

The design of a smart home controller based on ADALINE

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ABSTRACT

This paper proposes a prototype of an improved smart home controller that implements a neural network-based algorithm for enabling the controller to make decisions and act based on the current condition. Unlike previous approaches, this design also utilizes the use of IoT (internet of thing) technology and neural network based-algorithm for developing the controller. Since a smart home is equipped with various sensors, actuators, smart appliances, and mobile terminals, all of these devices need to be connected to the Internet to be able to communicate and provide services for its occupants. The construction of the proposed controller is carried out through several procedures, i.e. the implementation of the ADALINE (adaptive linear) as the neural network method, the design of the smart home controller prototype, and the validation process using mean average percentage error (MAPE) calculation. This prototype integrates functionalities of several household appliances into one application controlled by a smartphone. ADALINE is applied as an algorithm to predict output when the controller is in automatic mode. Although the obtained accuracy value is still not satisfactory, the value is bound to change when testing on more data. The work published in this paper may encourage the implementation of smart technology in more households in Indonesia.

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1. INTRODUCTION

In recent years, the advances of hardware and computing technologies have driven the smart technology further in our life. One example of the implementations is the smart home, or also known as the automated home. A smart home can be defined as a house which incorporates smart objects and devices that can send information and is equipped with the ability to connect to the Internet [1]. Almost any of the electrical devices within the house can be included in the system. This technology does not simply turn the devices on and off, but it should be able to sense the surroundings and the activities of the occupants. Based on that observation, it can act independently in predefined patterns or as the user's requirements. Other definition of a smart home is an application of computing and information technologies, that involves incorporating smart objects and connections to the outside world, in which home environment is monitored to provide services for its inhabitants and facilitate remote home control [2, 3]. This technology can be achieved via wired or wireless systems.

The main goal of smart homes is to promote comfort and convenience for their occupants, whether they are inside or outside the house. In reference of several literatures, the more detailed objectives of smart home technology are as follows [4-7] :

- Controlling home appliances via application using any device capable of wifi,
- Securing connection channels between application and the embedded system,
- Streaming real-time video from web camera,
- Providing extensible platform for future enhancement,
- Promoting energy efficiency, and
- Providing home safety.

Smart homes safety and energy efficient features accentuate their importance in today's smart technology era. The electricity consumption is expected to decrease when smart home is implemented. Although the study about the relation between smart home and the energy consumption is still at an early stage, one report from Singapore shows the reduction of the energy consumption by 20% after implementing smart technology [7]. This can be achieved by developing a system that is able to control the use of the appliances around the area automatically based on the current conditions, for example: switching off appliances if no one in the house, adjusting the output of fan based on the temperature sensors' readings, etc [5], and to monitor the electricity consumption of the house. A smart home is also expected to provide safer environment for children, older people, and people with special needs [6].

Smart home is widely associated with IoT (internet of things) as it is one example of IoT [8]. IoT provides devices, in smart homes, that are originally not connected to any network to be connected to the internet, thus can be monitored and controlled remotely by users. An interface, which is also known as an embedded system, is needed to enable the connection between devices and the Internet. Several designs of an IoT embedded system for a smart home model were proposed. One of the designs used RaspberryPi and NodeMCU. The prototype was equipped with several sensors for examining the temperature, rain, and detecting whether there is any suspicious movements in the house [9]. Another design used ATmega16 and AndroidApp as its main controller [10]. Several researches have discussed more fundamental issues on IoT-based smart homes, such as about connectivity and security. Communication problems exist as the integrated devices use sensors and other networking components came from different manufactures, models, and standards [11-13]. The heterogeneity of devices and appliances connected in smart home system leads to lack of compatibility [14, 15]. The dynamic nature of smart home environment and the number of traffic generated from different devices connected to IoT also become issues in this research area [16-18].

The implementation of an algorithm in a smart home is needed to enable it to make rational or smart decisions. Certain algorithm can be used to predict next events based on the frequency of occurrence, thus giving the smart home controller the capability to target the next particular events for automation [19]. Other method is based on fuzzy logic [20]. Other studies in many research areas implement neural network based algorithms to achieve more accurate control [21-23]. The neural network based algorithms are implemented in smart residential homes for recognizing and predicting the activity of the inhabitants. Smart homes may learn the habits of the residents, make inferences about the preferences and then take automated decision [21]. One of the studies implements artificial neural network (ANN) in home energy management scheduling controller for finding the optimum rate and the best value of neurons. The designed controller aims to on and off the household appliances automatically and the obtained result shows a reduction of electricity consumption, thereby reducing green house gas emissions and allowing energy conservation [23]. Research conducted by Taherkhani et al. uses deep convolution neural network. The research implements the method for recognizing daily living activities from multi modal data collected from a smart residential home. The training process employs dataset that consists of accelerometer data, video, and passive infra red sensor data [24].

Some of the research mentioned above have discussed the use of neural-based method in a smart home, however its implementation in hardware is not addressed. Thus, the proposed prototype of smart home controller presented in this paper will be discussed based on its method and its implementation. ADALINE algorithm is chosen as the algorithm for predicting actions that should be performed by the electronic appliances or devices connected to the smart home system. This method is known for its suitability to be applied for practical applications because of its simple structure on combining the properties of adaptive systems, linear activation function and the Least Mean Square rule [25]. The designed prototype is used to control home lightings, change the speed of fans based on the temperature, choose TV channels, and to activate the smart clothline. The hardware requirements for the prototype include Raspberry Pi, Arduino, relays, motors and various sensors, e.g. sensors for detecting motion, temperature, and water. More than one microcontroller is employed so that processing loads and generated traffic from different devices and sensors can be shared. The smart system can be monitored and controlled using smartphones, that work via 2 modes, i.e. manual and automatic (auto).

2. RESEARCH METHOD

Figure 1 illustrates the framework of the research. It shows three indicators, i.e. temperature, rain and light. The indicators are obtained from the sensors readings of smart home system controller and serve as the inputs of the prototype. Rain indicator is obtained from the water sensor, the light indicator is obtained from the LDR sensor and the temperature indicator is obtained from the temperature sensor. The values from the sensors calibrated and processed using ADALINE algorithm.

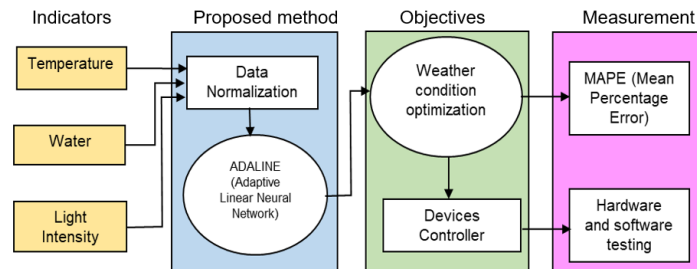


Figure 1. Research frame work of smart home controller using ADALINE

The adaptive linear neural network (ADALINE) is used to estimate, based on the sensors readings, the conditions faced by all connected appliances, so that the smart controller can act accordingly. This method is known for its suitability to be applied for practical applications because of its simple structure on combining the properties of adaptive systems, linear activation function and the Least Mean Square rule. It is often used for prediction and noise cancellation [25]. ADALINE can be illustrated as a neural system that consists of multiple nodes. Each node takes multiple input process and produces a single output. It was started as a single neuron structure developed by Bernard Widrow in 1959. ADALINE method is used to get an artificial nervous system model into a system [26]. The Structure of ADALINE, as shown in Figure 2, defines that the system inputs are calculated using an adaptation algorithm and multiplied by the weights. The output is processed by the linear activation function. As the activation function is linear, the output will be equivalent to linear combination of the inputs.

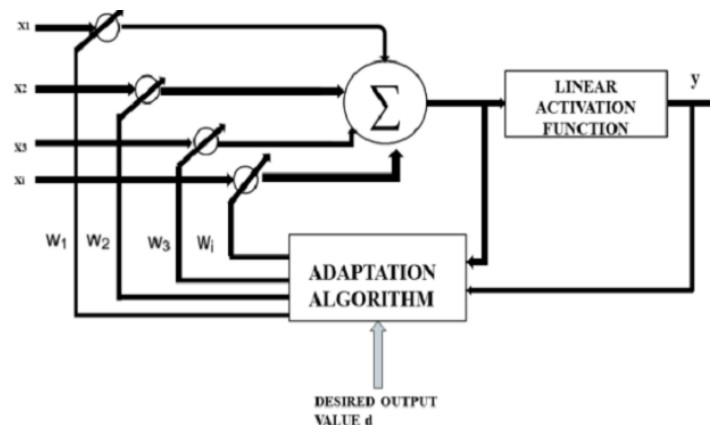


Figure 2. Structure of ADALINE for smart home system controller

For implementation of ADALINE, data from sensors (inputs) are collected and organized into a data matrix, that is often referred as a knowledge base. In ADALINE, input (X_i) is multiplied by the modified weight (W_i) and then summed by the summation unit (the output neuron). The approximate output (y) is compared to the target, and the resulting error (e) is used by the least mean square-based learning algorithm to train the weight of the neural network. The training algorithm for ADALINE is as follows:

- a. Weight initialization
- b. Learning rate (α)
 - Usually a relatively small value is used, which is 0.1.

- If the value is too large, the learning process does not reach convergence.
 - If the value is too small, the learning process will run very slowly.
 - Practically, the value of learning rate is determined between $0.1 \leq \alpha \leq 1.0$, where n is the number of input units.
- c. Practically, the value of learning rate is determined between $0.1 \leq \alpha \leq 1.0$, where n is the number of input units. Repeat until according to the conditions of stop criteria.
- For each pair of s, t do:
- Set input activation: $X_i = S_i$
 - Calculate

$$y = b + \sum X_i W_i \quad (1)$$

where:

y = output

b = biased value

X_i = input data

W_i = weight value

- Update bias (b) and weight (W_i)

$$b' = b + \alpha (t - y) \quad (2)$$

where:

b' = new biased value

b = old biased value

α = learning rate

t = target

y = output

$$W_i' = W_i + \alpha (t - y) X_i \quad (3)$$

where:

W_i' = new weight value

W_i = old weight value

α = learning rate

t = target

y = output

X_i = input data

Meanwhile the testing algorithm for ADALINE is:

- a. Weight Initialization (v). Obtain the weight from the learning process.
- b. For each bipolar input in x vector:
 - Set activation of the input unit x_i ($i = 1, \dots, n$)
 - Calculate the network value (net) from input to output

$$net = b + \sum X_i W_i \quad (4)$$

where:

net = network value

b = biased value

X_i = input data

W_i = weight value

- Apply activation function:

$$y = f(net) \begin{cases} 1 & \text{if } net \geq 0 \\ -1 & \text{if } net < 0 \end{cases} \quad (5)$$

where:

y = output

net = network value

Biased value (b) and weights (W_i) calculation are performed using MATLAB as shown in Figure 3. The activation function calculation for controlling a fan, for example, using 3 categories: cool (W_1), moderate (W_2), hot (W_3) and 1000 iterations produces the following weights and biased value: $W = [0.28571 \ -0.14286 \ 0.28571]$ and $b = [0.14286]$. The resulting activation function is, then, embedded in the microcontroller (Arduino). Figure 4 shows the system design block diagram consisting of several smaller system blocks that are used to interconnect :

- Raspberry, used as a mini server to bridging web server and set of tools that must be controlled.
- Apache WebServer, used to store web applications to control smart home devices consisting of air conditioners, lights, TV channels, and smart clotheslines.
- Access point, used to receive data sent by a computer through a wireless network, so the microcontroller will run the process of executing commands from the application program that has been created.
- Web browser, used as controllers to control smart homes consist of air conditioners, lights, TV channels, and smart clotheslines.
- Arduino Microcontroller Circuit, used to receive data sent by raspberries, so the microcontroller will execute the process of executing commands from the application program to be created.

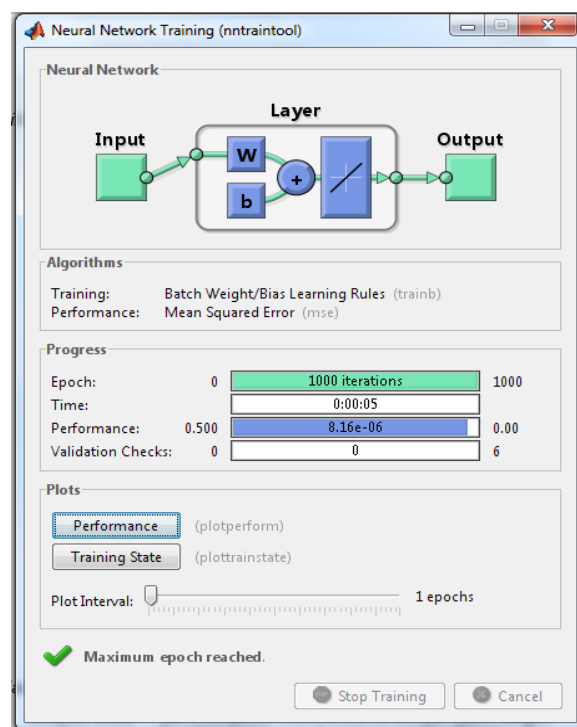


Figure 3. ADALINE calculation using MATLAB

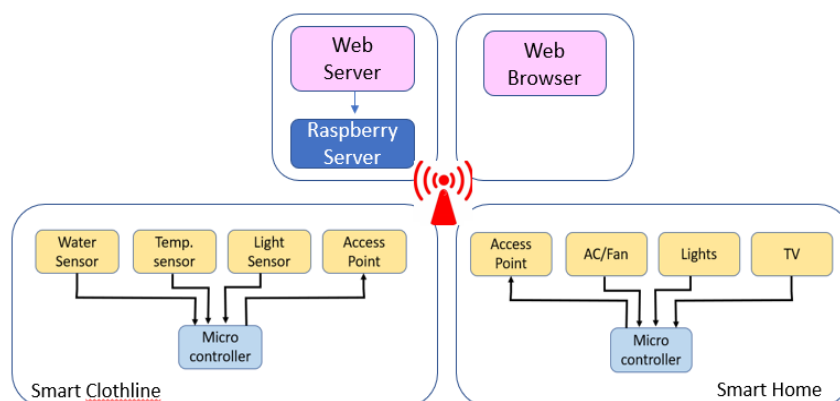


Figure 4. Smart home controller's block diagram

Figure 5 shows the circuit design of smart home system controlled by access point for intranet network and raspberry as web server. The smartphone is used as the client that is able to turn the lights on and off, change the speed of FAN (or air conditioner), choose TV Channels, and to control the smart clotheslines. The client performs this process by retrieving data to open the HTML5 framework from the Raspberry server computer, both of which are connected to the access point. After that the android client processes the turn on and off lights, AC, TV Channel, smart clothes by pressing the ON button on the interface and sending this command to the access point then received by the server. The server gives the command to the Ethernet Shield then passes it to the microcontroller, the command is received by the relay and the light will turn on.

The circuit requires of two chips of Arduino and one chips of Raspberry as the microcontrollers. One Arduino is to control the automation of lightings, fan, and TV. The other is used to operate the smart clothline. The Raspberry serves as the server of data sent by the smartphone client, then forward the command to the devices via the access point. Access points work as an intermediary between hardware (devices) and software in the process of controlling the appliances.

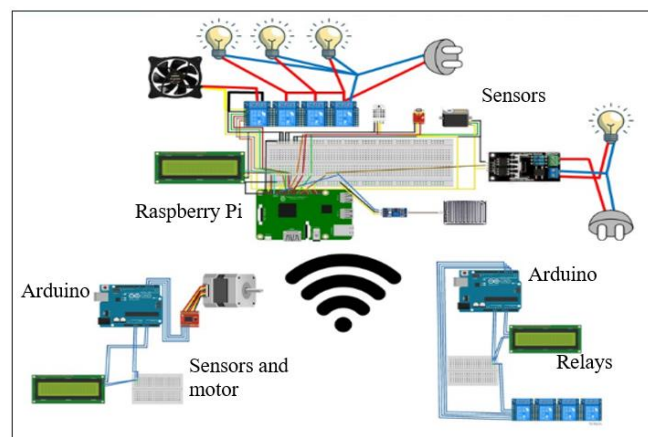


Figure 5. The circuit design of smart home system controller

3. RESULTS AND DISCUSSIONS

The functionality test has been conducted to verify that the system can perform as expected. The configuration of this device begins with the delivery of command to the smartphone browser. If the command is given by a smartphone client, it will be received by the Raspberry server through the Access Point (AP). If the user wants to access the Ethernet Shield it will be forwarded to the Ethernet Shield through an Access Point (wireless). The command sent to the Ethernet Shield is in the form of a data address (IP address) which is then accommodated by an Arduino microcontroller. This is where the command will be executed before forwarded to the relay or other appliances.

3.1. Results

The Figure 6 (a) shows the prototype of the smart controller and Figure 6 (b) shows the controller of a smart clothline or other household appliances. The Arduino Mega 2560 is used to control the lightings, a fan, and relays that can be connected to TV or AC (Air Conditioner). The operating system used in this prototype is Raspbian, a Debian Linux base. To enable the Raspberry to become the server, webservers, PHP, and MySQL are installed. The web server that have been used is Lighttpd, PHP is installed as the scripting language, and MySQL is implemented as the database server.

The controller for smartphone application is shown in Figure 7 and Figure 8. The main menu for the application as shown in Figure 7 (a) consists of two main buttons for enabling or disabling the smart system. The first button connects to the Arduino controlling the lightings, TV channels, and a fan. The second one activates the smart clothline. When users want to use the controller manually, they should choose to enable condition. The setting menu in Figure 7 (b) is used when the system is in manual mode. Through this menu, users can control the TV channels, the lightings, and the fan, and adjust the appliances according to their needs. Figure 8 shows the menu for controlling the smart clothline. Periodic report about the weather condition outside the smart home is also provided when users press the repor button. The informations displayed on the report are the date, time, temperature, light intensity, and rain detection. The status of the smart clothline: whether it is outside or inside is also shown.

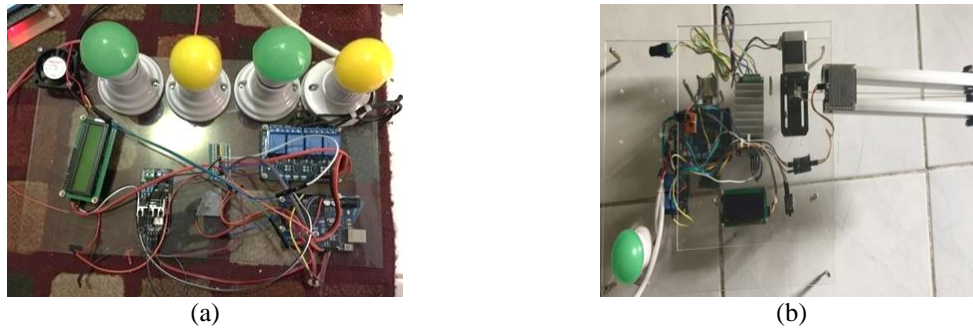
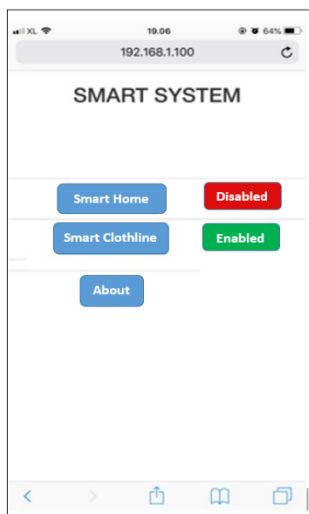
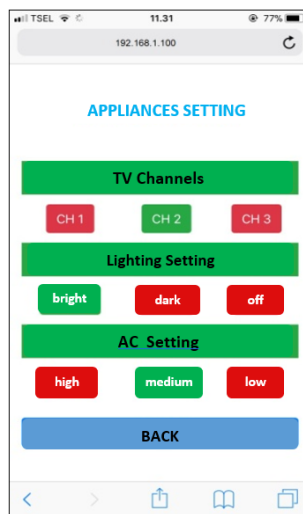


Figure 6. The smart home system controller prototype; (a) lighting and fan controller, (b) clothline controller



(a)



(b)

Figure 7. Smart home controller application; (a) menu, (b) appliances setting

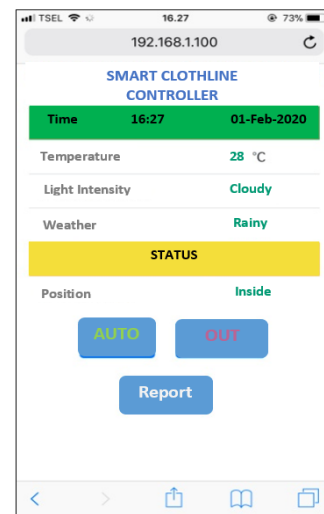


Figure 8. Menu for controlling smart clothline via smart phone

System validation testing uses the method of accuracy, as shown in Table 1 and Table 2, by comparing data obtained from calculation to the actual data. In this validation testing, the author uses 5 input data as the actual data then 5 data are tested using the ADALINE algorithm. Normalization steps have been taken and the data is ready to be entered into the ADALINE artificial neural network. This research uses the neural network tool (NNtool) in the MATLAB application and begins to build a network by training on input data and target data. Before starting the training process, it is important to know that the artificial neural network needs to have some input data, such as training data matrix, target data matrix and test data matrix/training data. To create a training data matrix, a knowledge base is needed to translate the indicators that have been determined. The knowledge base consists of a matrix of indicators, such as the intensity of light and rain detection. For example, as shown in Table 1, there are 5 inputs for each sensor as the indicators. These values are obtained from the normalization of input data. The data is used to be processed using the ADALINE algorithm which is adjusted to the training data matrix and the target data in the previous table.

Table 1. Real data in smart home testing

No	Light intensity (lux)	Rain intensity (mm)
1	56	88.5
2	56	89.75
3	56	89.25
4	56	90
5	56	88.75

Table 2. ADALINE's smart home testing data

No	Light intensity (lux)	Rain intensity (mm)	MAPE
1	173	120	1
2	173	200	0
3	240	230	1
4	290	300	0
5	360	570	0
		Total	2

From ADALINE's value, it can be obtained MAPE values using equations as shown below:

$$MAPE = \frac{100\%}{n} \times \sum \left| \frac{x_t - Ft}{x_t} \right| \quad (6)$$

$$MAPE = \frac{100\%}{5} \times 2$$

$$MAPE = 40 \%$$

Then the value of the accuracy of calculations with the ADALINE algorithm can be seen as follows :

$$Accuracy = 100\% - MAPE$$

$$Accuracy = 100\% - 40\%$$

$$Accuracy = 60 \%$$

Although the accuracy value obtained when applying the ADALINE algorithm is only 60%, but the value is bound to change when testing on more data.

3.2. Discussions

Figure 7 indicates that by using smart home system controller, some home household devices can be integrated in a regulatory system that implements IoT and the Neural Network algorithm. This is a significant improvement, because to date, the best achievable results is several household devices can't work automatically using a Web-based application. The neural network based smart home system controller will make home appliances easier to control and can be monitored continuously. Moreover, it will modernize the current working process and optimize energy saving. Web browser based application technology can be used to control any tools that setting manual or automatically.

4. CONCLUSION

This paper has argued that neural network algorithm namely ADALINE can be implemented to control household appliances as smart home controller. This study has identified that ADALINE is used when the system works automatically based on the readings of the existing sensors. When in manual mode, this system can be controlled via smart phones that act as remote controls. To enable the operation of this prototype, several microcontrollers are required. Some microcontrollers are used as controllers, some act as servers. Web browser is needed to control all the media connected to the smart system. Integrating web-based components and applications is expected to increase the flexibility (for users) in controlling the household appliances. Furthermore, automatic controller of household devices based on sensor readings is expected to increase the efficiency of electricity usage. The observations from this study suggests that it is possible to improve the hardware design. It is required to meet the standards to be a device that is ready to use higher capabilities components and sensors are required so that the performance of the controller can be better in the future. Further work needs to be done to develop as an Android-based household device controller.

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