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Integrating Face Recognition and IoT Sensors to Realize Smart Application of Health Monitoring at Home

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In this study, we construct a smart home health monitoring application using IoT sensing devices, a Wi-Fi network, and face recognition technologies. The daily activity data of elderly people around their homes can be collected by sensors and transmitted to Google spreadsheets via the IFTTT service platform by using the IEEE 802.11 protocol. Caregivers can use the application (app) developed in this study to monitor the visual data from the mobile network to inquire about the daily activity data of elderly people. Furthermore, it allows real-time monitoring to distinguish whether elderly people with health problems are meeting daily basic activity conditions. On the basis of the IoT architecture model, we develop programs within the sensing, network, and application layers. The sensing layer can use webcams to actively recognize the faces of elderly people and collect their activity data, the network layer program uploads data to the cloud via a Wi-Fi network, and the application layer displays long-term activity data for elderly people around their homes through the mobile network. The application layer of the app provides caregivers with an understanding of the activity status of elderly people through visual charts. The system implemented in this study can be further applied to smart care services for elderly people at home in the future. The services include fall detection and reporting when elderly people walk and also the heart rate monitoring of home residents through the app interface, thus realizing more intelligent care applications.

1. Introduction

The IoT is a network system that contains embedded electronic components, sensors, wire connections, and software. In short, through various sensor devices and communication protocols, the physical world and network are connected to exchange information and communication for the purpose of achieving applications for intelligent identification,

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positioning, tracking, monitoring, and management. The scale of IoT applications in industry is expected to be hundreds of times larger than that in e-commerce applications at present. Thus, there is a consensus among the information and communication technology (ICT) industries that the IoT will be the greatest development in the industry in the next decade.[1,2] The main goal of IoT technology is to realize intelligent applications and provide smarter approaches for industrial operation, and it has also been developed and applied in our daily lives and activities around our homes.[3] From the perspective of technology standardization, the IoT can be considered as the world's global information infrastructure, providing innovative services through ICT.[4] Smart homes are implemented using IoT sensors through the following four steps.[1]

1. An intelligent device controls sensors and actuators that interpret and execute program instructions and perform arithmetic operations via a microprocessor.
2. Servers are controlled through data received from IoT sensors sent by the microcontroller.
3. High-level computing is carried out by controllers, which send relevant controlling instructions.
4. The microcontroller receives the instructions of the server and operates actuators according to commands in the instructions.

In addition to smart home applications, the IoT also has various applications in intelligent factories, automatic driving, intelligent traffic, unstaffed stores, and smart health care. IoT-based intelligent applications are a high-end industry dominated by globally advanced countries. Smart home applications have become more popular in recent years; however, a crucial task is to create appropriate application scenarios that meet user needs in their home environment and in line with their personal use habits.[5] Through sensors, intelligent home applications will automatically connect to the internet and respond to changes in the environment to obtain big data. Using intelligent sensor components connected to a cloud server, the big data obtained from environmental information will be saved in a cloud database system for various further intelligent applications or uses.[5,6]

The World Health Organization (WHO) predicts that, by 2050, the population aged 60 years or more will double, while as many as 400 million people will be aged 80 years or more.[7] Such aging of the population has implications for the economy, society, health care, and so forth. How can IoT technology be applied in health care applications to monitor the health problems of elderly people? Moreover, how can an intelligent health care system be developed for specific situations to enhance the quality of life of elderly people around their homes? IoT technology can reduce the burden of caregivers. Research on smart home applications is attempting to address these issues, in partnership with the Taiwanese government's Healthcare 2.0 project. In Japan, the health care industry has also already integrated intelligent technology and information communication techniques to reduce the cost of human resources and increase the working efficiency of caregivers to solve the problem of insufficient human resources in health care. The development of a smart home health care system is clearly a significant opportunity for the ICT industry to provide innovative services.

IoT intelligent technology can record the interoperability and interconnection in the daily lives of elderly people.[8–10] Such data can be collected and used to determine the health of elderly people and for their health care. Chang *et al.* suggested that the activities and behavior of a user can be analyzed from sensor data through the IoT.[11] They proposed three stages of a slow-motion sensor mode that can be applied to develop a low-speed sensor helpful for the analysis of elderly people's behavior while gardening.[11]

In this study, we proposed a smart home health monitoring application based on the above concepts. Through face recognition technology, the activity status of elderly people with health problems around their homes can be accurately detected and their daily activity data can also be stored long term in cloud storage. This system monitors elderly people with health problems. It stores, analyzes, and visualizes their daily activities, providing family members, doctors, or caregivers with a basic understanding of their daily activities, which reflect their health status. To ensure the reliability of sensor data, we integrate face recognition technology to determine the physical characteristics and activities of elderly people to judge their health status and provide appropriate advice on health, exercise, or medication. The face recognition technology can be further developed to monitor the heart rate, detect when an elderly person has fallen to the ground, and so forth, to realize more intelligent care applications in the future.

2. System Construction Plan

2.1 System analysis

In the stage of system analysis, we consider the monitoring of elderly people from the viewpoint of the person being monitored, so that the system can obtain the daily activity data of elderly people around their homes to monitor their health without them being restricted by additional wearing devices. To achieve this, we use facial recognition technology combined with environmental data collected by IoT sensor devices, and we upload the data to the cloud then store it in Google Forms. In the application layer of our proposed system, Unity C# is applied to design its user interface (UI), by which data in the cloud is sent to a smart phone and then visually presented; therefore, big data is processed into clear and meaningful figures, allowing a caregiver to monitor the daily activities of elderly people and establish whether their health status is unchanged or has declined. The data can be visualized and identified via the following aspects:

1. Daily activity data of elderly people around their homes: We use Open Source Computer Vision Library (OpenCV) computer vision technology as the image recognition tool of the monitored elderly person, which can build an image database of the person and analyze and compare the characteristics of dynamically moving images. OpenCV is widely used in image recognition. It can read and store pictures and videos and process images. Therefore, we integrate the functions provided by OpenCV with sensor data collection to identify the activity data of elderly people. Three related functions must be programmed in the system: (a) recognition of the activities of elderly people and their living environment, (b) observation of these activities and their changes over time, and (c) correlation between the activities and their times and its explanation.
2. Operation of sensors and data collection: Sensors and webcams are placed at critical points in the living environment of the elderly person to collect data through the observation of their activities.

In this study, we consider the living environment illustrated in Fig. 1. We use this environment, which includes an outdoor area, because elderly people should ideally carry out an outdoor activity such as walking along the path between A and B, which will enable a more continuous exercise with a larger number of steps, and thus be more suitable for monitoring the activity of elderly people and their health. A path for indoor activities can also be devised and used for monitoring if an outdoor path is not available.

2.2 Data schema design and behavioral classification

The activity data of elderly people can be accumulated using sensors and saved in a data file in the cloud. Chang *et al.* designed a sensor for slowly moving objects such as elderly people. Using sensors for slow design in most cases requires (a) the use of detection capabilities to accumulate data for specific observed human behaviors, (b) the collected data to have cumulative, meaningful, and clear behavioral patterns, enabling data analysis and the production of reports or information to explain the behavior of the observed person, and (c) the sensors and system model to reflect the slow activities of elderly people such as gardening and walking.(11) From the above-mentioned principles, we define the data schema related to the activity of elderly people walking between points A and B in Fig. 1 by

(a) defining the data schema, that is, the design of the data table in the database;
(b) defining the data table fields for the activity, including the fields of Person_ID, Sensor_no., and Timestamp; and
(c) uploading the data to a Google Form in the cloud via the IFTTT service platform.

3. IoT Technology Implementation

In this study, face recognition technology and IoT sensors are integrated and used to monitor the activities of elderly people around their homes and realize the function of smart care. First, we use the face recognition function of OpenCV to detect the faces of elderly people to determine whether the data collected during their walking actions can be transmitted to a table in the cloud through the IoT sensors (controller) and Wi-Fi using the IFTTT service platform.

Fig. 1. (Color online) Path designed for data collection during walking activity by elderly person.

Face recognition: OpenCV is currently the most well-known and widely used image processing library. Its source has been released for free use in business and research. OpenCV converts the face image region of interest (ROI) into a database of facial embeddings to read stored images or videos and train, classify, and calculate the facial embeddings of a database of faces. After a camera is started, an image can be compared frame by frame with the face data in the database to achieve real-time face detection and recognition. Using a function library related to machine learning and deep learning, the name of the most similar face can be extracted and the result that matches the target object is displayed. The integration of OpenCV and artificial intelligence (AI) can be applied in daily life and in the workplace, such as for AI face recognition, automatic car parking, assisted driving, and other technologies.

Wi-Fi transmission: A key factor in the penetration rate of devices for smart homes is the availability of Wi-Fi broadband, which is why Wi-Fi has become the world's most popular home wireless technology.[5,11,12] There are also many Wi-Fi-based applications in our daily lives. For example, through an access point (AP), a smartphone can simultaneously control home lighting and automatically identify a vehicle entering or exiting a parking lot.[11] Wi-Fi is suitable for these applications because it has broadband and multiple virtual links, and the function of Wi-Fi transmission has been built into all tablets and smartphones.

In this study, we use an ESP32-S single-chip microcontroller with low power consumption that integrates Wi-Fi and dual-mode Bluetooth. The ESP32 series uses a Tensilica Xtensa LX6 microprocessor and includes a dual core with built-in antenna switches, RF converters, power amplifiers, low-noise receiver amplifiers, filters, and power management modules. Owing to the rapid development of mobile phones, Wi-Fi positioning has become an important technology for retrieving position information. We designed the architecture of the home activity monitoring system for elderly people in this study shown in Fig. 2, in view of the above discussion of IoT technologies that can be realized for smart home applications.

On the basis of the discussion in Sect. 2.1 and the system architecture of the activity-monitoring application shown in Fig. 2, we use IoT technology to develop the three-layer model shown in Fig. 3. The first layer is the application layer (including the core programs that support the face recognition application), the second layer is the network layer, and the final layer is the

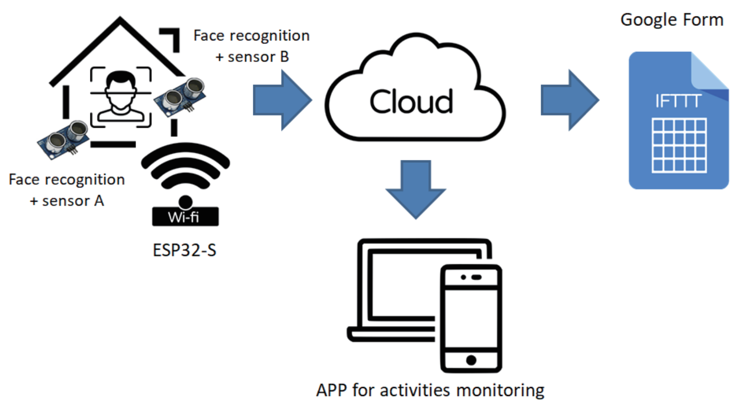


Fig. 2. (Color online) System architecture of activity-monitoring application.

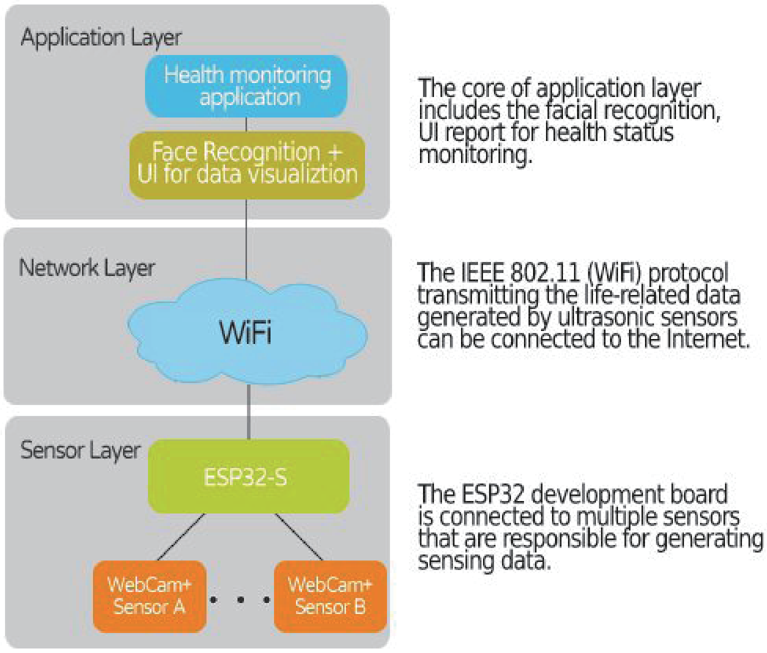


Fig. 3. (Color online) Three-layer model developed for IoT implementation.

sensor layer. Since for data transmission, the network layer must connect to the internet, the IEEE 802.11 protocol, which supports internet networks, is required.

1. Application layer: The core program of the application layer performs facial recognition and compiles the UI report including visual charts of the activities of elderly people, which can be viewed by family members to monitor their health. In accordance with the slow design criteria in Sect. 2.1, it is necessary to provide a report based on the subject's activity data to provide a meaningful explanation of their behavior.
2. Network layer: This layer uploads the data from ultrasonic sensors to the Google Form in the cloud server through low-power network media such as Wi-Fi and TCP/IP to store activity data. In this study, we adopted the IEEE 802.11 (Wi-Fi) protocol to transmit the activity data generated by ultrasonic sensors connected to the internet. The data is stored in the cloud database for the app to use in its background program calculations to present the data to caregivers and family members as aggregated daily activity reports. In the TCP/IP protocol of network data transmission, the IFTTT network service platform is used to transmit messages, and one-to-many message transmission is provided through the publish/subscribe mechanism, allowing various mobile applications in the application layer to share and exchange messages. The network layer uses the ESP32 microcontroller for signal transmission. This microcontroller acts as the central control and connection control, handles all logic signal and I/O processing control processes, is responsible for receiving incoming or outgoing signals from/to the outside world, and parses the signal requirements for the sensor to execute. The compiler of the ESP32 Wi-Fi chip uses C/C++, which is officially supported. However, there are various interpreters for Python, Lua, JavaScript, and other programming

languages. ESP32 is open-source hardware and an interactive, low-cost development board with a Wi-Fi module. At the core of the module is an ESP32-S3FN8 Xtensa® 32-bit LX7 CPU that operates up to 240 MHz. The ESP32 microcontroller has a plug-and-play USB socket. The specifications and pins of the ESP32 hardware are shown in Table 1.

3. Sensor layer: The sensor layer is composed of an Arduino or ESP32 development board connected to multiple wired and wireless sensors that are responsible for generating sensing data, including temperature and humidity, ultrasonic, and IR sensors. At present, a variety of communication technologies can connect sensors to hubs or network gateways. The transmission power consumption, cost, and coverage are major concerns for IoT applications. (1) As part of the sensing layer, we need to set up activity-monitoring sensors along the outdoor activity path shown in Fig. 1. We installed ultrasonic sensors at points A and B (as shown in Fig. 1) as activity data collection points for elderly people around their homes. Ultrasonic sensors can be used to accurately calculate the distance of an object from a person within a valid distance range. The physical wiring of the sensors is as follows. (1) The Trig and Echo pins of the ultrasonic sensor at point A are respectively connected to GOIP 13 and 12 of the ESP32-S microcontroller. (2) The Trig and Echo pins of the ultrasonic sensor at point B respectively are connected to GOIP 27 and 26 of ESP32-S. (3) The Gnd (ground) pins of the two sets of sensors are connected to the ESP32-S Gnd slot. (4) The 5 V pins of the two sets of sensors are connected to the ESP32-S 5 V slot. The sensor used for face recognition is connected to the host computer through a USB via webcams. The above operating mode of the program can be understood from Fig. 4, which shows a flow chart of the processes in the activity-monitoring system.

4. Experimental Results

On the basis of the open-source code resources for image processing, computer vision, and pattern recognition programs provided by OpenCV, we use the Unity platform to develop a face detection and recognition system in C# language (as shown in Fig. 5). As indicated by the flow chart of the system in Fig. 4, when someone approaches the ultrasonic sensor in Fig. 1, the face recognition system function of OpenCV is activated. Note that the face recognition system has already scanned and loaded the face data of the caregiver and elderly person in advance, as shown in Figs. 6(a) and 6(b).

Table 1
ESP32 hardware specifications.

32-bit Xtensa @ dual core @ 240 MHz	
Supports wireless 802.11 b/g/n standards 2.4 GHz	
Bluetooth 4.2 BR/EDR and BLE	
Built-in TCP/IP protocol, support for multiple TCP Client connections	
Communication port voltage 3.3 V	
Power input	4.5–9 V (10 V max); supports USB power supply
34 GPIOs, 4 × SPI, 3 × UART, 2 × I2C	Supports UART/GPIO data communication port
Transmission rate 110–460,800 bps	
2 × I2S, RMT, LED PWM, 1 host SD/MMC/SDIO	
SPI flash memory	Flash size 4 MB

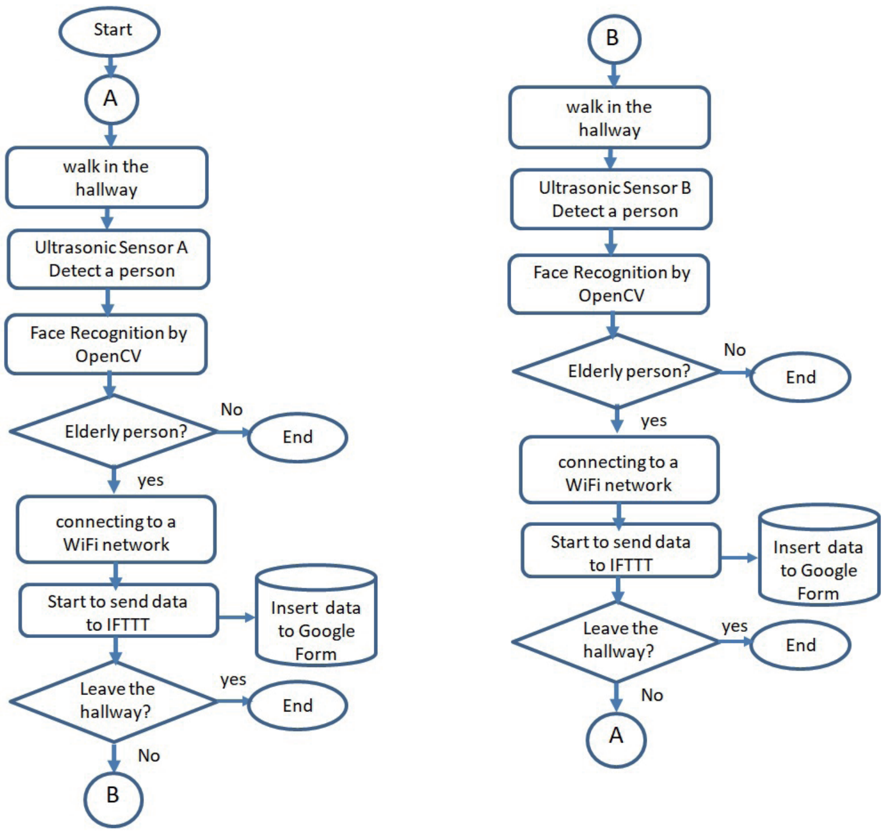


Fig. 4. (Color online) Flowchart of proposed system.

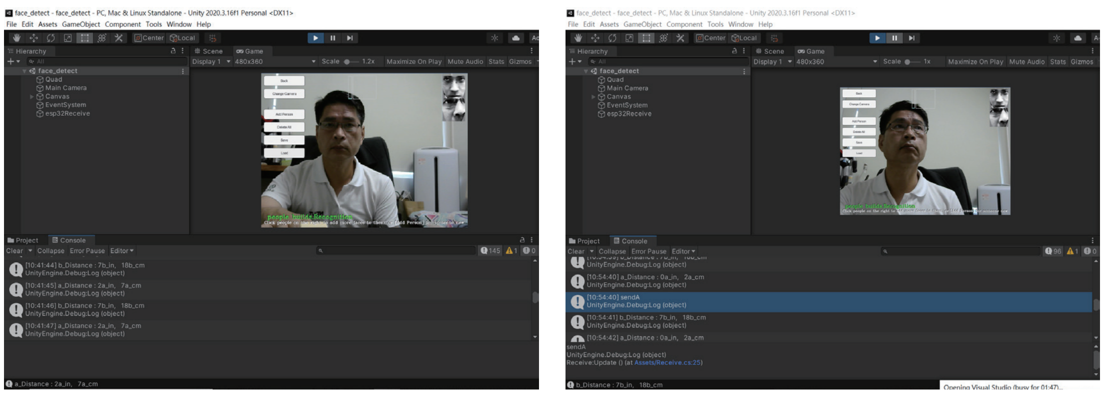
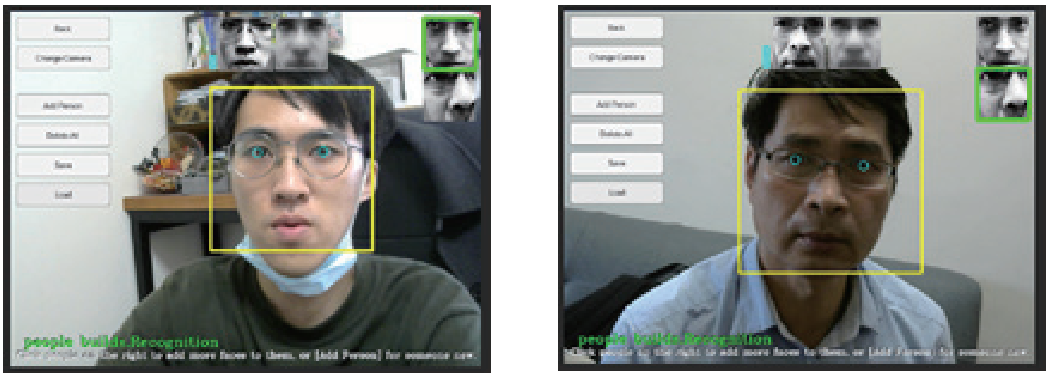


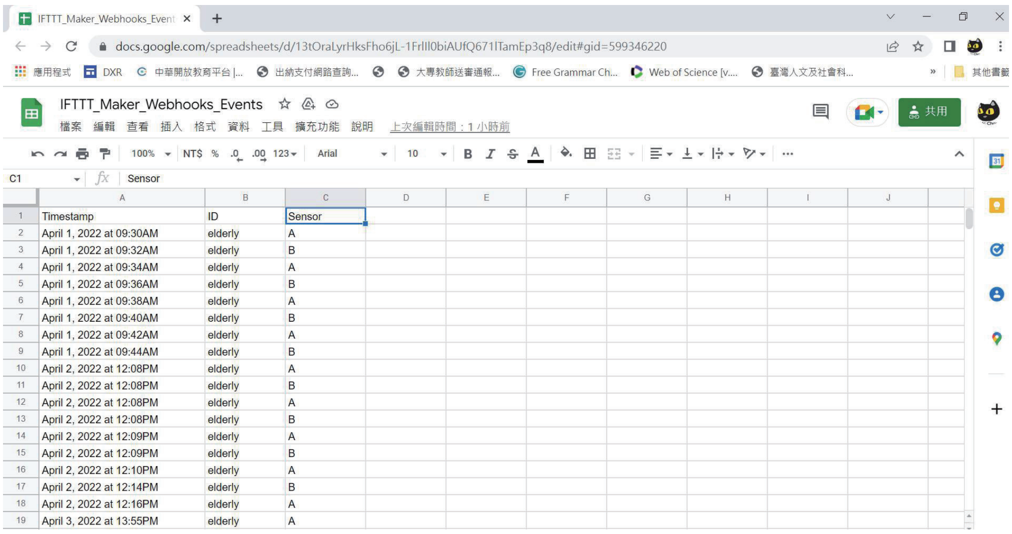
Fig. 5. (Color online) Proposed face recognition system developed on Unity platform.

When the face recognition system determines that an image corresponds to the elderly person in Fig. 6(b), it immediately starts the Wi-Fi to transmit activity data, and the IFTTT service system transmits the acquired sensor data and stores it in a Google Form (as shown in Fig. 7). The above-mentioned functions are specifically implemented for the elderly person walking



(a) (b)

Fig. 6. (Color online) Facial profiles of (a) caregiver and (b) elderly person stored in activity-monitoring application.



Timestamp	ID	Sensor
April 1, 2022 at 09:30AM	elderly	A
April 1, 2022 at 09:32AM	elderly	B
April 1, 2022 at 09:34AM	elderly	A
April 1, 2022 at 09:36AM	elderly	B
April 1, 2022 at 09:38AM	elderly	A
April 1, 2022 at 09:40AM	elderly	B
April 1, 2022 at 09:42AM	elderly	A
April 1, 2022 at 09:44AM	elderly	B
April 2, 2022 at 12:08PM	elderly	A
April 2, 2022 at 12:08PM	elderly	B
April 2, 2022 at 12:08PM	elderly	A
April 2, 2022 at 12:08PM	elderly	B
April 2, 2022 at 12:09PM	elderly	A
April 2, 2022 at 12:09PM	elderly	B
April 2, 2022 at 12:10PM	elderly	A
April 2, 2022 at 12:14PM	elderly	B
April 2, 2022 at 12:16PM	elderly	A
April 3, 2022 at 13:55PM	elderly	A

Fig. 7. (Color online) Daily activity data of elderly person stored in Google Form.

between points A and B. The ESP32 microcontroller in the network layer executes the following code after confirming that the elderly person is within the sensing range of the ultrasonic sensors at A and B:

```
// Check if the elderly person is walking from A to B:
    if(a_cm <= MinDistance){
    String url=IFTTTUrl+"?value1=A";
    SendHttp(url);
    IsAPoint = true;
    IsBPoint = false;
    }
    if(b_cm <= MinDistance){
    String url=IFTTTUrl+"?value1=B";
```

```
    SendHttp(url);
    IsAPoint = false;
    IsBPoint = true;
    }
```

If the facial recognition system detects that the person is the caregiver in Fig. 6(a), the above code is not activated. That is, ESP32 only transmits the activity data of the elderly person to the Google Form in Fig. 7. We show a plot of the activity data of this experiment for April 2022 in Fig. 8. To meaningfully interpret the daily activity data of elderly people, the correlation and significance of activities over time are compiled into a visual statistical chart in accordance with the principle of slow design in Sect. 2.

According to the long-term observation in Fig. 8, it takes about 30 min for the elderly person to walk back and forth between points A and B about 15 times. This is in line with the daily activity requirements of sub-healthy elderly people. In Fig. 8, if the number of activities (i.e., an elderly people walking from A to B and back to A) in the day is greater than 15, then the data for that day is marked in green, and if the number of activities is less than 15, then the data for that day is marked in red to indicate a warning. On the basis of this concept, we further visualized the report data in Fig. 8 in the smartphone app. The caregiver can monitor the screen of the daily activity of the elderly person through a smartphone at any time and place (as shown in Fig. 9). Through the app interface, the caregiver can be informed of the activity of the person on each day and also over a longer period of time, including the recommended activity data. In the future, intelligent functions can be added to the system, such as a warning when the minimum amount of exercise in the current month has not been reached and the ability to adjust the number of weekly activities.

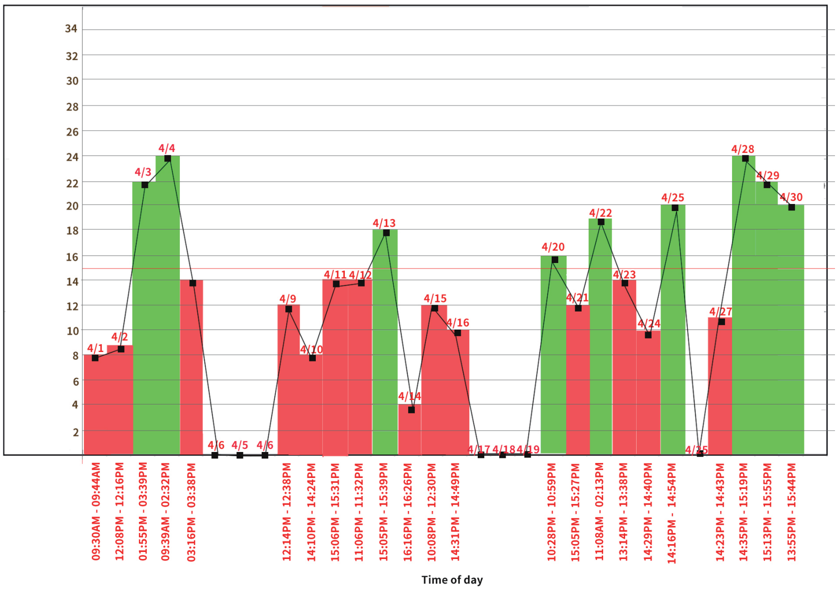


Fig. 8. (Color online) Statistical chart showing correlation and significance of activities of elderly person over time.

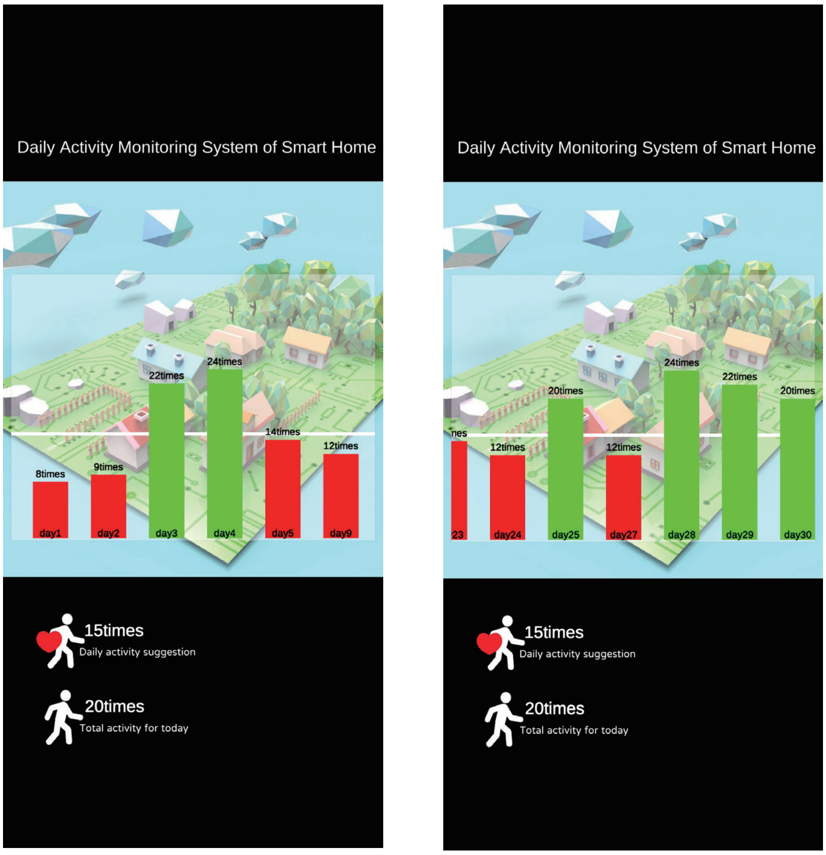


Fig. 9. (Color online) Activity-monitoring and analysis screen of elderly person on smartphone.

5. Conclusions

The activity-monitoring application system built in this study has four main features. Firstly, elderly people do not need to wear any devices, which can reduce feelings of aversion toward the system. Secondly, the necessary sensors can be set along different activity paths according to the home design. Thirdly, advanced functions can subsequently be added to the system such as the detection of a fall followed by the immediate notification of the caregiver. Lastly, the system can be used to measure heart rate in the future. For example, the heart rate of elderly people can be used as decision data to notify a medical unit. The behavior data of elderly people at home and around their homes can also be provided to medical units for analysis to determine whether they remain in good health.

We used the IoT combined with the ESP32 module to develop the smart home care application because it involved IoT sensors, Wi-Fi data transmission, cloud storage, and face recognition technologies. At present, the application is suitable for monitoring and analyzing the daily activities of elderly people, and the above advanced smart care functions are expected to be developed. Smart care-related applications have become the focus of development of the information industry in countries with aging populations. The technologies include digital technology, network technology, IoT, cloud databases, and face recognition technologies. In the future, the use of such smart applications is expected to grow explosively. Therefore, the technology and development of smart applications and the training of people with appropriate skills will be the focus of the academic and industrial sectors. The results of this study provide an example of a smart innovation that can be used to inspire other applications and for training.

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