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Research Article

Development of a Home Healthcare System for a Person Under Monitoring with Remote Access Through Web Application

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ABSTRACT

The crisis brought about by the spreading of coronavirus disease 2019 (COVID-19) pushed the medical field around the world to explore techniques to monitor one's health condition. A critical aspect of containing illness is isolation; however, it could also lead to less interaction between a patient and a corresponding caregiver. This study aimed to develop a home healthcare system for a person under monitoring, like those experiencing illness, that is easy to use and multifunctional. The system includes the following devices: a smart medicine box that could remind the patient which medicine to take at a specific time of the day; an automated vital signs monitoring device that could automatically retrieve vital signs from a pulse oximeter and temperature sensor; general communication devices between the patient and the caregiver; and a web application that is locally available for the patient and the caregiver and could be accessed by a doctor using the Internet. The said devices are interconnected via a local network, and a raspberry pi syncs the data from the local database to the cloud database, where the doctor can view it using the online web application. The said devices were successfully implemented and interconnected via a router and tested with an Internet connection. The delays recorded in the devices were low enough to make them acceptable for possible medical usage in the future once medically proven safe to use.

Keywords: Bluetooth low energy, emergency, infrared, internet, medicine box, person under monitoring, router, vital signs, web application, Wi-Fi.

INTRODUCTION

Individuals who are unable to take care of themselves fully on their own require home healthcare. The individual is supported by skilled (nurses and doctors) and non-skilled health professionals (family) throughout their time in need. According to a study [1], individuals receiving home healthcare are at risk of being admitted to the hospital unexpectedly, usually due to a worsening of a chronic illness. This could be easily prevented if the doctors could remotely monitor the individual's health. Some of the most sought vital signs of healthcare workers from patients are the following: pulse rate; respiration rate; blood pressure; oxygen saturation in blood; blood sugar; sweat; and body warmth [2].

Considering the ongoing COVID-19 pandemic, researchers used the data of 46,945 patients from New York City who were under investigation for COVID-19 to determine the vital signs that needed to be monitored to prevent COVID-19 mortality [3]. Based on their findings, oxygen saturation, body mass index, respiratory rate, heart rate, and body temperature contributed the most to predicting COVID-19 mortality. Furthermore, nearly one-third of elderly home healthcare patients have a possible medication problem or are using a medicine that isn't recommended for their age group. Most elderly home healthcare patients use more than five prescription drugs regularly, and many patients break from their medication regimen [4]. For a person under monitoring, especially if this person is elderly or has difficulty memorizing the schedule of medicine intake, a reminder system will be deemed useful. In this paper, the development of a home healthcare system was developed. The system uses wireless technology such as the Internet and Bluetooth for communication. The system comprises a smart medicine box, an automated vital sign monitoring system, a general communication device, and a web application that is locally available for the patient and caregiver that shows the real-time status of the individual's vital signs. The web app also has an online hosted website intended for the monitoring purposes of the patient's doctor.

LITERATURE REVIEW

A study by Castillo [5] was about a smart medicine dispenser with online capabilities. This device is a solution to the problem of delayed medicine intake. The users can set the time at which the pills are dispensed automatically. Its features lie in its offline and online capabilities. The users can adjust the dispensing timings using Wi-Fi through its mobile application. Furthermore, its offline ability uses the built-in keypad as input. The device has two medicine chambers. During dispensing, the device buzzes to inform the patient or the caregiver that the medicine was dispensed. The limitation of this study is that the device only has two medicine chambers capable of storing two specific pills and capsule sizes.

Another study also explored the development of a smart medicine box wherein, aside from making sure that the right medicine is being taken at the right time, a temperature sensor is also included to monitor the patient's body temperature. Through this sensor and the developed smart medicine box using a servo motor, the doctor can monitor the patient's status if the right medicine is taken, and the body temperature is not at a critical level. The system was developed using an Arduino Uno as its microcontroller and Wi-Fi module for IoT implementation. However, some limitations were seen in the study, such as only having one sensor for vital sign monitoring, a big drawer for storing the three types of medicines, and poor visualization of the data in the web application that could be improved [6].

On the other hand, multiple studies were conducted to develop a wearable device that can monitor the health parameters of its users in real-time. A wearable device consisting of sensors that can measure heartbeat, body temperature, and blood pressure was developed as a novel design called Wearable IoT-cloud-baSed hEalth monitoring system [7]. It adopted the idea of a body area sensor network wherein multiple sensors are being applied to different parts of the body and developed an embedded system that patients can use through the insertion and attachment of fingers. It utilized the cloud to have a storage and processing location for the collected data, data visualization, and emergency notifications through the web application. However, the limitations of the conducted research are the immediate sending of data to the cloud instead of having a base station. A reliable Internet connection is necessary for the implementation of this system.

Nowadays, a wearable, non-invasive health monitoring device is being studied through the IoT cloud platform [8]. The study is a collection of sensors placed in a wearable belt/collar that can detect and monitor the person's pulse rate, respiratory rate, and temperature. This is to assist in the constant health monitoring and care for patients and the elderly. Through the IoT cloud platform, doctors and family members can actively monitor the patient's health. Moreover, it also has a GSM functionality for alerts through text messaging (SMS). Additionally, any abnormal parameter values were immediately sent to the doctor through SMS. The limitations found in this device were its device, which was in the form of a belt/collar, and it can only monitor the three parameters mentioned above

DESIGN APPROACH

A. System Overview

The proposed system aims to develop a home healthcare system that is easy to use and multifunctional. It is intended for a person under monitoring and requires additional assistance from a caregiver. Figure 1 shows the main architecture of the home healthcare system. The architecture consists of different components connected to a single Wi-Fi. The web application is the main interface where the user can view the data and control most devices wirelessly. This web application consists of different account types with further restrictions ensuring that the control of devices does not overlap. The web application has been hosted both locally and on the cloud. Locally hosting the web application allows the entire system to function without an internet connection if all devices are connected to a single network. Cloud hosting the web application will enable doctors to view and monitor the patient.

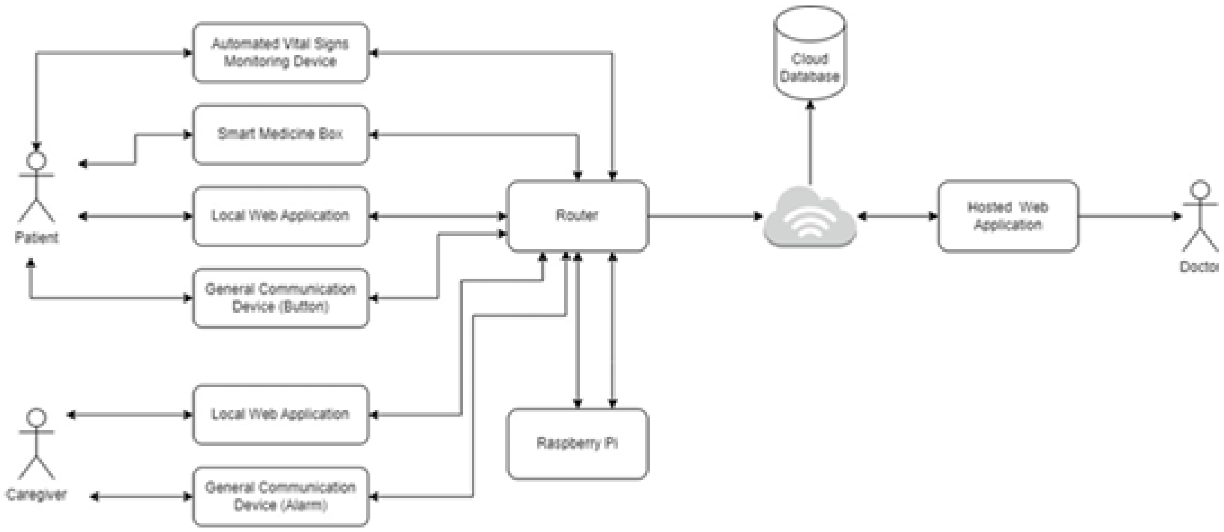

Fig 1. Main Architecture

Fig 2 below shows the overall hardware design. The microcomputer used in this study was a Raspberry Pi that received all incoming inputs from different devices and then sent these to the database. All subsystems have Wi-Fi capability of transmitting information to the Raspberry Pi. The primary devices in the system were the smart medicine box, automated vital signs monitoring device, and the general communication system.

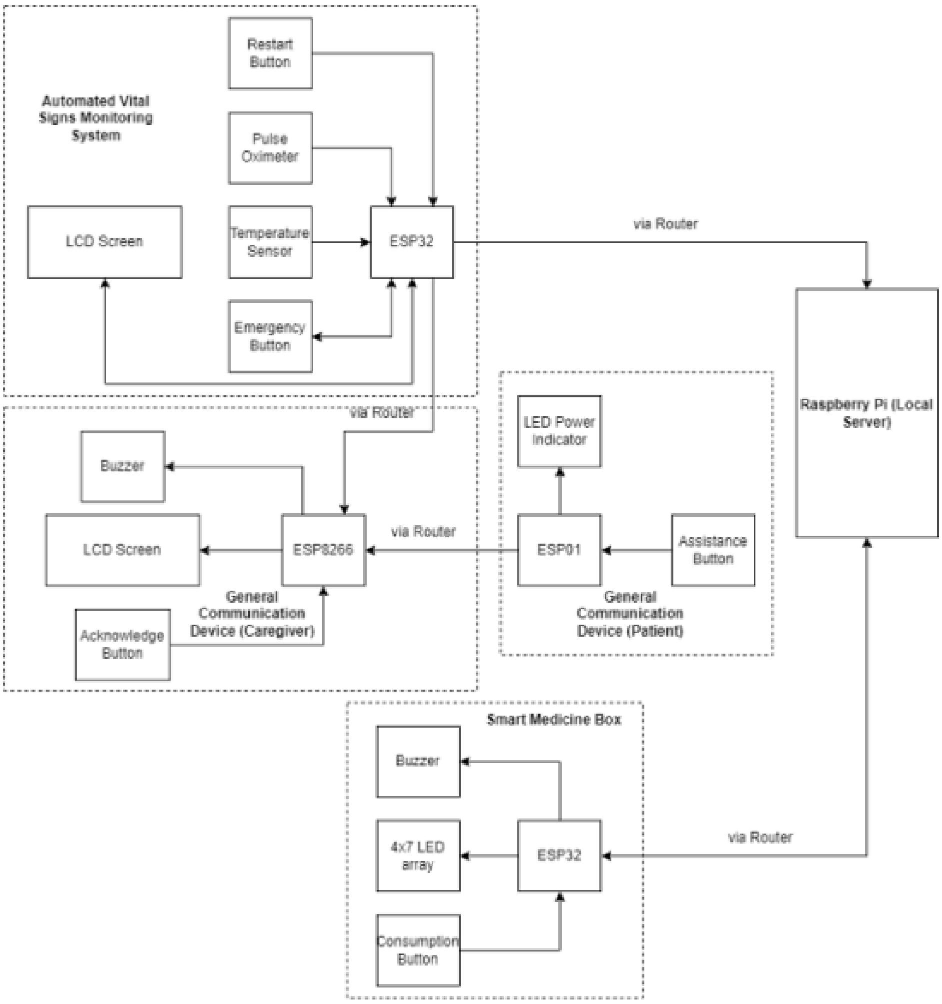

Fig. 2. System Hardware Design

B. Main Components of The System

Smart Medicine Box

The smart medicine box consists of 28 individual cells allowing four different time schedules for each day of the week. The LED of the corresponding cell will light up, and the buzzer notifies the patient when he is scheduled to take medicine contained inside the cell. The LED and buzzer will stay turned on until the patient pushes the button confirming that the medicine has been consumed. The smart medicine box uses four-line decoders (74LS138), and its output is connected to each row of the medicine box. The schematic diagram of the medicine box circuit is shown in Fig 3.

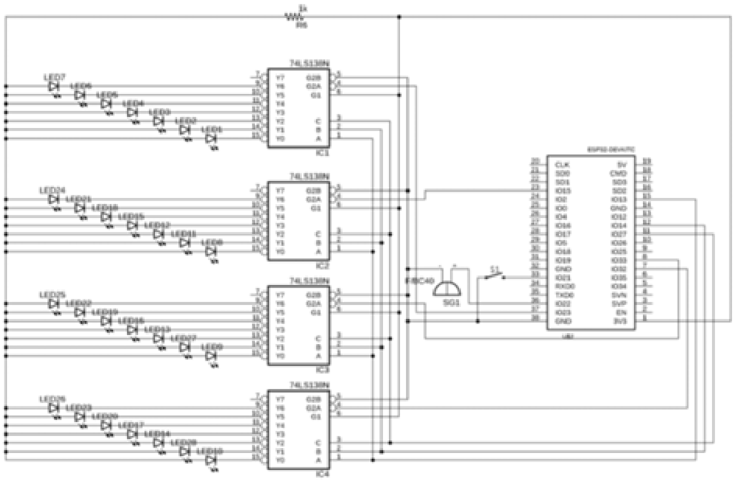

Fig. 3. Smart Medicine Box Schematic Diagram

In the actual implementation, shown in Fig. 4, the smart medicine box was enclosed in an acrylic box. A DC port is also present on the side of the enclosure allowing the user to quickly provide power to the device by simply using a 5V DC adapter.

Fig. 4. Actual Smart Medicine Box

Automated Vital Signs Monitoring Device

The automated vital signs monitoring device used the following hardware components for its implementation: ESP32, MLX90614 contactless temperature sensor module, 16x2 LCD module, and push buttons. Oxygen saturation, pulse rate, and perfusion index would be retrieved from the commercially available BLE-enabled pulse oximeter. For measuring the body temperature of the user, the automated vital signs monitoring device utilized an MLX90614 infrared (IR) thermometer – a small size and low-cost temperature sensor that is easy to integrate. A micro-USB to USB cable was used for the system's power supply. The user could plug the USB side into the adapter of the charger used for mobile devices or a power bank. This is shown in Fig. 5,

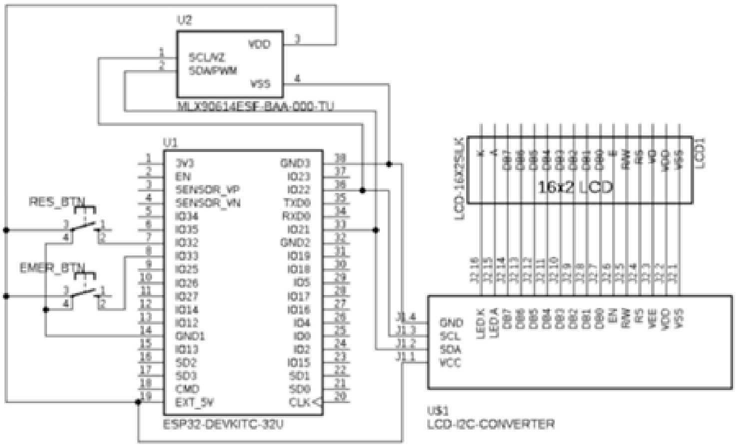

Fig. 5. Automated Vital Signs Monitoring Device Schematic Diagram

The Figure below shows the actual hardware implementation of the device. The red button indicates the emergency button, while the yellow button restarts the device. The sensor in between these buttons is the infrared thermometer. The researcher incorporated a 16x2 LCD screen to check the device's status.

Fig. 6. Actual Automated Vital Signs Monitoring Device

General Communication Devices

The general communication system allows the patient to communicate easily or call for the caregiver's assistance. Its two main components are the patient's communication button and the caregiver's communication alarm. Figure 7 shows the circuit diagram for the communication button. It is composed of ESP 01 and a push button. The implementation of this device is cheap, small, and has low power consumption. On the other hand, Figure 8 shows the circuit diagram for the communication alarm. The output components used are a buzzer and LCD. The buzzer will turn on whenever the notified state is triggered, and the LCD will show the message. The input component used is a push button. It ensures that the caregiver notices the communication alarm and reads the message.

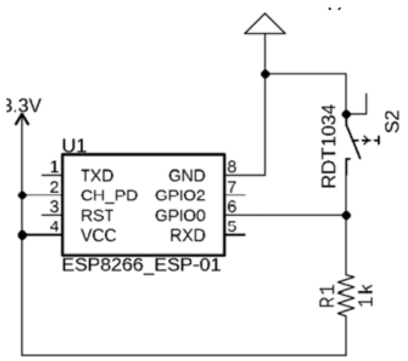

Fig. 7. Communication button schematic diagram

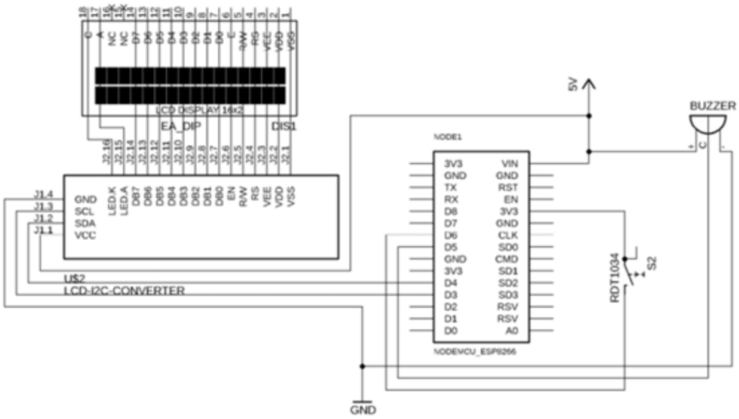

Fig. 8. Communication alarm schematic diagram

Plastic enclosures were used in the actual implementation of the general communication devices. The plastic enclosures secure the device and make it easy to carry for the patient and caregiver. The assembly is shown in Figure 9.

Fig. 9. Actual General Communication Devices (Alarm and button)

Web Application

The web application served as the main interface that allowed the users to view the vital signs data, control the schedule of the medicine box, and an alternative method to communicate with the general communication device. All the data was stored in a MySQL local database. The web application runs on top of the Raspberry Pi 4 Model B is shown in Figure 10. Additionally, a cloud-hosted version of the web application was developed using the Google Firebase Platform to enable users to remotely access the web application without direct access to the local network.

Fig. 10. Raspberry Pi 4

RESULTS AND DISCUSSION

A. Software Implementation

The web application implemented in this study has four account types. All users can view the complete vitals record and the medicine box schedule. For the unique features, the Patient account type allows using the assistance and emergency button to communicate with the communication alarm. Next, the Caregiver account can edit the medicine box schedule. Following it is the Guest account that only has view permissions in the dashboard. A doctor account with an intermediate dashboard allowed the account to manage multiple patient clients and view the patient dashboards with guest permissions. Fig. 11-14 depict the interfaces.

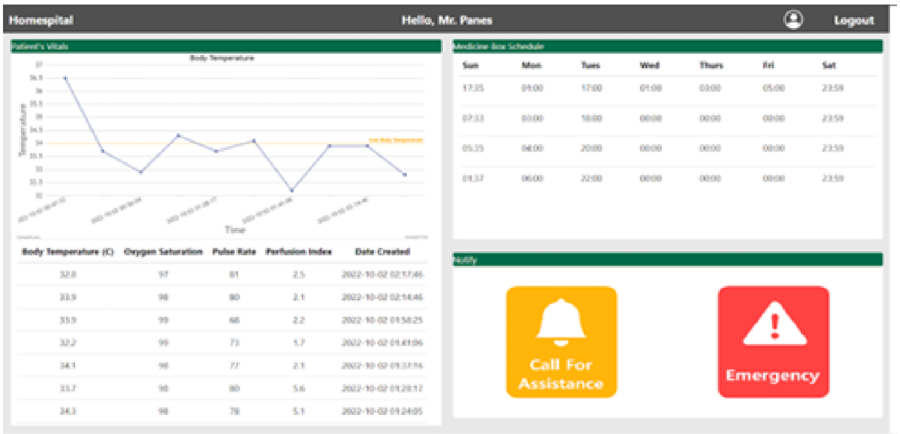

Fig. 11. Patient Dashboard

Fig. 12. Caregiver Dashboard

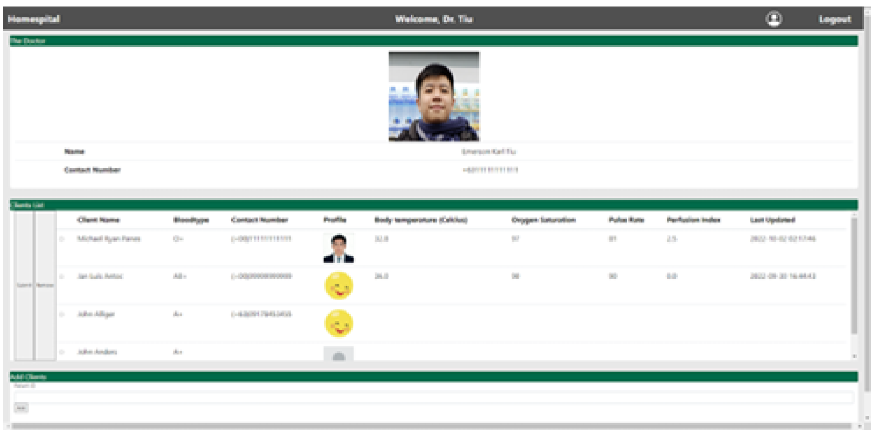

Fig. 13. Doctor Dashboard

Fig. 12. Guest Dashboard

B. System Evaluation

Response Time Test of Smart Medicine Box

A total of 30 trials were conducted to measure the response time of the smart medicine box. The response time is the difference between the set trigger time and the actual trigger time, and the target is to achieve a delay of less than one minute. For all the trials, the trigger response recorded did not exceed 10 seconds and had an average of 8.3 seconds. To conclude the result, a one-sample t-test was performed to compare the mean delay of the smart medicine box. As shown in the Table 1, with a mean of 8.3 seconds and a standard deviation of 1.207 seconds, the computed t-value was -7.7, less than the critical value. Additionally, the p-value was less than the alpha. Therefore, this result strongly suggests that the mean delay of the smart medicine box is less than 10 seconds and exceeded the goal of a less than one minute delay.

Table I. Left-Tailed One Sample T-Test on the Delay of the Smart Medicine Box

Statistics	Value
Trial Count	30
Mean	8.3000
Standard Deviation	1.2100
Standard Error	0.2209
Hypothetical Mean	10
Alpha	0.01
Tail	1 (left-tailed)
Degrees of Freedom	29
T Value	-7.7140
P Value	0.0000
T Critical Value	-2.4620

Response Time Test of the Automated Vital Signs Monitoring Device's Emergency Notification

A total of 30 trials were conducted to measure the response time of sending emergency message of the device. The expected delay would be less than 10 seconds. The data shows that the device achieved an average delay of 4.86 seconds. To further prove it, a left-tailed, one sample t-test was conducted in the trials. As shown in Table 2, the calculated t-value was less than the critical value and the p-value was less than the alpha. Therefore, the measured delay in sending the emergency notification from the automated vital signs monitoring device to the caregiver was statistically lower than 10 seconds.

Table II. Left-Tailed One Sample T-Test on the Delay of the Automated Vital Signs Monitoring Device's Emergency Request

Statistics	Value
Trial Count	30
Mean	4.8640
Standard Deviation	0.4096
Standard Error	0.0748
Hypothetical Mean	10.0000
Alpha	0.0500
Tail	1 (left-tailed)
Degrees of Freedom	29
T Value	-68.6868
P Value	0.0000
T Critical Value	-1.6991

Response Time Test of Automated Vital Signs Monitoring Device's Sending of Data to the Local Database

A total of 30 trials were conducted to measure the device's delay in sending vital signs to the local server. The delay was measured using an internal timer in the device's microcontroller. The one sample t-test shows that the device's delay is statistically lower than 10 seconds. Having as much lower delay as possible would help prevent the loss of information regarding transmitting the latest status of the patient's vital signs. The results are showing the values for the time delay of data transmission delay is presented in Table 3.

Table III. Left-Tailed One Sample T-Test on the Delay of the Automated Vital Signs Monitoring Device's Emergency Request

Statistics	Value
Trial Count	30
Mean	4.8913
Standard Deviation	0.5262
Standard Error	0.0961
Hypothetical Mean	10.0000
Alpha	0.0100
Tail	1 (left-tailed)
Degrees of Freedom	29
T Value	-53.1774
P Value	0.0000
T Critical Value	-2.4620

Calibration Test of Infrared Thermometer in a Non-Air-Conditioned Room

The calibration techniques applied in the automated vital signs monitoring device's infrared thermometer is finding the difference between ear and wrist temperature and the effect of the ambient temperature. The expected percentage error of the difference is lower than 5%.

A total of 30 trials were conducted to calibrate the infrared thermometer in a non airconditioned room. The one sample t test shows that the recorded error percentage in non-air-conditioned setting is statistically lower than 5% (calculated t value was less than the critical value and p-value less than the alpha).

Table IV. Left-Tailed One Sample T-Test on the Error Percentage Between Wrist-Ear Temperature in a Non Air Conditioned Room

Statistics	Value
Trial Count	30
Mean	1.4097
Standard Deviation	0.7386
Standard Error	0.1348
Hypothetical Mean	5.0000
Alpha	0.0500
Tail	1 (left-tailed)
Degrees of Freedom	29
T Value	-12.6865
P Value	0.0000
T Critical Value	-1.6991

Response Time Test of General Communication Device

Since the general communication devices are expected to be used where the room of the patient and caregiver is separated inside the household, the delay is measured at 5 feet (near), 15 feet (medium), and 25 feet (far) distances with 30 test trials. The delay is measured between the time when the communication button was pressed and after the communication alarm was triggered. The average delay for 5 feet is 2.28 seconds, 15 feet is 2.17 seconds, and 25 feet is 2.19 seconds. A one-way ANOVA test shows that there are no significant differences in the delay of the general communication devices at three different distances since the p-value (0.4065) is greater than the alpha value (0.01). The response time of the general communication device is the same regardless of the distance if the device is connected to a local Wi-Fi network.

Table V. One-Way Anova Test for the Measured Delays in Three Distances Between the General Communication Devices

Source	SS	Df	MS	F	Prob > F
Columns	0.18782	2	0.09391	0.91	0.4065
Error	8.98207	87	0.10324		
Total	9.16989	89			

Usability Testing

This study used a system usability scale to measure the usability of the system. There were 30 respondents participated in the survey, and each of them was asked to complete seven (7) tasks related to a patient interacting with the system and four (4) tasks relating to a caregiver interacting with the system. At the end of the tasks, the participants were asked to answer the SUS questionnaire. The Figure below summarizes the overall SUS score, and all the devices fall into the acceptable and "good" category.

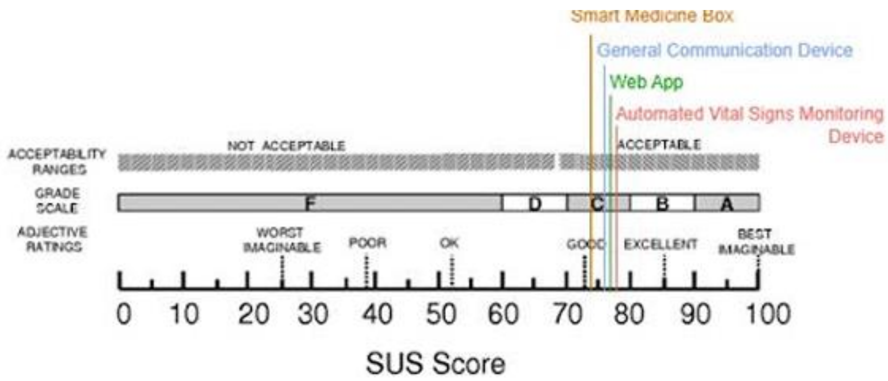

Fig. 15. SUS Scores of The Devices and Web Application mapped onto the Acceptability Chart

CONCLUSION AND RECOMMENDATION

A home healthcare system consisting of a smart medicine box, automated vital signs monitoring device, general communication devices (a button and an alarm), and a web application was successfully developed and tested. The smart medicine box is responsible for a timely medicine intake with four available time slots per day. The automated vital signs monitoring device can send vital signs to the local server. It also has an emergency button that the patient could use for immediate needs. The general communication button and alarm worked accurately, and the distance between them did not affect its performance. Finally, the web application successfully integrated all these devices into one application wherein there are different classifications of users: patient; caregiver; doctor; and guests.

The researchers recommend multiple improvements and additions to the different devices used in the system. Adding a detection mechanism for opening the lids will be beneficial for the smart medicine box. This implementation would omit the button because turning off the LED and buzzer will be automated.

Additionally, integrating the pulse oximeter and the temperature sensor into a single wearable and portable device for ease of use. It will allow users to quickly scan their vital signs without a separate enclosure for the ESP-32 and temperature sensor. If this cannot be incorporated together, use a commercially available thermometer with Bluetooth capability. It would lessen the problem with calibration, and the study could focus more on the automatic retrieval of vital signs.

In terms of a variety of data, adding more options for vital signs that can be recorded would also be beneficial, especially for doctors who will observe the patient's vital signs, such as ECG and blood pressure. An additional feature to allow patients to upload their old medical records as a PDF is also deemed valuable based on the medical consultation done by the researchers. Lastly, improving the displays of the wearable vital signs monitoring device and general communication device instead of a 16x2 LCD to remove or at least increase the maximum number of characters displayed at a time.

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