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Creating a Safe Living Environment for the Elderly Using Smart Devices

Ming-Ling Yang,[1*] Chi-Chun Tao,[2] Po-Chuan Hsieh,[3]
Chao-Hsiu Lin,[3] Ming-Chin Ho,[1] and Yan-Chyuan Shiau[4**]

[1]Department of Architecture and Urban Planning, Chung Hua University,
No. 707, WuFu Road, Section 2, Hsinchu 30012 Taiwan
[2]Planning Division, Architecture and Building Research Institute, Ministry of the Interior,
13th Floor, No. 200, Section 3, Beisin Road, Hsindian District, New Taipei City 23143 Taiwan.
[3]Department of Civil Engineering, Chung Hua University, No. 707, WuFu Road, Section 2, Hsinchu 30012 Taiwan
[4]College of Architecture and Design, Chung Hua University,
No. 707, WuFu Road, Section 2, Hsinchu 30012 Taiwan

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There are nearly 500000 homes in Taiwan where elderly individuals over the age of 65 live alone and face daily inconveniences and dangers. In this study, we introduce an "elderly smart home environment safety monitoring and protection system." The system consists of a control board, sensing elements, and controllable facilities. When the system detects hazards such as high carbon monoxide concentrations or fire, it automatically activates alarms, ventilation fans, window openers, and gas shut-off devices, sends Line notifications, and unlocks doors to allow rescue personnel to enter. To gather data on the daily activities of the elderly, we installed smart monitoring alert control hosts along with various sensors and controllable facilities. Following evaluation, three different versions of the safety monitoring and protection equipment for elderly smart homes were proposed for reference and potential purchase. In this paper, we outline the principles for introducing smart safety protection equipment into the living spaces of the elderly, considering factors such as user health status, user-friendly design, communication facilities, house age, and wiring of smart devices. The proposed protection system enhances home safety and monitoring capabilities for the elderly and serves as a valuable reference for promotion by the government and related industries.

1. Introduction

With the increasingly serious issue of population aging in Taiwan, an aging society has become a reality. According to the National Development Council's estimates, by 2025, individuals aged 65 and above will comprise more than 20% of the total population. This trend underscores the critical importance of ensuring the safety and monitoring of the living environment for the elderly. Currently, Taiwan's elderly care policies focus on two main

[*]Corresponding author: e-mail: linda.train@msa.hinet.net
[**]Corresponding author: e-mail: ycshiau@ms22.hinet.net
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objectives: assisting the elderly in maintaining their independence and autonomy, and enhancing social sustainability by strengthening intergenerational integration and improving the stability of social structures.

To address the challenges posed by an aging society, in this study, we explore the feasibility and benefits of introducing smart safety protection equipment into the living spaces of the elderly. Specifically, the research objectives are as follows:

A. Collect and analyze domestic and international cases of the use of smart devices in elderly-friendly housing and discuss their applications.
B. Examine the conditions for introducing smart devices into the living spaces of the elderly in Taiwan and develop an "Elderly Smart Home Environment Safety Monitoring and Protection (ESMP) System" tailored to the home needs of the elderly to enhance their safety.
C. Conduct a literature review to collect relevant monitoring and analysis technologies and use smart devices to measure the physiological data and daily living habits of the elderly to provide references for future care services.
D. Establish the ESMP system, which includes carbon monoxide (CO) concentration detection, kitchen fire safety monitoring, and other functions, to provide effective emergency response measures for care groups and rescue personnel.

The significance of this research lies in the development of a comprehensive home safety monitoring and protection system for the elderly. By leveraging artificial intelligence (AI), the Internet of Things (IoT), and 5G technologies, we aim to enhance the quality and safety of home life for elderly individuals using this system. Additionally, it provides valuable references for the government and related industries in addressing the demands of an increasingly aging society.

2. Literature review

2.1 Current status of elderly care in Taiwan

Taiwan has officially become an aged society. According to population statistics from the Ministry of the Interior, as of the end of March 2018, individuals aged 65 and above accounted for 14.05% of the total population.(1) By the end of June 2023, Taiwan's total population was 23373283, with 4188313 individuals aged 65 and over, accounting for 17.92%. This demographic shift poses significant challenges for government policies to address issues related to the quality of life and dignity of the elderly, as well as the increasing burden of care on the working-age population due to declining birth rates.

Compared with major countries worldwide, Taiwan's proportion of the population aged 65 and over is second only to Japan and some European and American countries and is comparable to South Korea. The National Development Council estimates that it will take only eight years for Taiwan to transition from an aged society to a super-aged society, a pace faster than those of Japan, the United States, France, and the United Kingdom, and comparable to those of South Korea and Singapore, highlighting the rapid aging trend in Taiwan.

To address the challenges of an aging society, the Executive Yuan implemented the "Long-term Care Plan 2.0" on January 1, 2017, aiming to establish a high-quality, affordable, and accessible long-term care service system. Additionally, on November 22, 2017, the government passed the "Act for the Recruitment and Employment of Foreign Professionals," relaxing regulations on visas, residence, insurance, taxation, and retirement to attract foreign professionals to work and live in Taiwan.

Future projections indicate that Taiwan will enter a super-aged society by 2025, with an estimated 4.73 million elderly people, equivalent to one in every five individuals being elderly. The dependency ratio of the working-age population to the elderly is expected to increase rapidly, rising from 6.9% in 1981 to 16.2% in 2014, and projected to surge to 81.4% by 2061. This demographic shift necessitates joint efforts from the government and society to address its implications effectively.(2)

2.2 Issues facing the elderly in modern societies, both globally and domestically

The challenges faced by the elderly in modern societies, both domestically and globally,(3) are summarized in Table 1.

These issues require the concerted efforts of governments, families, social groups, and individuals to improve the living conditions of the elderly and enhance their quality of life in their later years.

Table 1
Elderly issues in modern societies domestically and internationally.

Problem	Description
Loss of social status	Owing to physical and mental decline, elderly individuals lose their positions and roles after retirement, impacting their income and self-esteem, and possibly leading to loneliness, suspicion, and psychological crises.
Early retirement and low income	Many elderly individuals withdraw from the labor market early, leaving them with limited retirement income, often living near the poverty line and lacking funds for basic living needs.
Decline in social value and anxiety	In capitalist societies, elderly individuals often have low income and diminished social value. The loss of their status after retirement affects their mental health.
Ambiguous meaning of existence	Rapid technological advancements can make the meaning of existence unclear for elderly individuals, while societal pressures such as social Darwinism further impact their mental health.
Health decline and lack of care	As their health deteriorates, elderly individuals often worry about inadequate care, which limits their daily activities and lowers their quality of life.
Loss of relatives and emotional instability	Many elderly individuals become widowed, and the loss of spouses or relatives creates significant emotional stress, possibly leading to loneliness or even suicide.
Poor living environment	A significant number of elderly individuals live alone in poor environments, making them vulnerable to crime and, in some cases, leading to death from hunger or cold.
Sexual needs of elderly people	Healthy elderly individuals continue to have sexual needs, but societal discrimination and lack of in-depth research create challenges in addressing this aspect of their lives.
Physiological degeneration and malnutrition	Physical decline, such as dental issues, often leads to malnutrition, making elderly individuals more susceptible to illness.
Elder abuse and neglect	Many elderly individuals suffer from abuse, humiliation, or abandonment, with insufficient official and societal intervention, making this a serious issue.

2.3 Discussion on smart home care for the elderly

2.3.1 Functions required for smart home care for the elderly

Comprehensive healthcare includes preventive care, disease diagnosis and treatment, long-term care, and hospice care, providing integrated, coordinated, and continuous patient-centered care. Elderly care technology must address the challenges of population aging and declining birth rates, ensuring the sustainability of caregiving labor and services. Product designs should offer both universal and personalized solutions. The global trend in senior housing emphasizes "deinstitutionalization," allowing elderly individuals to age naturally in their original residences, supported by barrier-free facilities, home services, nursing services, assistive devices, and rehabilitation support. The main housing options include independent living, assisted living, nursing homes, and continuing care retirement communities.

2.3.2 Usage of smart devices in smart home care

Smart home care products can be categorized into three main types:(4)

(1) Health care: Collecting physiological data to help elderly individuals monitor their health, with features such as smart pillboxes, gait analysis, and rehabilitation assistance.
(2) Environmental safety: Using sensor data for activity localization, fall detection, bed exit sensing, and more to ensure safety.
(3) Life support: Providing services such as meal preparation, transportation, and housekeeping, while emphasizing psychological support.

These services are interconnected through smart technology, fulfilling basic needs while accumulating user information to provide customized solutions. As society continues to age, medical technology is increasingly shifting toward the care industry, including smart care, health management, health promotion, and rehabilitation programs. Emerging technologies such as AI, Virtual Reality/Augmented Reality (VR/AR), big data, and IoT are now being applied to caregiving.(5) These advancements are reshaping traditional medical care models and fostering innovative business solutions for smart care. The design of smart elderly care housing should adhere to eight principles: flow, autonomy, respect, security, reminders, interaction, control, and flexibility.(6) These principles integrate space design with smart technology to enhance the quality of life for elderly individuals.

2.3.3 Monitoring and analysis techniques for physiological data of the elderly

Heart rate and respiratory rate are critical health indicators. Traditional measurement methods typically require physical contact and are not continuous. However, AmCad BioMed Corporation has developed three noncontact physiological signal measurement technologies that combine AI and computer vision: "facial microvibration," "temperature change," and "color change due to blood flow." These technologies are highly accurate, nearing medical-grade precision, and offer significant clinical value.(7)

(1) Facial microvibration: This technology enables the observation of microvibrations of the face during heartbeats and breathing to estimate heart rate and respiratory rate. It is not affected by ambient light sources and can evaluate stroke risk using only one PC, enabling simultaneous multiperson measurements.
(2) Temperature change: The average temperature of the forehead, mask, and nose areas is measured by utilizing object detection technology to locate the face, which estimates heart rate and respiratory rate by analyzing temperature variations. This technology allows for the simultaneous measurement of body temperature, heart rate, and respiratory rate using a thermal imager, even when the subject is wearing a mask.
(3) Color change due to blood flow: Subtle facial color changes caused by changes in blood flow are monitored to estimate heart rate and respiratory rate. This technology is designed for lightweight applications, making it suitable for low-computing-power devices such as laptops and Raspberry Pi boards.

These technologies can be utilized in various applications, including physiological signal measurement systems, baby monitors, and smart mirrors. They are particularly suitable for environments such as negative pressure isolation wards, postpartum care centers, homes, and gyms. By reducing the risk of contact-based infections, these technologies enable safe, noncontact, and remote medical care. They have already been commercialized and applied in settings such as epidemic prevention wards and quarantine hotels.

2.4 Related domestic and international research studies

2.4.1 Discussion on pleasant experience of smart living environment for the elderly

Lee and Kim(8) introduced the concept of the “silver tsunami,” referring to the rapid increase in the aging population. This demographic shift has garnered attention from various sectors, shifting the focus from merely extending life expectancy to improving the quality of life of the elderly. Age-related changes significantly impact the ability of elderly individuals to participate in meaningful activities. The development of smart technologies, including health applications and sensor-based monitoring networks, has proven effective in enhancing the well-being of the elderly. The research team developed an evaluation framework comprising four categories: wellness, independence, acceptance, and design, encompassing dimensions such as safety, health, interaction, enjoyment, and automation.

2.4.2 Impact of smart monitoring systems on the safety of the elderly living at home

Ma and Xu(9) investigated the effect of smart monitoring systems on the safety of elderly individuals living at home, with the Huchang Community in Ningde City as a case study. Using hierarchical regression analysis and structural equation modeling, they found that individual health has the most significant impact on the elderly’s sense of security. Moreover, smart monitoring systems serve as a moderating factor in this process, enhancing their sense of security. This moderating effect is particularly pronounced for elderly individuals with poor health, significantly improving their overall sense of safety.

2.4.3 Research on smart home technology to improve the quality of life of the elderly

Aggar *et al.*[10] explored the role of smart home technology in enhancing the quality of life of elderly individuals. Their study highlighted the desire of elderly individuals to maintain independence at home and how smart home technology can support this goal. Such technology provides a healthier and safer living environment while fostering connections with family and the community. Key technological benefits include remote control of appliances, automatic medication reminders, health monitoring, and disease management, all of which improve the elderly's access to medical services. The study also examined strategies for integrating information and communication technology (ICT) into smart homes to promote social interactions and community engagement. Although digital literacy remains a barrier to the adoption of ICT by elderly individuals, the integration of intuitive communication technologies (such as voice control) has shown promise in enhancing their acceptance and use of these technologies.

3. Prototype design and implementation results

3.1 Prototype system architecture

In this study, we developed the "Elderly Smart Home ESMP System" using IoT sensing elements and ICT technology. By integrating various sensing elements, control boards, controllable facilities, and management software, we designed the system architecture (Fig. 1).

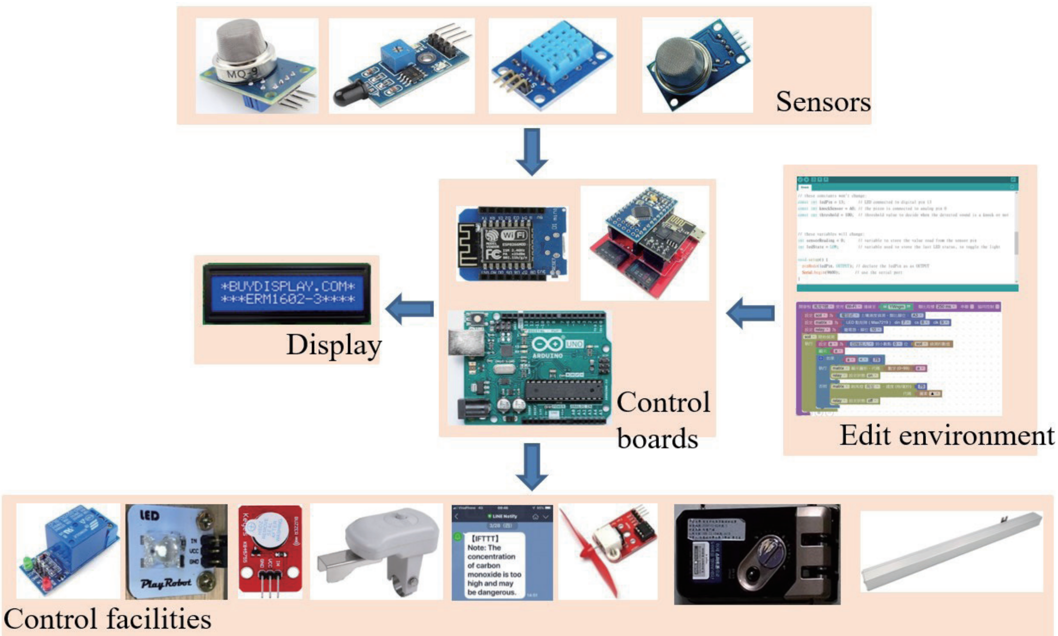

Fig. 1. (Color online) System research framework.

The proposed safety monitoring and protection mechanism for elderly home environments incorporates IoT and ICT technologies, leveraging relevant sensors, control boards, controllable facilities, software development, and Line communication settings as key components.

3.2 System control board, sensors, and controllable components

Various types of IoT component were utilized in this research. These components were selected on the basis of specific scenarios and appropriately connected to integrate the functionality of the system design. The objective was to design the operational mechanism of the elderly home ESMP system. The system is primarily divided into three categories: control boards, home environment sensing elements, and controllable facilities, as outlined below:

A. Control boards used in this research:
- (1) Arduino control board
- (2) D1 Mini board
- (3) Webduino board

B. Environmental sensing elements used in this research:
- (1) CO sensor
- (2) Flame sensor
- (3) DHT11 temperature sensor
- (4) MQ-8 natural gas methane sensor

C. Controllable facilities used in this research:
- (1) Relay
- (2) Gas shut-off device[11]
- (3) Electronic door lock
- (4) Electric door opener
- (5) Alarm
- (6) LCD module
- (7) IFTTT
- (8) Line notification system
- (9) Electric window opener[12]
- (10) Fan

3.3 System prototype

The prototype of the "Elderly Smart Home ESMP System" developed in this research is shown in Fig. 2.

3.4 System prototype execution

In this study, we established the "Elderly Smart Home ESMP System" by connecting control boards, sensing elements, and controllable facilities, along with developing control software and

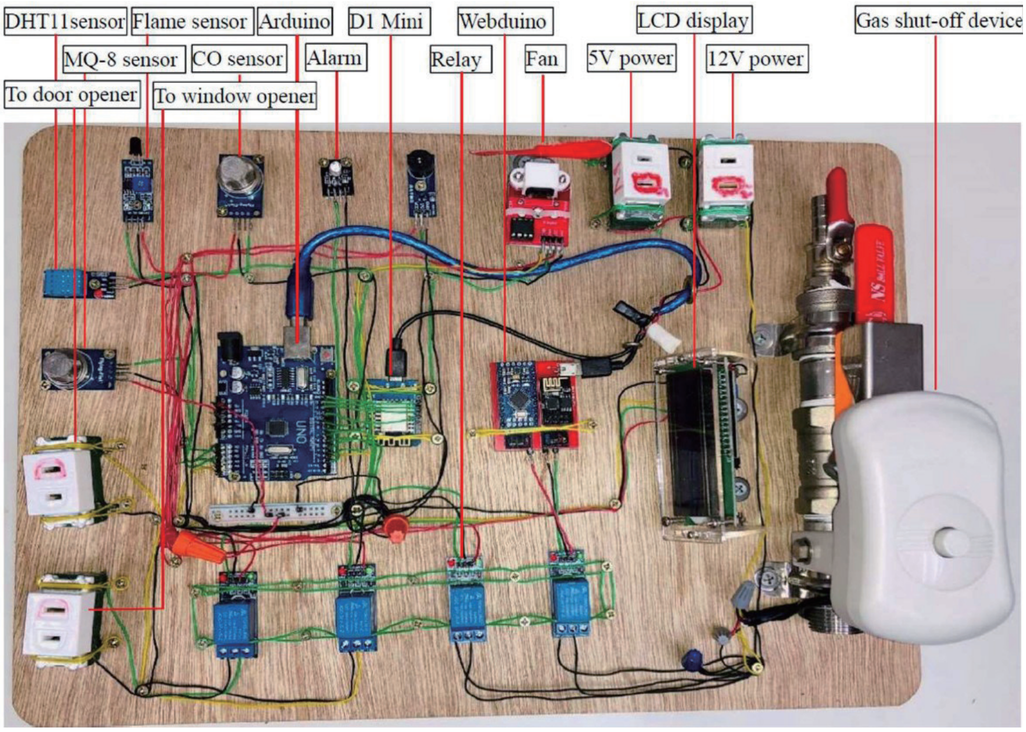

Fig. 2. (Color online) System prototype diagram.

Line communication settings. This integration results in a smart safety monitoring and protection mechanism tailored for elderly home environments.

The CO sensor used in this study is MQ-9. Since creating a high-CO-concentration environment is both challenging and harmful to humans, we simulated CO concentration by burning charcoal in an enclosed space (Fig. 3) to trigger the CO sensor. Other simulations included using a lighter to mimic a gas leak for the gas sensor, a hairdryer to simulate the generation of high-temperature air for the temperature sensor, and a mobile phone flashlight to produce strong light for the flame sensor. After connecting the control board to the sensors and control mechanisms, and uploading the control program to the board, the system was tested. The following results were obtained when the sensors were triggered: (Fig. 4)

A. Under normal conditions, the CO concentration reading is 109, the flame reading is 942, the gas reading is 27, and the temperature reading is 24 ℃.
B. When a lighter is brought close to the gas sensor, the gas concentration spikes to 500.
C. When hot air is blown at the temperature sensor using a hairdryer, the temperature rises to 65 ℃.
D. When a mobile phone flashlight illuminates the flame detection head, the flame value drops to 298.
E. When the CO concentration increases in the enclosed space due to burning charcoal, the CO concentration spikes to 920.

When a high CO concentration is detected, the system activates the alarm with flashing lights and sound (Fig. 5), turns on the fan (Fig. 6), opens the window (Fig. 7), activates the gas

Fig. 3. (Color online) Enclosed space for simulating CO detection.

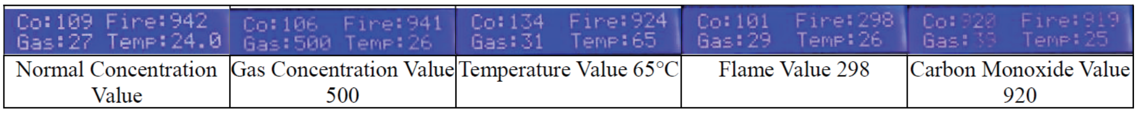

Fig. 4. (Color online) Display of sensor detection changes.

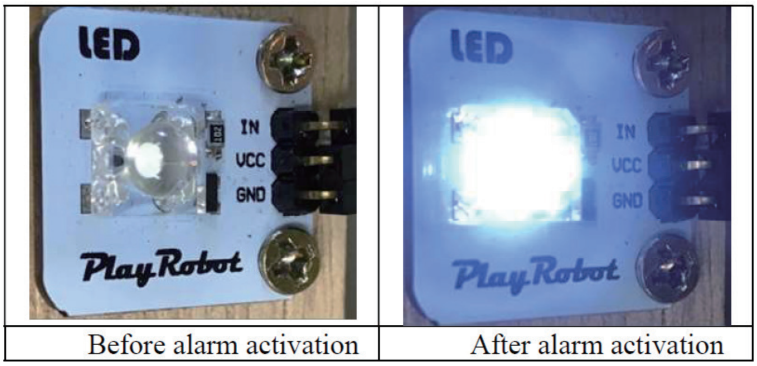

Fig. 5. (Color online) Alarm activation display.

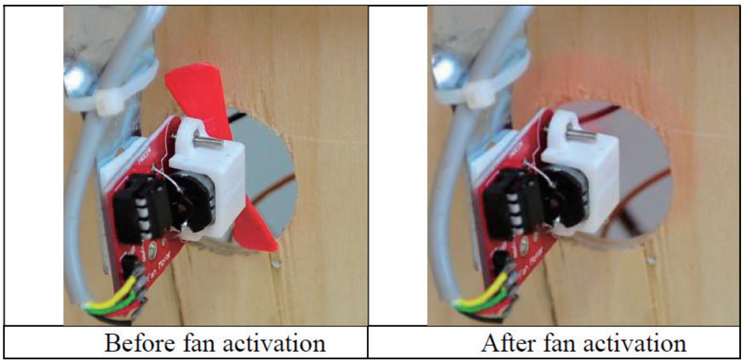

Fig. 6. (Color online) Fan activation display.

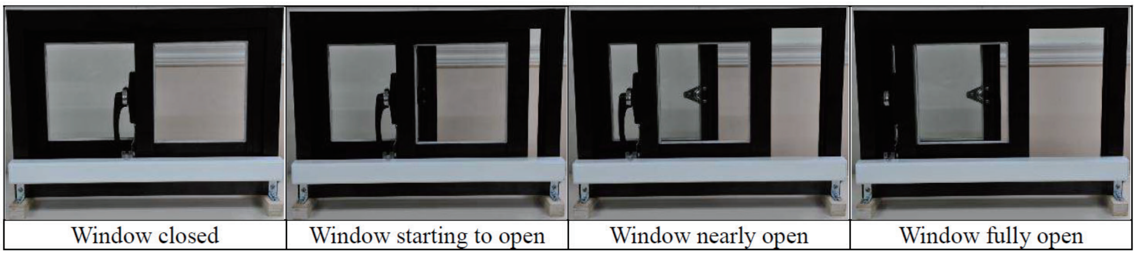

Fig. 7. (Color online) Automatic window opener display.

shut-off device (Fig. 8), sends a Line notification to the mobile phone [Fig. 9(a)], unlocks the electronic door (Fig. 10), and opens the door (Fig. 11). When the sensors detect flames, high gas levels, or high temperatures, the system performs the following actions: executes the gas shut-off, sends Line notifications [Figs. 9(b)–9(d)], and unlocks the door to facilitate assistance with fire extinguishing.

4. Collection of elderly living behavior patterns and recommendations for smart safety equipment

4.1 Relevant information on home safety equipment for the elderly

Smart devices and equipment in elderly-friendly homes can provide a safer, more convenient, and comfortable living environment, significantly enhancing the quality of life of elderly individuals. Below are some common smart devices and equipment found in elderly-friendly homes, both domestically and internationally, along with their respective functions (Table 2).

These smart devices and equipment can be tailored to specific needs and budgets, improving the comfort, safety, and livability of elderly-friendly homes. Additionally, they provide enhanced medical and social support, enabling the elderly to live independently in their homes for longer periods.

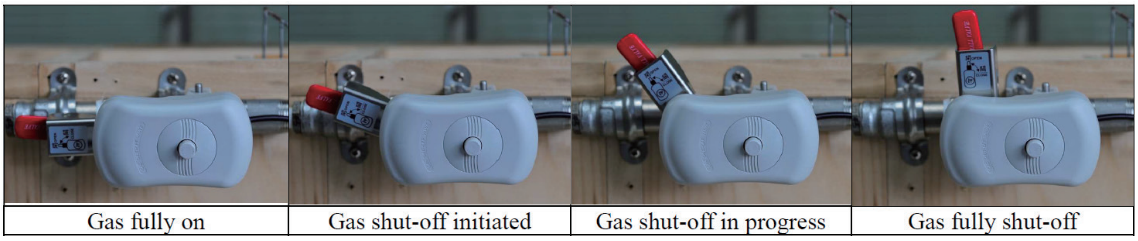

Fig. 8. (Color online) Gas shut-off valve turning 90 degrees to cut off gas supply.

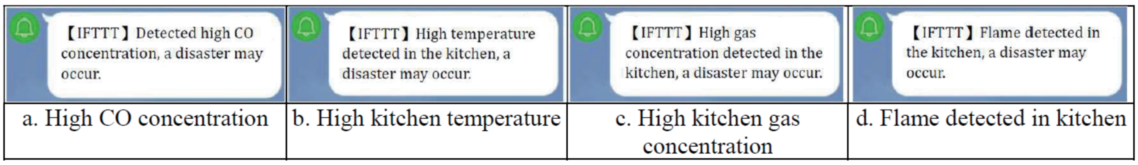

Fig. 9. (Color online) Various Line notification screens on mobile phone.

Fig. 10. (Color online) System activating electronic door lock opening function.

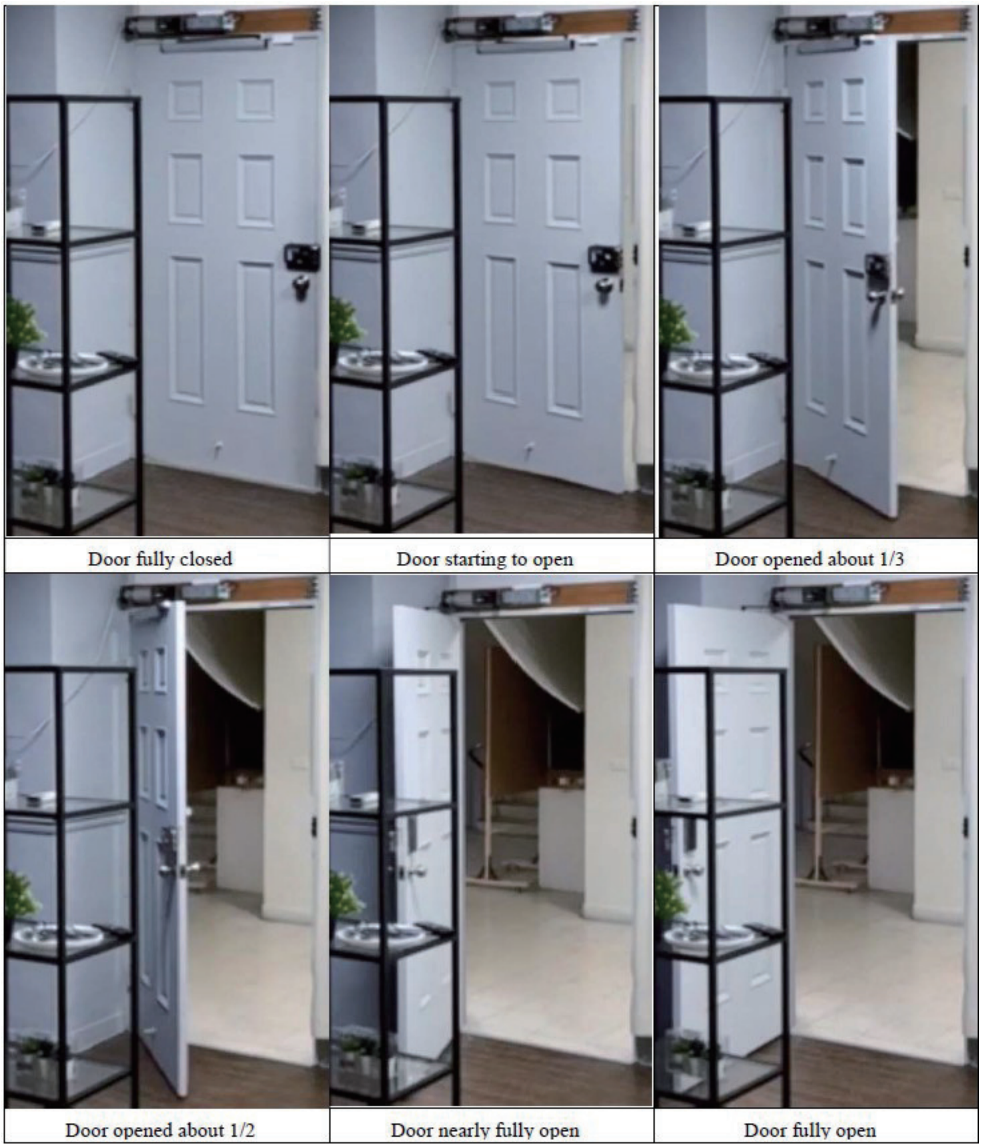

Fig. 11. (Color online) System activating door opening function.

4.2 Algorithm for predicting abnormal living conditions of the elderly

In this study, we installed a blood pressure gauge, kitchen human presence sensors, refrigerator door magnetic sensors, and smart door locks in elderly individuals' homes and collected recorded data from these devices. We employed long short-term memory (LSTM),[13] which effectively handles long-term dependences and is particularly suitable for analyzing sequence data related to living conditions. The LSTM computation process is illustrated in Fig. 12.

Steps used in the LSTM algorithm to predict abnormal living conditions of the elderly:

A. Data preparation: Convert the collected living condition information into time-series data. Each time step includes data such as blood pressure and data from PIR sensors, refrigerator door magnetic sensors, smart door locks, and others.

Table 2
Common smart devices and their functions in elderly-friendly homes.

Equipment type	Equipment name	Application function
Home monitoring system	Smart cameras and sensors	Monitor the activities of the elderly, detect falls or sudden events.
	Application alerts	Send alert messages to family members or caregivers for immediate response.
Smart lighting system	Automatic lighting	Automatically turns on lights when it detects the elderly's movements or insufficient light.
	Remote control	Allows the elderly to control the lighting system via smartphone or voice assistant.
Smart door lock	Sensor touch panel, fingerprint lock, auto-lock function, low battery alert.	
	Enables remote mobile app unlocking and temporary access code authorization control.	
Smart home assistant	Voice assistant	Allows the elderly to control home devices, check information, and set reminders via voice commands.
	Smart home hub	Integrates various devices, including smart plugs, smart door locks, and smart curtains, to increase home automation.
Elderly health monitoring equipment	Heart rate monitor and blood pressure gauge	Connect to smartphone apps for the elderly and caregivers to track health data.
	Sleep monitor	Tracks the elderly's sleep patterns and provides suggestions for improving sleep.
Safety alarm system	Emergency button	Allows the elderly to notify caregivers or emergency services by pressing the button at any time.
	Smoke and CO alarms	Smart alarms can automatically send alerts and notify family members or local fire departments.
Smart bed and mattress	Body position monitoring	Monitors the sleeping posture of the elderly and provides adjustment suggestions to reduce body pressure.
	Bedside alarm	Triggers an alarm when a fall or abnormal movement is detected.
Elderly social interaction equipment	Video call system	Enables the elderly to stay in touch with family, friends, and caregivers via video calls.
	VR and games	Promotes physical and brain activities to enhance social participation and cognitive health.

(Source: Compiled from this study)

B. Creation of the LSTM model: Create an LSTM model comprising one or more LSTM layers, along with appropriate input and output layers.
C. Model training: Train the LSTM model using the prepared dataset. During training, the model learns patterns in the time-series data to predict abnormal living conditions.
D. Model evaluation: Evaluate the performance of the trained model using a test dataset, assessing metrics such as accuracy and precision.
E. Predict abnormal living conditions: Use the trained model to analyze new time-series data and determine whether there are abnormal living conditions.

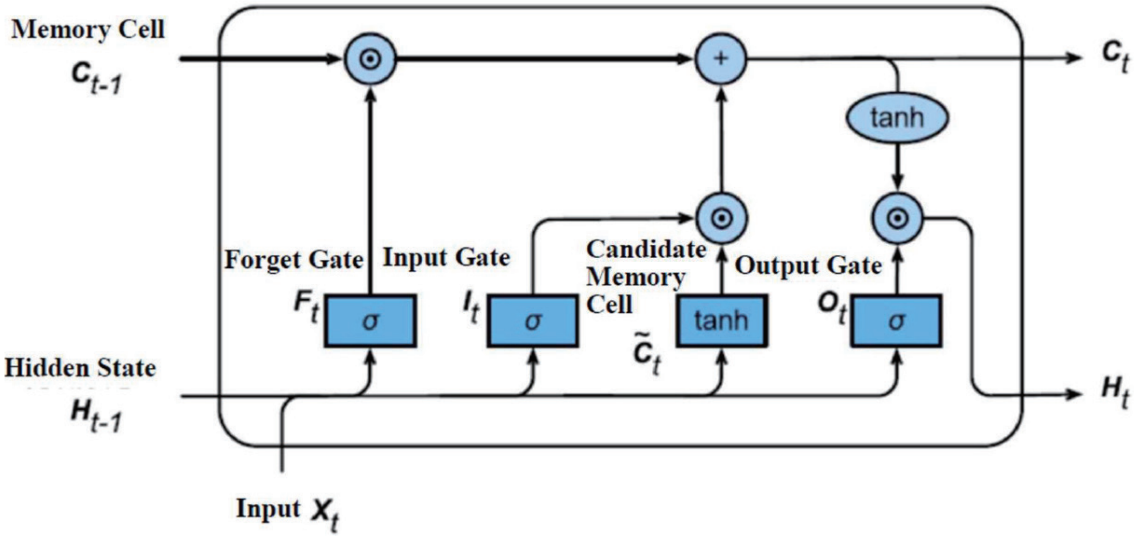

Fig. 12. (Color online) LSTM computation process.

Mathematical formulas for LSTM:

In an LSTM, the hidden state h_t and the cell state C_t at each time step t are updated as follows:

Forget Gate: Controls the forgetting of information from the previous time step in the cell state.

$$f_t = \sigma\left(W_f \cdot \left[h_{t-1}, x_t\right] + b_f\right) \tag{1}$$

Input Gate: Controls the extent to which the cell state is updated.

$$i_t = \sigma\left(W_i \cdot \left[h_{t-1}, x_t\right] + b_i\right) \tag{2}$$

Output Gate: Controls the extent to which the cell state is output to the hidden state.

$$o_t = \sigma\left(W_o \cdot \left[h_{t-1}, x_t\right] + b_o\right) \tag{3}$$

Update Cell State:

$$\tilde{C}_t = \tanh\left(W_C \cdot \left[h_{t-1}, x_t\right] + b_C\right) \tag{4}$$

$$C_t = f_t * C_{t-1} + i_t * \tilde{C}_t \tag{5}$$

Update Hidden State:

$$h_t = o_t * \tanh\left(C_t\right) \tag{6}$$

Here, W_f, W_i, W_o, and W_C are weight matrices; b_f, b_i, b_o, and b_C are bias terms; σ represents the sigmoid function; x_t is the input at time step t; and · denotes the concatenation operation.

4.3 Collection of normal behavior patterns of the elderly living alone

In this study, data on the daily activities and routines of elderly individuals were collected for subsequent research analysis and application. Various IoT-related facilities, produced by Taiwan Wireless City Networking Technology Co., Ltd.,(14) were installed in the homes of the elderly to gather relevant behavior pattern data.

4.3.1 Installation of sensors for behavior pattern collection

The behavior pattern sensors installed in this study included the following:

A. Multifunctional smart monitoring and alarm control host and PIR human far-infrared sensor: Used to detect the home activities of elderly individuals (Fig. 13).

B. Door magnetic sensors: Installed on door frames and refrigerator doors to monitor the elderly's entry and exit from rooms as well as refrigerator usage (Fig. 14).

C. Gas and CO combined detector: Installed in the kitchen area to detect high CO concentrations or gas leaks (Fig. 15).

D. Gas shut-off device: Installed at the main gas valve in the kitchen (Fig. 16). This device activates immediately to cut off the gas supply when high CO concentrations or gas leaks are detected.

E. Blood pressure gauge: This device (Fig. 17) automatically uploads measurements such as blood pressure and heart rate to the cloud upon completion.

The types of operation of IoT-related facilities installed in this study are summarized in Table 3.

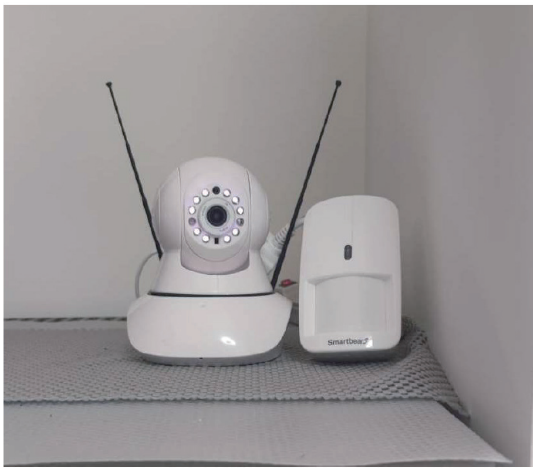

Fig. 13. (Color online) Multifunctional smart monitoring and alarm host and PIR human far-infrared sensor.

Fig. 14. (Color online) Door magnetic sensor.

Fig. 15. (Color online) Gas and CO detector.

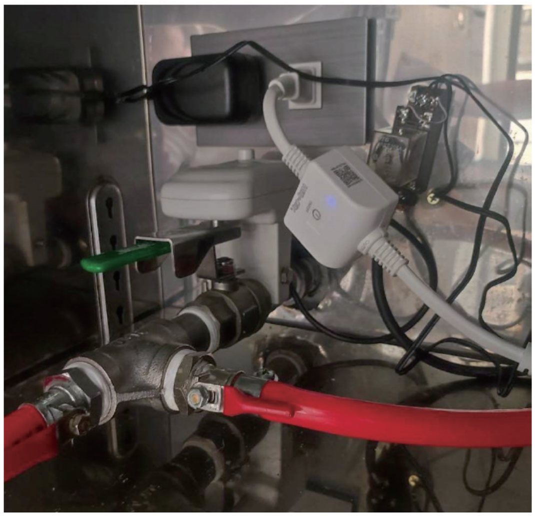

Fig. 16. (Color online) Gas shut-off device installed at gas inlet.

Fig. 17. (Color online) Blood pressure gauge.

Table 3
Record of IoT-related facility operation types.

Room	Equipment	Alarm date	Alarm time	Device event	Event description	Read value
Living room	Blood pressure gauge	June 12, 2024	07:15:25	[Blood Pressure Monitor]: active	Just woke up, measuring blood pressure	132/77/73
Kitchen	PIR human far-infrared sensor	June 12, 2024	08:14:40	[PIR Sensor]: active	Entered the kitchen	
Kitchen	Door magnetic sensor	June 12, 2024	08:16:19	[Door Sensor 41]: doorSensor	Opened the refrigerator	
Kitchen	Gas sensor	June 12, 2024	08:39:16	[Gas Sensor]: active	Detected smoke and CO concentration, shut off the gas valve	
Living room	Door magnetic sensor	June 12, 2024	09:25:03	[Door Sensor 41]: doorSensor	Opened the main door to leave	

4.3.2 Results of smart facility system execution

The operation records and daily activity correlations of the IoT-related facilities installed in this study on June 21, 2024 are shown in Table 4.

Situation Reports:

A. Situation report 1: Data recorded on July 10, 2024 showed no activity in the kitchen or refrigerator from 7 AM to 10 AM. A Line notification was proactively sent to notify family members (Fig. 18).

B. Situation report 2: On July 26, 2024, at 7:35 AM, the elderly individual measured a blood pressure of 165/105 mmHg with a heart rate of 120 bpm. A Line notification was proactively sent to notify family members (Fig. 19).

C. Situation report 3: On August 2, 2024, at 12:12 PM, the kitchen gas sensor detected smoke and a CO concentration exceeding the threshold. The system automatically shut off the gas valve and sent a Line notification to notify family members (Fig. 20).

4.4 Smart safety equipment for elderly living spaces

On the basis of a literature review, expert interviews, site visits, and expert consultation meetings, in this study, we compiled a set of smart home facilities to enhance safety in elderly living spaces. The facilities were based on the smart home technologies developed by Taiwan Wireless City Networking Technology Co., Ltd., including two-way communication and monitoring devices.

4.4.1 Consolidated smart devices for the elderly

The names and pictures of smart devices consolidated in this study are shown in Table 5.

Table 4
Operation records and daily activity correlations of IoT-related facilities.

Room	Equipment	Alarm date	Alarm time	Device event	Event description	Read value
Living room	Blood Pressure Monitor	June 21, 2024	07:20:12	[Blood Pressure Monitor]: active	Just woke up, measuring blood pressure	124/73/75
Kitchen	Far Infrared	June 21, 2024	07:24:59	[PIR Sensor]: active	Entered the kitchen	
Kitchen	Refrigerator	June 21, 2024	07:26:48	[Door Sensor 41]: doorSensor	Opened the refrigerator	
Kitchen	Far Infrared	June 21, 2024	07:55:22	[PIR Sensor]: active	Entered the kitchen	
Kitchen	Refrigerator	June 21, 2024	07:57:04	[Door Sensor 41]: doorSensor	Opened the refrigerator	
Living room	Main Door	June 21, 2024	08:05:03	[Smart Lock]: unlock	Opened the main door to leave	
Living room	Main Door	June 21, 2024	08:24:41	[Smart Lock]: unlock	Returned home	
Kitchen	Far Infrared	June 21, 2024	08:25:22	[PIR Sensor]: active	Entered the kitchen	
Kitchen	Refrigerator	June 21, 2024	08:26:18	[Door Sensor 41]: doorSensor	Opened the refrigerator	
Living room	Main Door	June 21, 2024	09:03:22	[Smart Lock]: unlock	Opened the main door to leave	
Living room	Main Door	June 21, 2024	11:24:03	[Smart Lock]: unlock	Returned home	
Kitchen	Far Infrared	June 21, 2024	11:35:04	[PIR Sensor]: active	Entered the kitchen	
Kitchen	Refrigerator	June 21, 2024	11:36:57	[Door Sensor 41]: doorSensor	Opened the refrigerator	
Kitchen	Refrigerator	June 21, 2024	11:58:39	[Door Sensor 41]: doorSensor	Opened the refrigerator	
Kitchen	Far Infrared	June 21, 2024	14:08:25	[PIR Sensor]: active	Entered the kitchen	
Living room	Main Door	June 21, 2024	14:12:36	[Smart Lock]: unlock	Opened the main door to leave	
Living room	Main Door	June 21, 2024	17:15:40	[Smart Lock]: unlock	Returned home	
Kitchen	Far Infrared	June 21, 2024	17:28:15	[PIR Sensor]: active	Entered the kitchen	
Kitchen	Refrigerator	June 21, 2024	17:31:22	[Door Sensor 41]: doorSensor	Opened the refrigerator	
Kitchen	Refrigerator	June 21, 2024	18:12:54	[Door Sensor 41]: doorSensor	Opened the refrigerator	
Kitchen	Far Infrared	June 21, 2024	20:08:19	[PIR Sensor]: active	Entered the kitchen	
Kitchen	Far Infrared	June 21, 2024	21:56:35	[PIR Sensor]: active	Entered the kitchen	

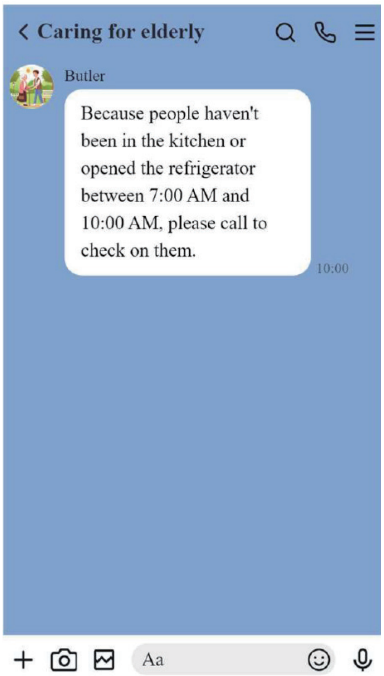

Fig. 18. (Color online) Situation report 1.

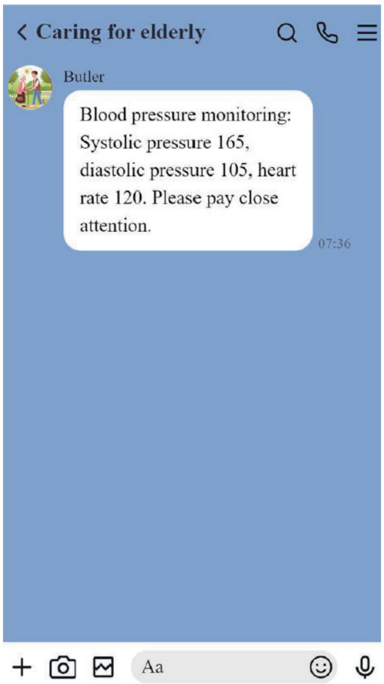

Fig. 19. (Color online) Situation report 2.

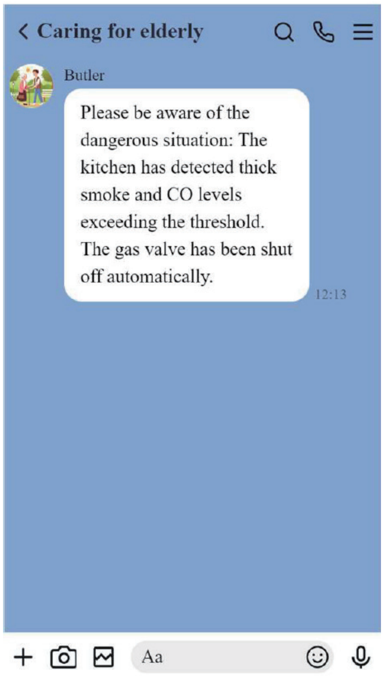

Fig. 20. (Color online) Situation report 3.

Table 5
(Color online) Names and pictures of smart home safety facilities for the elderly.

		
Two-way communication monitoring device	Fire smoke detector	Gas and CO detector
		
PIR wireless infrared human detector	Wireless door magnetic sensor	Multifunction temperature and humidity detector
		
Smart voice control host	Single-hole smart online switch socket	Smart door lock
		
Gas shut-off machine valve controller	Gas leak alarm shut-off machine valve	Wireless fixed emergency Call Bell

4.4.2 Recommended smart devices for the elderly

On the basis of the team's analysis and compilation, the recommended version of smart home safety equipment for the elderly, including costs and installation locations, is shown in Table 6.

4.4.3 Relevance between the prototype system architecture developed in this study and the recommended solution

The prototype of the "Elderly Smart Home ESMP System" developed in this study and the recommended elderly smart home safety equipment solution are related, as shown in Table 7.

4.4.4 Recommended installation locations for elderly smart home safety devices

The recommended installation locations for elderly smart home safety devices are illustrated in Fig. 21, corresponding to the following labeled devices:
A. Two-way communication monitoring device
B. Single-hole smart online switch socket
C. PIR wireless infrared human detector
D. Wireless door magnetic sensor
E. Gas shut-off machine valve controller
F. Gas leak alarm shut-off machine valve
G. Smart door lock
H. Fire smoke detector
I. Gas and CO detector
J. Smart voice control host
K. Multifunction temperature and humidity detector
L. Wireless fixed emergency call bell

Table 6
Recommended version of smart home safety equipment for the elderly.

Facility name	Unit price (NT$)	Quantity	Subtotal	Installation location
Two-way communication monitoring device	19800	1	19800	Kitchen or living room
Single-hole smart online switch socket	2760	1	2760	Kitchen gas switch
PIR wireless infrared human detector	1800	1	1800	Kitchen
Wireless door magnetic sensor	1500	1	1500	Refrigerator
Gas shut-off machine valve controller	3800	1	3800	Kitchen gas detection
Gas leak alarm shut-off machine valve	6800	1	6800	Kitchen gas switch
Smart door lock/wireless network box/controller	16600	1	16600	Main door smart lock
Fire smoke detector	1950	1	1950	Kitchen
Gas and CO detector	3500	1	3500	Kitchen
Smart voice control host	12800	1	12800	Living room
Total (including tax)			71310	
Installation fee (30%)			21393	
Grand total			92703	

Table 7
Relationship between the system architecture developed in this study and the recommended solution.

Recommended elderly smart home safety equipment solution in this study	Elderly smart home ESMP system						
	Sensing device				Arduino		Two-way monitoring facility
	CO sensor	Gas sensor	Temperature and humidity detector	Flame sensor	Control panel	Program editing environment	
Two-way communication monitoring device							V
Single-hole smart online switch socket							
PIR wireless infrared human detector							V
Wireless door magnetic sensor							V
Gas shut-off machine valve controller							
Gas leak alarm shut-off machine valve							
Smart door lock/wireless network box/controller							
Fire smoke detector				V			
Gas and carbon monoxide detector	V	V					
Smart voice control host					V	V	
Multifunction temperature and humidity detector			V				
Wireless emergency call button							V
Wireless fixed emergency call bell							V
Mobile app for above devices							

Table 7
(Continued) Relationship between the system architecture developed in this study and the recommended solution.

Recommended elderly smart home safety equipment solution in this study	Elderly smart home ESMP system								
	Output and control devices								
	LCD monitor	Relay	Audible alarm	Flash alert	Gas cutter	Fan	Electronic locks	Line notification	Window opener
Two-way communication monitoring device			V						
Single-hole smart online switch socket		V			V	V			
PIR wireless infrared human detector									
Wireless door magnetic sensor									
Gas shut-off machine valve controller		V			V				
Gas leak alarm shut-off machine valve					V				
Smart door lock/wireless network box/controller							V		
Fire smoke detector									
Gas and carbon monoxide detector									
Smart voice control host									
Multifunction temperature and humidity detector									
Wireless emergency call button									
Wireless fixed emergency call bell									
Mobile app for above devices			V	V				V	

Fig. 21. (Color online) Recommended installation locations for elderly smart home safety devices diagram.

4.4.5 Principles for implementing smart safety protection equipment in elderly living spaces

After completing the development of the prototype for the "Smart Home ESMP System for the Elderly," testing various system functions, and integrating and installing available market products, the considerations for implementing smart safety protection equipment in elderly living spaces are summarized in Table 8.

Table 8
Principles for implementing smart safety protection equipment in elderly living spaces.

Consideration	Description
Consider the health status of the user	The elderly should be at least in a sub-healthy state or have mild disabilities; those with severe disabilities are not suitable for living alone.
Friendliness and barrier-free design	Before implementing the equipment, the friendliness and barrier-free design of the living environment should be evaluated.
Building communication facilities	Smart devices require wireless communication capabilities within the house and connection to the internet to enable communication with the outside world.
Building age and wiring	The smart devices in this study use wireless communication, making them suitable for both new and old buildings without age restrictions.
Survey of electrical appliances and stoves used by the elderly	A survey of electrical appliances and stoves should be conducted before implementing smart devices to ensure appropriate equipment selection.
Selection of appropriate sensors and their installation locations	Sensors should be selected on the basis of specific needs and installed accordingly. Three options are available: economical, recommended, and complete versions.
Survey of resources from backend medical or management units	Confirm contact persons such as family members, neighbors, or community management centers, and adjust the notification order as necessary.
Collection of sensor data and setting of alert thresholds	Each sensor has preset thresholds that can be adjusted according to user needs for optimal usage.
Willingness to install portable sensing and two-way communication devices	Portable sensing devices provide real-time reporting. If the elderly is unwilling to wear them, monitoring can be achieved through a two-way communication device or by analyzing daily activity data to identify abnormalities.

4.5 Discussion

4.5.1 Novelty of this study

The innovation presented in the article primarily lies in the development and implementation of the "Elderly Smart Home ESMP System." This system integrates various smart technologies, including IoT, AI, and 5G, to create a comprehensive home safety and monitoring solution specifically tailored for elderly individuals. The key innovative aspects include the following:

A. Comprehensive integration of smart technologies
   The system combines IoT sensors, control boards, and automated response mechanisms to detect and address hazards such as CO leaks, fires, and gas leaks. It automatically activates alarms, ventilation systems, and emergency notifications, thereby enhancing the safety and autonomy of elderly residents.

B. User-centric design
   The system is designed to meet the specific needs and conditions of elderly users, considering factors such as health status, ease of use, and the physical environment (e.g., house age and wiring status).

C. Proactive emergency response

The system's ability to automatically unlock doors and notify emergency personnel via Line notifications ensures a rapid response in crises, potentially saving lives and mitigating the severity of incidents.

D. Behavior monitoring and data collection

Smart monitoring is employed to track the daily activities and physiological data of elderly individuals, enabling the detection of abnormal patterns. This feature provides critical insights for caregivers and healthcare providers, facilitating more personalized and timely interventions.

E. Prototype development and testing

In this paper, we detailed the creation of multiple versions of the smart home safety system, demonstrating its practical applications through prototypes that were tested and validated in real-world scenarios.

F. Market and application research

The study also included a comprehensive analysis of existing smart home safety equipment, offering a framework for the introduction and promotion of these technologies in elderly living spaces.

These innovations contribute to the advancement of elderly care by leveraging modern technology to create safer and more supportive living environments for the aging population.

4.5.2 Comparison with similar studies

Lee and Kim:(8) Their study introduced the concept of enhancing the quality of life for the elderly using smart home technologies focused on wellness, independence, and design. While effective in improving psychological and physical well-being, their approach lacked the integrated emergency response and behavioral analysis offered in our study.

Ma and Xu:(9) Their research highlighted the role of smart monitoring systems in enhancing the safety of elderly individuals but focused on static analysis rather than dynamic and predictive capabilities. Our study advances such systems by using LSTM for predictive monitoring and real-time responses.

Aggar *et al.*:(10) Their work explored smart home technologies for supporting elderly independence, emphasizing connectivity and health management. However, their framework did not address critical safety concerns such as gas leaks or fires, which are central to this study.

5. Conclusion

In this study, we utilized intelligent facility equipment and integrated IoT components to construct a prototype of the "Smart Home ESMP System for the Elderly." We verified that, in the event of high CO concentration, natural gas leakage, or potential fire hazards, the system can automatically activate sound and light alarms, shut off the natural gas supply, send emergency Line notifications, and unlock the front door. This enables community property management companies, care groups, or rescue personnel to enter the home and provide aid during emergencies.

For elderly individuals living alone or with other elderly individuals, the system can monitor daily activities through sensor activation records, analyze collected data, and establish normal living patterns to detect abnormalities in their behavior or activities. When necessary, the system can initiate two-way communication for confirmation or notify family members and backend care institutions for emergency assistance.

To facilitate the introduction of intelligent home safety and monitoring equipment into living spaces, in this study, we compiled a range of mature smart home safety monitoring equipment currently available on the market. A multifunctional smart monitoring alarm control host, PIR body infrared sensors, door magnetic sensors, and gas shut-off devices were installed in the homes of elderly individuals. We successfully collected activation records from these devices and verified that their sensing and monitoring functions operated as expected. The findings suggest that it is feasible to integrate smart safety protection equipment into elderly living spaces, providing a valuable reference for promoting home safety care for the elderly in the future.

The following are our contributions made from our study:

A. Collected and analyzed domestic and international cases and applications of intelligent equipment for elderly housing.
B. Developed a prototype of the "Smart Home ESMP System for the Elderly" based on the needs of elderly individuals and successfully verified its system functions.
C. Compiled and reviewed mature smart home safety monitoring equipment available on the market, installed this equipment in the homes of elderly individuals, recorded sensor activation data, and confirmed their operational functions.
D. Created a categorized list of smart home safety and monitoring protection equipment, including names, functions, and prices. These were organized into three versions based on different needs, providing a reference for selection.
E. Provided suggestions for installation locations for smart devices and outlined principles for introducing these smart safety protection devices into elderly living spaces. These guidelines serve as a reference for the integration of smart safety protection equipment into the homes of the elderly.

Acknowledgments

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