up click button of the electric load over the last 24 hours added with its (next day) forecast and accuracy.

IV. Results and Analysis

A. Forecast Accuracy

The next day forecast calculation compared with the actual amount of electric load is shown in Fig. 12. To evaluate the accuracy, MAE, MSE, and MAPE numerical calculations were used. Mean Absolute Error (MAE) is defined as validation of the suitability of the absolute forecast error average regardless of its positive or negative orientation. Meanwhile, Mean Square Error (MSE) is defined as validation of the suitability of the squared error forecast. However, MAE and MSE do not facilitate comparisons between a series of different scales due to different time intervals. Therefore, to solve these limitations, Mean Absolute Percentage Error (MAPE) was added. MAPE below 10% is considered a very accurate forecast. Whereas, MAPE between 10-20% is considered good. MAPE between 20-50% is interpreted as a reasonable (feasible) forecast. And MAPE more than 50% is considered not accurate [18]. The MAE, MSE, and MAPE values in Fig. 12 are 0.098, 0.004, and 9.81%, respectively.

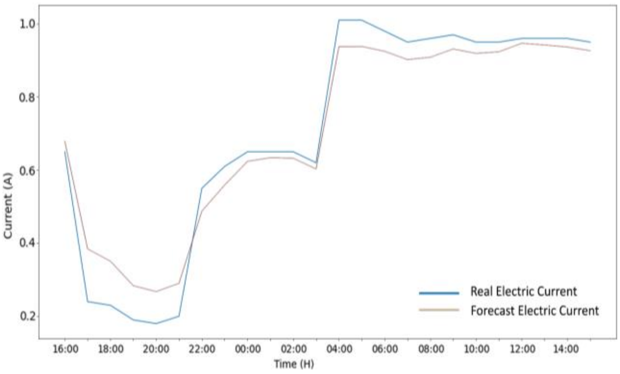

Fig. 12. Real time electric load with its next day forecast results.

B. Performance Testing

In this research, the data transmission was carried out 7433 times a day (24 hours) for a month. Then four analyses are used to test the IoT system performance, namely latency, throughput, reliability, and availability (using amazonaws.com as MQTT broker). Latency or delay is the time needed to transfer the data package from the origin to the final destination in milliseconds (ms) [19]. Throughput is the effective data transfer rate or the total number of a successful data package arrived that observed at the final destination during a specified time interval in bits per second (bps) [19]. Reliability is the percentage probability of a device performing a satisfied predetermined task for a certain period under certain conditions [20]. Meanwhile, availability is a metric used to assess the percentage possibility that the system can operate and perform its functions at a certain time [20].

The use of AWS cloud computing server led to 83.11ms latency, 360.99bps throughput, 99.765% reliability, and 99.766% availability in IoT smart home system. The latency and throughput results can be categorized according to ETSI TIPHON TR 101 329 Quality of Service (QoS). While the reliability and availability results can be categorized according to ISO / IEC 25010.

V. Conclusion

This work designed an electric load forecasting with the development of microcontrollers, sensors, and actuators, added with cameras, LCD touch screens, and minicomputers, to improve the IoT smart home system. The IoT receptacles and fittings succeeded to control and monitor electrical appliances via a web interface remotely. Meanwhile, the IoT cameras succeeded to publish images, process image information, and display video via a web interface remotely. Added with the local workstation (as cloud computing backup) also succeeded to perform forecast calculation, devices control and monitor via private intranet network. Whereas, the PCA and ARIMA provide a very accurate short-term forecast for the household electric load. Moreover, the IoT smart home system performance provides excellent data package transfer speed and delivery.

Conflict of Interest

The authors declare no conflict of interest.

Authors Contributions

Hamdi W. Rotib executes hardware and software development according to research purposes and wrote all documentation report; Muhammad B. Nappu acted as the project leader to ensure excellent research result; Zulkifli Tahir acted as the software development supervisor; Ardiaty Arief acted as the mathematics method approaches advisor; Muhammad Y. A. Shiddiq assists hardware and software development execution according to user requirement.

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