Performance Evaluation of Elderly Home Automation Control (EHAC) IoT System

Karsten Cheng Kai Phua[1†] and Wei Wei Goh[2††], Mohsen Marjani[3††]

Taylors University, Subang Jaya, Malaysia

Summary
As the number of elderly is increasing rapidly every year, many elderly still choose to stay independently despite difficulties and challenges faced in their daily routine. The elderly have desperate needs to support their daily life. Internet of Things (IoT) helps to support and improve elderly's life in many ways to meet their life's needs and requirements. Home Automation Control (EHAC) is a research based system that supports the elderly with a controlled automation solution that controls and operates various home electrical appliances based on the measurement of heart pulse rate and environment temperature. This paper works on EHAC system to evaluate the performance of an Internet of Things based system in elderly's daily routine. This paper presents the experiments that are conducted to test the proposed IoT based system and provide discussions on the analysis of the results. The EHAC system was deployed into pilot test to measure the effectiveness and performance of the EHAC algorithms. The test result reveals 0.0239% of error in the accuracy of pulse rate and validation index of 1 in three iterations. The outcome of this paper is to validate the test results from the IoT testing on EHAC system. This study is limited to the scale of the elderly, future work could be done to explore how EHAC algorithms could be useful to the disabilities as they share similar problems and challenges of physically challenged and enhancement of EHAC system with additional functions based on the testing results. This paper contributes towards the healthcare industry by introducing an innovative solution that allows the elderly to control home appliances using their pulse rate.

Keywords:
Internet of Thing (IoT), Testing, Elderly, Automation, Sensors

1. Introduction

The number of elderly in Malaysia has rapidly increased every year. According to the department of statistics Malaysia, the population older than 65 years had increased 1.4% from 2014 and accumulative of 7% of the share of the Malaysian population in 2020 [1]. There are numerous issues faced by the elderly due to decreasing their abilities. Basic tasks such as controlling home appliances become too difficult to perform due to physical conditions [2]. Despite all these challenges, many elderly still choose to live independently in their own home. There are a lot of works to be considered and the long term is needed to meet the daily requirements of the elderly. Internet of things (IoT) is a new approach of the technology for elderly. Internet of things can help to support and improve the elderly's life in many ways to meet the needs and requirements.

Today the internet has become ubiquitous. It has become an essential part of human life and influencing human life in unimaginable ways. However, the journey is yet to come to an end. Human beings are moving towards an era of pervasive connectivity where even more variety of objects and appliances can be connected through the internet. "Internet of Thing (IoT) was first introduced by Kelvin Aston in 1999 as "we need a standardized way for computers to understand the real world". Aston further described that physical objects can be connected all around the world through the internet via sensors at anytime and anywhere [3]. The term "IoT" has been defined by different researchers in different ways. Patel et al described IoT as a network that allows anything to be connected to the internet through the stipulated protocols with information sensing equipment to conduct, exchange, and communicate information to achieve smart recognitions, positioning, tracing, monitoring, and administration [4].

There are many commercial IoT devices that were developed for the use of the elderly; however, the lack of user-friendly design of the devices has made it uncomfortable for the elderly to wear for a long duration. Despite these challenges, there are various study has been done by researchers on the ubiquitous computing in the healthcare. Boo-Ho Yang et al had proposed a ring-sensor to monitor the elderly's pulse rate for 24 hours however it has not been commercially produced [5]. Surantha et al had proposed a "sleep apnea monitoring" solution to ensure that the elderly have quality sleep duration by reviewing the sleep quality problem and the importance of sleep quality monitoring [6].

According to Ananda et al, the authors had proposed a solution that controls the home appliance based on voice recognition. However, the lack of accuracy and misinterpretation shows the downside of the system [7]. Ahluwalia et al suggested that the long-term care of the

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elderly can be improved through the support of IoT to increase the elderly's comfort and safety at home to stay independently [8].

As IoT advances, some testing and experiments are required to ensure the high performance and effectiveness of the operation. In one study, ten commercial wearable fitness devices were examined and conducted a comparative analysis to a research grade pedometer. The test results reveal that seven out of ten devices show a similar output while five show a relatively close output with the research-grade device [9]. Another comparative study was carried out to compare the step count and total daily energy expenditure (TDEE) of seven commercial wearable fitness devices and two research-grade devices for 48 hours of time frame. The comparative study shows that the commercial device shares a strong correlation with the research grade in terms of the measurement of step count, however, the TDEE was underestimated. IoT testing is described as testing tools to evaluate the overall performance of an IoT based system, and an IoT system needs to meet several criteria to be usable, such as usability, reliability, data integrity, security, and performance [10]. Usability measure the interaction between the system and the elderly, reliability represents the degree of probability the system perform correctly in a certain time of period, data integrity measure the accuracy and validation of the data transmission between microcontrollers and database, security refer to the accessibility of users to the system and performance represents the overall attributes of the system.

IoT testing [10] provides insight and control over various interconnected IoT devices. According to the literature, there are several IoT testing approaches that have been introduced by researchers [11-13]. These frameworks aimed to identify testing for IoT system that involves devices, networks, processors, operating systems, standards, and platforms. A researcher claimed that there are similarities and contrast between IoT testing and normal software testing as IoT focuses on different fundamentals that connected the user and objects [14]. Table 1 shows a comparison between IoT testing and software testing based on the components involved in the experiments. The IoT testing approach can be different based on the system architecture involve, hence test-as-a-user is often used than a test based on requirements in IoT testing. IoT testing is important to find out all possible bugs and to ensure each of the modules of the system is well functioning.

In this paper, we provide an extensive overview of IoT testing on the effectiveness and performance of the EHAC system. Home Automation Control (EHAC) [20] is a research-based IoT designed for the elderly who wish to live independently. The initial prototype has been developed on a small scale consists of sensors, microcontrollers that allow the elderly to control and operate various home electrical appliances based on the measurement of their heart pulse rate and environment temperature. The EHAC system will be deploy into several tests to measure the effectiveness and performance of the EHAC algorithms. IoT testing [10] has been adopted to evaluate the performance of the EHAC system according to the benchmark of pulse rate per minute by age and pre-set of instructions. Several experiments are conducted to evaluate the performance of the EHAC system. The basic element of this IoT testing consists of benchmarking, pilot testing, and dataset experimentation. The objectives of this paper are (1) to identify the defects from the EHAC system and (2) to evaluate the effectiveness of the EHAC system from the perspective of the Malaysian elderly. This study is significant in the enhancement and improvement of the EHAC system to benefit the Malaysian elderly for a quality life in the light of living in an ambient assisted environment and energy conservation.

Table 1: Comparison IoT testing vs software testing

Experiment Component	IoT Testing	Software Testing
Sensors	✓	×
Objects	✓	×
Application	✓	✓
Network	✓	✓
Database	✓	✓
Security	✓	✓

The outcome of this paper is to identify and validate the test results from the IoT testing on the performance of the EHAC system. The EHAC system must meet criteria to be useful to the elderly. This study aims to ensure that EHAC system can perform effectively under any circumstances. The rest of the articles are as follows, section 2 provides the background studies of the EHAC system. Section 3 discusses the evaluation of testing approaches carry out in this paper. Section 4 presents the results and discussions. In the end, the conclusion and future works of this study are discussed in Section 5.

2. Elderly Home Automation Control (EHAC)

Internet of Things technology has been heavily used in different industries such as healthcare, agriculture, architecture, and more [15-16], it has proven that IoT is able to improve elderly life in many ways. In the literature review, research has taken into account to identify the problems and challenges faced by the elderly, the needs and requirements, and the existing system in this study area. Most of the elderly prefer to stay independently despite their age, family always worries when they have to leave their elderly alone at home. Persons with movement challenges and decreased memory are especially at high risk of an incident [17]. This paper has introduced the EHAC (developed based on the Internet of Things framework) system for the elderly to live independently without assistance from a third person.

In this new era of communication and technology, the explosive growth of devices to communicate physically or wirelessly has become fundamental to people's daily life. Bui et al [18] described that the sensing equipment in IoT can be heavily useful for the healthcare industry. For instance, a doctor can monitor the patient's wellbeing without physical monitoring but can be anywhere and at anytime. In fact, the sales of wearable devices have rapidly increased in recent years, with sales up to 126 million units in 2019 [19]. These wearable devices come with fitness tracking application has continuously gained its popularity as the correlation between lifestyle and healthcare. EHAC presents a new approach to utilize IoT integrated with a pulse sensor and environment temperature sensor to support the elderly with a controlled automation solution that controls and operates electrical home appliances based on the measurement of pulse rate, environment temperature, and instructions. There are many commercial wearable devices that equip with medical sensors with capability to measure different parameters such as pulse rate, blood pressure, body temperature, and respiration rate. However, the limitation of these devices limited the user to perform additional action and so far there is no commercial product that control home appliances based on the measurement of pulse rate [19]. EHAC embedded decision making instructions where it makes decisions based on specific conditions for the elderly to remote control their home appliances without having any physical interaction with the ON/OFF switch based on their heart pulse rate accordingly [20]. EHAC aims to reduce the elderly's movement by eliminating the use of remote controller use.

In the idea of IoT architecture, a three-layer architecture was proposed in the early stage of the Internet of Things and then develop into four and five layers to fulfill the requirements of IoT. Based on findings, the author had proposed a new version of architecture from modification of the previous architectures which later use in the development of the EHAC system. The new architecture consists of five layers; sensor, network and internet, data storage, data processing, and application and cover by a security layer. In the new architecture, the processing layer is spitted into data storage and data processing layer which serves as a temporary storage layer that provides storage functionalities such as data replication, distribution, and storage and provides a diverse set of services to the lower layer. The system design of EHAC is developed based on the Internet of Things architecture [21]. Fig. 1 illustrates the EHAC System Architecture.

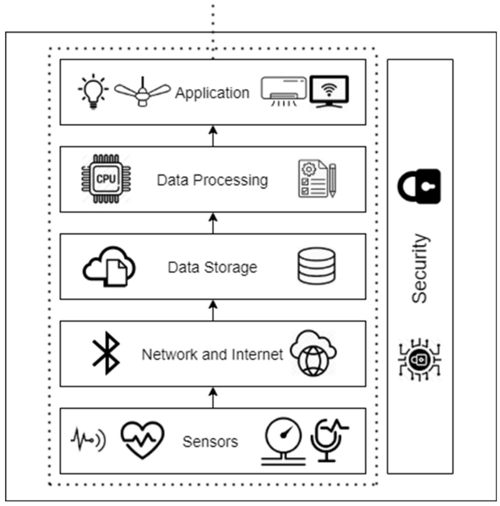

Fig. 1 EHAC system architecture

EHAC system consists of sensors, microcontrollers, and controllers. The back-end of the system has been developed using Arduino. Arduino is an open-source cross-platform that offers C and C++ programming language focuses on Internet of Things projects [22]. The communication and configuration have been managed through the Blynk server and HTTP RESTful API [23]. Data such as the elderly's pulse rate and environment level are stored in a Firebase database and real-time data monitoring can be done through EHAC mobile application. Fig. 2 presents the EHAC system design.

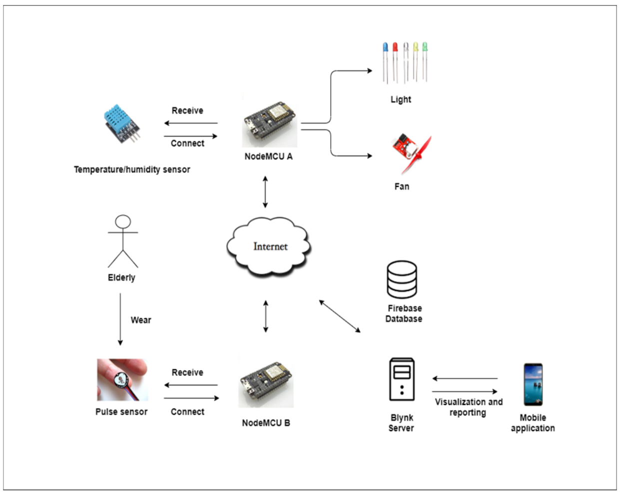

Fig. 2 EHAC system design

2.1 Elderly Home Automation Control (EHAC) algorithms

EHAC's algorithm was developed to eliminate the use of remote control use and allow automation to do its work. For instance, the microcontroller (see Fig. 3) that reads the elderly's heart pulse rate will trigger the instructions to the microcontroller (see Fig.4) that are connected and activate the electrical home appliance through the Internet when the condition is met. The following describes the coding for EHAC's solution.

```
program start
initialize variable Heart_rate = 0
initialize function Heart_rate();
initialize variable B
set Heart-rate sensor to virtual pin v3 (D1 to V3)
start infinite loop
call function read variable Heart_rate
if
  (Heart_rate >= 63 && Heart-rate < 97) //example
    set V3 as value 1
  else
    set V3 as value 0
```

Fig. 3 Microcontroller B pseudo-code

```
program start
initialize variable trigger = 0
initialize function temp();
set variable trigger = param.asInt() in v3 (V3)
start infinite loop
call function temp();
if
  (temp == 30 && humidity == 60)  //example
    turn D3 light on
    turn D6 fan on
      else
        turn D3 light off
        turn D6 fan off
receive signal from Nodemcu A
if(trigger == 1)
  turn on D2 light
    else
    turn off D2 light
```

Fig. 4 Microcontroller B pseudo-code

The pseudo-code above shows the algorithms that trigger the home electrical appliance based on the pulse measurement. The code used the "if-else" conditional statement, using **if** to specify a block of code to be executed, if the statement is true, and **else** to specify a block of code to be executed if the statement is false. In this case, the statement is reading the heart rate value. For instance, if the heart rate value is above 63 and below 97, data analysis measurements will assume that the elderly being awake, hence the light will be trigger by the command to switch on, and if the heart rate value is below 60, the light will be switched off itself assuming that the elderly are sleeping.

3. Evaluation on EHAC Performance

This section discusses the evaluation of EHAC performance. The assessment of the system aims to meet the testing criteria such as usability, reliability, data integrity, security, and performance. Several IoT testing has been carried out to evaluate the performance of the EHAC system. IoT testing has been according to the benchmark of pulse rate per minute by age and pre-set instructions. Table 2 shows the elderly pulse per minute and Table 3 demonstrates the pre-set instructions. These data play a significant role to perform accurate results in the experiment.

Table 2: Average pulse rate based on age [26]

Age in years	Average max heart rate in beats/minutes	Target rate range in beats/minutes
40 – 44	180	90 – 153
45 – 59	175	88 – 149
50 – 54	170	85 – 145
55 – 59	165	83 – 140
60 – 64	160	80 – 136
65 – 69	155	78 – 132
70 - 74	150	75 – 128

Table 3: EHAC pre-set instruction

No	Scenarios	Actions
1	If temperature < 28	Turn off fan
2	If temperature > 38	Turn on fan
3	If heart rate value > 60	Turn on light
4	If heart rate value < 60	Turn off light
5	If heart rate < 60 && temperature < 28	Turn off fan and light
6	If heart rate > 60 && temperature > 38	Turn on the fan, turn off the light

3.1 Benchmarking

Benchmarking [24] is referred to as a process to determine the best processes to achieve the project aim. Benchmarking is adopted in this study to measure the accuracy of the elderly's heart pulse rate. This benchmark follows the method of accuracy test [25]. EHAC database receives real-time data such as the elderly's pulse rate and environment level. The input is in form of a numerical integer and output is in the form of action to be complete in the system flow. In this test case scenario, the benchmark aims to address the questions of how accurate is the data. Two mathematical formulas (see Eq. 1 & 2) are used during the test to first gather the average pulse rate, and then proceed to calculate the percentage of error. On the setting, the value of 70 is set as the accepted pulse rate value. The benchmark test will be run for 3 hours and it is estimated to gather 10800 values as pulse rate per second.

$$Avg\ of\ pulse\ rate\ = \frac{R1+R2+R3+R4\ldots Rn}{\mathrm{N}} \quad (1)$$

$$\%\ error = \frac{\mathrm{R-A}}{\mathrm{A}}\ x\ 100\% \quad (2)$$

3.2 Pilot Test

The pilot test was conducted with 3 elderly as experiment participants that meet the experiment requirement such as age and are physically challenged. The numbers of participants are affected due to the outbreak of Covid-19 and restriction of MCO. This pilot test aims to validate the EHAC algorithms in an actual environment and the results will be used to validate the effectiveness of the EHAC system. The pilot test was continuously conducted in a time frame of one week. The pilot test involves capturing the elderly's pulse rate and environment temperature. The functionality of electrical home appliances; on and off statuses are controlled by the instructions from the microcontrollers hence were also tested during the experiment. A pulse sensor was placed on the elderly's hand wrist as a wearable device during the experiment period to gather pulse rate and the main microcontroller that connects the electrical home appliance was placed at the elderly home. The pilot test monitors real-time conditions and scenarios such as system usage, power usage, and temperature of the system. All data were stored in the Firebase database during the experiment. Fig. 5 shows the dataset collected during the experiment.

Fig. 5 EHAC Database

3.3 Dataset Experimentation

The dataset experimentation is conducted through the Firebase database to ensure the scalability of the proposed system. EHAC algorithm goal is to control home appliances through the dataset of pulse rate and environment temperature to trigger the pre-set instruction. Multiple experiments were conducted after pilot testing to identify how variables of pulse sensor and environment temperature can combine to influence the outcome of the results. A required adjustment had been done to eliminate unwanted data. The final dataset was identified throughout multiple rounds of experiments and EHAC's Pre-set instructions with accurate range are finalized.

4. Discussion and Results

On the benchmark testing, the average pulse rate shows 71.67 from 10800 set of data. The value was then used to measure the % error of the data accuracy. The results reveal that there is 0.0239 % of error in the accuracy of pulse rate. The % error occurs due to some undefined data. This is affected by the quality of sensors, such as the sensor unable to read the pulse rate when the user is moving. Based on the investigation, an assumption can be made that better sensors can significantly affect the % error of data accuracy. Likewise, the benchmarking shows that the % error of the data accuracy can be differentiated accordingly based on the total number of data collected and the quality of the sensing equipment.

On the other side, some tests are conducted throughout some experiments and each of these experiments was categorized into three iterations. Each result was generated based on the EHAC pre-set instruction and was divided into the following group; 1 and 0 which represents pass and fail respectively. The verification is determined by the accuracy of the index results and the primary findings from the testing show the significance of the study. From the experimentation results, it shows that the EHAC algorithms are capable of identifying the elderly's pulse rate and environment temperature. The electrical home appliances can be controlled effectively by the elderly through accurate input of pulse rate or environment level. Table 4 lists details of the experimentation validation index.

Table 4: Experimentation validation index

Experimentation	Verification	Functionality	Accuracy Index
1	Pulse rate sensor	Fan: ON/OFF Light: ON/OFF	1
2	Environment temperature sensor	Fan: ON/OFF Light: ON/OFF	1
3	Pulse rate sensor + temperature sensor	Fan: ON/OFF Light: ON/OFF	1

This paper shows the importance of IoT testing for the study of the EHAC system. It has been proven that the EHAC system can perform effectively with the automation of home electrical appliances control through the elderly's pulse sensor with accurate data transmission and instructions between microcontrollers, electrical home appliances, and database. From the experiment results, we can state that the EHAC algorithms show a positive impact on the living of the elderly and energy conservation. EHAC system was tested and measured based on several tests and the results show consistency despite using different methods of test. The results from the experimentation proven that the EHAC algorithms carry advantages to the elderly. From the literature point, the EHAC system can benefit the elderly. These experiments showed that by setting the correct variable combination with the pulse rate of the elderly, home appliances can be controlled efficiently given the right commands. Based on the perspectives of the elderly, the EHAC system eliminates the amount of elderly's movement required to control the electrical home appliances. It benefits the elderly especially when they are staying alone without assistance from any third person. The experimentation shows that EHAC algorithms not only benefit the elderly but also in terms of energy conservation. Home appliances will be switch off automatically during the unnecessary duration. However, through experiment observation, there are several barriers faced by the elderly during the experiment, such as the elderly find it difficult to understand the operation and wearing a device on hand for the whole day is an inconvenience for them.

5. Conclusion

The living quality of the elderly to stay independent without assistance from a third person can be improved with the help of the Internet of Things. From the experiments, it has been found that technical assistance is important for the improvement and support of the elderly daily routine. Based on the IoT testing, it has been found that the EHAC system can expand its connectivity towards more home appliances such as rice cooker, and television. As the results demonstrated how the EHAC system can be beneficial to the elderly, future work could be done to explore how these algorithms could be useful to the disabilities as they share similar problems and challenges of physically challenged. Also, the EHAC algorithms have a strong potential in the healthcare industry and further improvement can be made for the EHAC system.

Other further study includes enhancement of EHAC system with additional functions based on the testing results and to explore the benefits of using EHAC system. This paper, however, is limited to the scale of the elderly in Malaysia, and the EHAC algorithms are not applied to other individuals as the ON/OFF of home appliances is dependent on the elderly's input (pulse rate) and environment level. This may subject to the inaccuracy of the outputs. Another future plan is to implement emergency detection into the EHAC system to avoid and decrease the rate of further physical damages for the elderly during an emergency state. The challenges of this paper are to conduct experiments with suitable participants during the outbreak of Covid-19. The outcome of this paper has been achieved through identifying and validating the test results from the IoT testing on the performance of the EHAC system. This paper contributes towards the healthcare industry by identifying and measuring the performance of an innovative solution that allows elderly to control home appliances with their pulse rate. The main objective of this paper has been achieved through IoT testing.

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