Develop an Intelligent Hierarchical Alert Mechanism for Elderly Residential Institutions

Lun-Ping Hung[1(✉)], Zong-Jie Wu[1], Chiang-Shih Chun[1], Shih-Chieh Li[1], and Chien-Liang Chen[2]

[1] Department of Information Management, National Taipei University of Nursing and Health Sciences, Taipei, Taiwan, R.O.C.
lunping@ntunhs.edu.tw

[2] Department of Innovative Living Design, Overseas Chinese University, Taichung, Taiwan

Abstract. The tsunami of aging is coming making the population structure in Taiwan to change drastically. The elderly population with disability quickly rising which is accompanied by the doubling of the problem care. Family members who cannot be there with their elders due to economic burden send them to boarding typing institutions. Traditional medical care model cannot effectively manage due to limitations in deficient professional medical labor and medical resources resulting in the enigma of increasing social cost. In light of the fast development of information technology, that many innovative and cross-field applications can now be effectively placed into clinical institutions to enhance medical treatment efficiency and expand the scope of policy have become an important key. The research will bring in the basic concept of IoT and deploy medical grade IoT modules combined with communication transmission technology through edge computing connecting phasal warning mechanism to attempt to deploy deeply into clinical situation simulation to help the elderly self-examine their own health status on a regular basis in order to construct an appropriate model for health care and to reduce the waste of overcentralized social resources in large medical institutions for creating a life-protecting, protection, health care elderly care life environment so the institutional caring quality can be increased and that the combination of medical care for establishing a healthy elderly society.

Keywords: Internet of Things · Edge computing · Long-term care · Institutional care · Multichannel gateway

1 Introduction

The aging tsunami has brought about drastic changes in Taiwan's population structure. According to the assessment report released by the National Development Council in August 2020 [1], it is estimated that the elderly population over 65 years old will reach 20.6% of the total population in 2025, which means that one in every five people will be elderly over 65 years old. A rapid increase in the number of elderly people leads to a growing shortage of care resources. Many families send elders to care institutions

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because they cannot live with them due to work or other factors. Due to the shortage of professional medical personnel and the limited use of medical resources, the traditional medical model cannot bear the impact of the aging trend, and the failure to effectively manage will lead to the increase of social costs. In recent years, information and communication technology and Internet of Things technology have made continuous progress. Innovative and cross-disciplinary applications of ICT will be effectively applied in the clinical care environment. In addition to improving the efficiency of medical care, it can also expand the application scope of medical information in line with policies.

According to the development of IoT applied in healthcare technology, Belghith et al. divided Medical IoT into application IoT and service IoT [2]. Sensors are embedded in health devices, and data are transmitted to professional medical care personnel through wireless transmission, so as to make analysis or provide suggestions for users. The universality and convenience of IoT can be effectively applied in the medical field to help the elderly solve problems in life, such as care.

However, there is no significant benefit to the care environment only through the intervention of existing IoT equipment. At present, there are different brands of equipment on the market, so it is not easy to combine them. When data tracking of physiological monitoring is needed, there are a variety of different brands of equipment to choose from, and the wireless communication mode among equipment manufacturers is different, resulting in the consumption of more human resources in the management and use. Therefore, it is the most urgent task to standardize the management of healthcare-related devices, to pay attention to the status of the elderly at any time by virtue of the real-time monitoring achieved through the IoT, and to construct a healthy and safe care environment.

This study intends to use a multi-dimensional gateway to establish a universal wireless communication transmission switching mechanism and design the edge computing effect, so as to disperse the real-time data received. This will not only reduce the burden on cloud systems, but also enable important data related to life safety to be processed, judged and analyzed quickly. The medical-level IoT module can be combined with communication transmission technology to gradually deploy into the clinical setting. In addition to the regular health examination, the care unit can also track the physiological status of the elderly at any time. Moreover, a real-time warning can be achieved through the edge computing effect to build an appropriate medical care model and reduce the excessive concentration of social resources in large medical institutions, thus improving the quality of care, and providing a friendly living environment for the elderly combined with medical care.

2 Literature Review

2.1 Smart Medicine

The development of IoT has brought powerful effects to the new medical environment. For example, in a general medical clinic or nursing environment, IoT technologies have been used for intervention and monitoring through the public network. Although these devices face the challenges of security and privacy, they will bring significant benefits to the medical field [3]. Tarouco et al. proposed in 2012 that in the home-based care/monitoring project for patients with chronic diseases of REMOA, the interoperability and security of the Internet of Things can be used to transmit the data to the cloud care system through the bridge equipment of the gateway intermediary layer for data calculation and threshold policy alarm, so as to effectively protect the real-time and low-cost healthcare environment of patients, family members and medical units [4].

2.2 Multichannel Wireless Transmission

The diversity of communication protocols in the Internet of Things leads to the dilemma of wireless communication between devices and the cloud. To realize barrier-free communication between different protocols for data transmission and communication exchange in clinical practice, Wi-Fi, BLE, ZigBee and Sigfox protocols were mainly used in this study. In order to achieve interoperability through four kinds of communication transmission, relevant foreign successful cases were found. For example, Amiruddin et al. built three kinds of communication protocol tools in a multi-communication gateway. After the IoT device is connected to the gateway, corresponding wireless transmission selection is made for the communication protocols used by various IoT devices, and data received by the three different communication protocols are integrated after selection [5]. In 2018, Vargas et al. proposed the design of the gateway interface layer. The interface layer contains (1) data conversion: JSON is used as the data format standard; (2) data processing: message processing is used to reduce delay time; (3) protocol conversion: corresponding, selecting and using is carried out according to different communication protocols; (4) data storage: the device data is uploaded to the cloud, and the data is uploaded to the database for cloud computing and data storage on the server through the Ethernet communication protocol using the TCP/IP transmission mode [6]. In 2015, Al-Fuqaha et al. introduced the technology, protocol and procedure of the Internet of Things, and explained the cooperation between different communication protocols and their application in the Internet of Things service [7]. In 2016, Marinčić described the problem of signal interference in different communication protocols. To ensure that these communications did not interact with each other leading to signal loss or confusion, SMAMCAT was used to analyze the sensitivity differences among these communications [8].

2.3 Edge Computing

With the rapid growth of IoT services, the amount of data used in sensing devices for healthcare has increased and become more complex. Based on the decentralized execution effect of edge computing, it uses similar functions of devices to help respond to critical needs and eliminate redundant data before cloud computing, and sends the filtered data to the cloud for complex analysis or permanent storage. This can not only reduce the complexity of data transmission, but also save power and reduce latency [9, 10]. In the field of healthcare, it is necessary to ensure the stable physiological state of users at any time, which is very sensitive to the response time. Therefore, it is necessary to use edge computing to build a communication architecture with high real-time response, so as to provide a fast, convenient and efficient notification mechanism.

In 2017, based on the concept of the Internet of Things, Gia et al. used the health monitoring system to track personal physiological status, and embedded edge computing effect into the gateway to enhance the physiological data obtained by the system from the sensor, and transmit the data to the gateway through specific wireless communication to solve the delay problem, and then transmit the complex tasks to the cloud server for calculation and processing. The results show that edge computing intervention is helpful to improve system efficiency and provide a real-time response with low latency to network edge architecture [11].

Table 2 shows a comparison between cloud computing and edge computing [12, 13]. Although cloud computing has good analytical capability and hardware resources, edge computing is more suitable for the environment of healthcare IoT due to its characteristics of the distributed load and fast response. It can speed up emergency notifications by spreading out tasks, and effectively reduce the burden of centralized computing in the cloud.

Table 1. Comparison table of cloud computing and edge computing

	Cloud computing	Edge computing
Response time	Minutes to weeks	Milliseconds to minutes
Data analysis	Aggregate analysis	Partial analysis
Geographical coverage	Global	Region
Hardware resources	Sufficient computing resources and storage space	Limited computing resources and storage space
Distributed load	No	Yes
Deployment mode	Centralized mode	Distributed mode

According to the above literature on elderly care, smart medicine, edge computing and so on, we understand that the shortage of medical personnel in the current healthcare industry leads to the problems of patient and equipment management. Therefore, the main goal of this study is to establish an intelligent institutional care environment of IoT. Through the real-time monitoring of the front end equipment of IoT, the edge computing alarm processing of the middle-end gateway and the data access and comprehensive processing of the back end platform and database, the tracking and management of the medical-level platform can reduce the security concerns of patients, the medical burden of family members and the management cost of the institution, so as to improve the effectiveness and quality of the care environment.

3 Application of EWMA Combined with Edge Computing in Long-Term Care Institutions

Based on the concepts of the IoT sensing layer, network layer and application layer, this study established an intelligent distributed alarm service mechanism. The sensing layer is the IoT device and gateway, and the network layer is the multi-communication switch, as shown in Fig. 1. The content includes a multi-channel switching mechanism, edge computing secure encryption mechanism, adaptive threshold alarm mechanism, as described in the following section in detail.

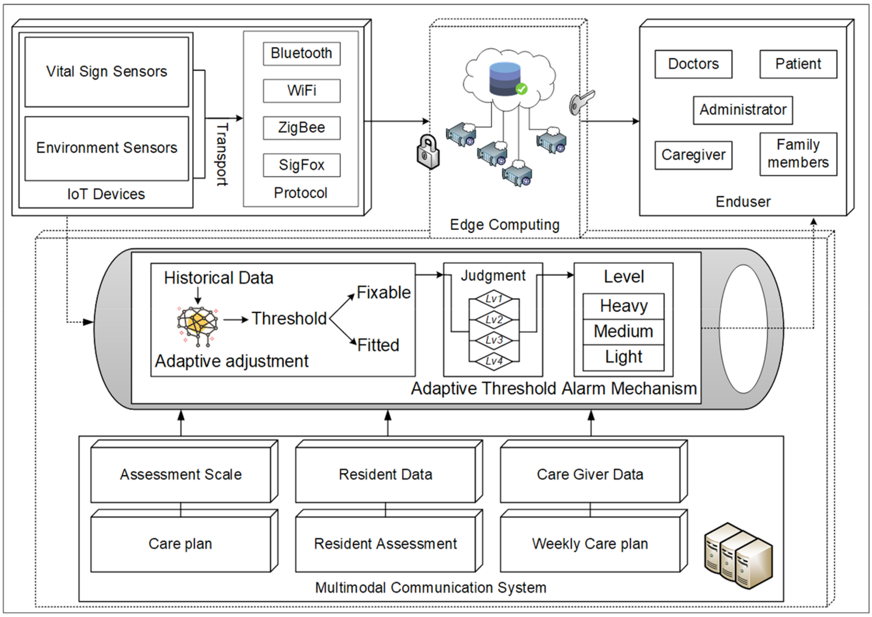

Fig. 1. Plan structure chart

3.1 Multichannel Switching Mechanism

In this study, a cross-communication gateway was built to combine Bluetooth and WIFI communication in wireless communication mode into the same module. The TXD green part is the signal transmitting point, and the RXD blue part is the signal receiving point (Fig. 2).

Sigfox and Zigbee are combined into the same module (Fig. 3). The RXTX/RFMOD orange part is the wireless signal receiving point, corresponding to the internal RF wireless signal, and MOSI blue part is the wired signal transmitting point. The MISO green part is a wired signal receiving point, and the SPI data transmission module (Fig. 4) is used to exchange data between two integrated modules. The wireless signal is transmitted to the Bluetooth-WIFI module and data is uploaded using MQTT, a lightweight transmission protocol based on TCP/IP over the wireless network.

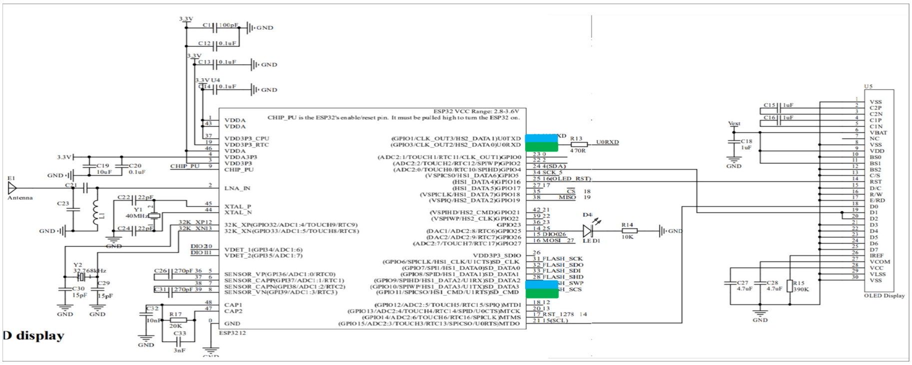

Fig. 2. Bluetooth and WIFI module diagram of multi-channel gateway (Color figure online)

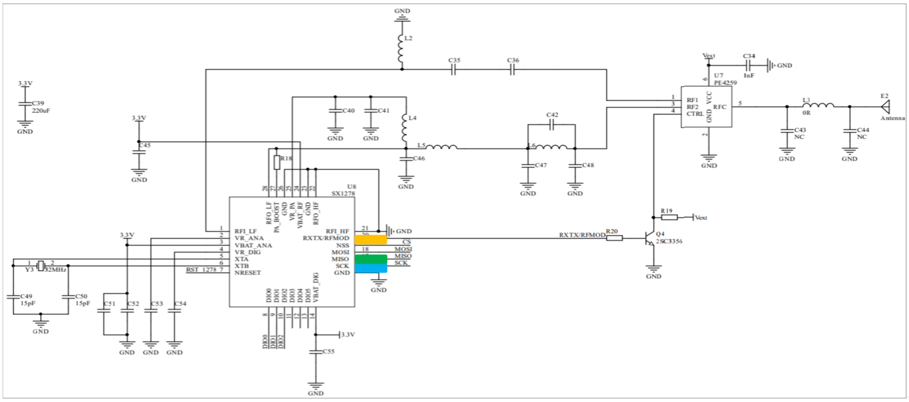

Fig. 3. Sigfox and Zigbee module diagram of multi-channel gateway

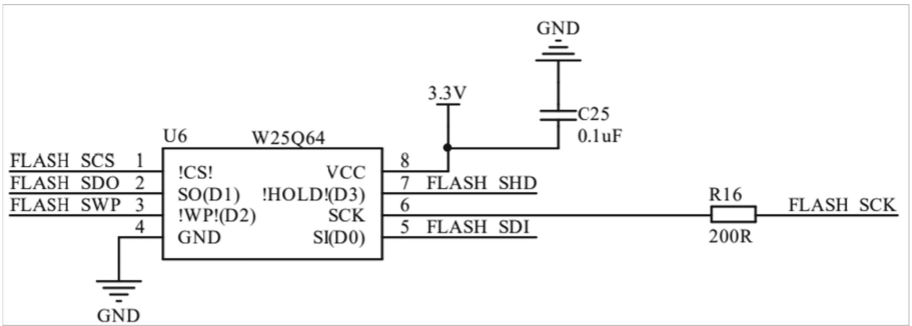

Fig. 4. SPI module diagram of multi-channel gateway

3.2 Security Encryption Edge-Computing Distributed Mechanism

In the clinical practice of care institutions, the data collected by IoT devices contain physiological signals and environmental values and different devices have different packet sizes, so the transmission in a fixed packet size will result in a waste of bandwidth and memory. In order to reduce the above problems and ensure the security of data, it is necessary to strengthen data identification. Therefore, this study adopted Prasad Calyam's optimal encryption mode and the packet cutting scheme after verification in both TLS and DTLS. AES256 encryption algorithm was adopted in the former, while CHACHA20 encryption algorithm was adopted in the latter. In practice, there have been many verification examples of the two encryption algorithms. It can effectively protect the data and make the data not easy to be falsified and retrieved, and can be applied to establish the pre-shared key for communication between the two parties for authentication among edge devices, gateways and cloud servers [14].

The distributed computing flow of signal transmission is shown in Algorithm 1. First, the data size is taken as the judgment benchmark for choosing TLS and DTLS, and data are transmitted through the streaming or package mode. When the 1024-bit packet is used as the transmission case, the data packet is [1024/128] = 8. But using 130 bits as the standard results in 126 blank bits for the second packet. Then, in the encryption process of TLS, the four steps including AddRoundKey, SubBytes, ShiftRows, and MixColums are repeated with 14 encryption cycles, until the MixColumns is omitted in the last encryption cycle, and replaced by AddRoundKey. During the encryption process of DTLS, the matrix is repeatedly changed in 20 encryption cycles and the shift operation is performed with quarter-round.

Algorithm 1 : Signal encryption distributed operation mode

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Data: Data to be transmitted, data
Data: Protocol to be used for transmission, protocol
Data: Cipher to be used for encryption, mac
Data: encryption algorithm, enc
Result: The best security scheme is chosen
/* data.PACKET_SIZE in bits */
if data.PACKET_SIZE >= 128 then
   protocol ← TLS
   mac.TYPE ← BLOCK
   enc == AESGCM256
   for Times = 1,….,14 (256bytes) do
      AddRoundKey ( )
      SubBytes ( )
      ShiftRows ( )
      MixColums ( )
      If Times == 14 then
         AddRoundKey ( )
         SubBytes ( )
         ShiftRows ( )
         AddRoundKey ( )
      end
   end for
else
   protocol ← DTLS
   mac.TYPE ← STREAM
   enc == Chacha20
   for Times = 1,….,20 do
       InitialMatrix ( )
       QuarterRound ( )
   end for
end
```

3.3 Adaptive Threshold Alarm Mechanism

In the long-term care institutions, the elderly attach the most importance to emergencies. If the front-line staff can be notified immediately when an incident occurs, the crisis can be safely averted. However, not every incident will result in serious injury or death. Therefore, phased alarms should be conducted according to the risk level of the incident. The weight of the hazard level can be judged by the threshold setting of the related IoT equipment. The accuracy of the threshold will help to exclude false alarms and missed alarms. A single threshold setting will cause many false alarms and missed alarms, and a single threshold cannot be adjusted flexibly according to the situation, which will have a negative effect on caregivers, emergency units and family members.

Therefore, we use EWMA to adjust the threshold value and the physiological data of people receiving care appropriately. EWMA has been used for many years by scholars to adjust the mobility threshold. Aslansefat adjusts the threshold through this mode in gas engines and obtains a practical application of the adaptive threshold [15]. In this case, an adaptive threshold alarm mechanism that is suitable for the current situation of the care institutions is proposed.

In most cases, the threshold value is usually fixed as the basis for judging whether the event is normal or abnormal. The threshold value is set as Eq. (1), where m is the average value of all data, v is the variance of marked signals in all data, and α is the parameter exponential that can be freely adjusted by the designer.

$$T = \Updownarrow \mp \alpha v \tag{1}$$

In situational design, if an alarm occurs under normal conditions, it is called a False Alarm Rate (FAR), as shown in Eq. (2). On the contrary, if there is no alarm under abnormal conditions, it is called Missed Alarm Rate (MAR), as shown in Eq. (3), where x_{tim} represents a fixed threshold. For the clinical application of care institutions, the health of the care receiver and the environment of the institution is different, so the threshold value of the IoT should be adjusted flexibly according to the different situations, and the customized monitoring condition judgment is the core element.

$$FAR = \int_{x_{tim}}^{+\infty} q(x)dx \tag{2}$$

$$MAR = \int_{-\infty}^{x_{tim}} p(x)dx \tag{3}$$

To minimize the False Alarm Rate and the Missed Alarm Rate, this study referred to the extended adaptive threshold method proposed by Koorosh to significantly reduce FAR and MAR. The main difference is that when the data is cut into normal and abnormal parts, the adaptive threshold is applied to each part, and it is adjusted according to the upper limit of normal data and the lower limit of abnormal data. Combined with a multi-objective constrained genetic algorithm, the threshold is optimized and adjusted to evaluate the accuracy of the alarm. Finally, the FAR and MAR are calculated according to the corrected threshold repeatedly to determine whether the threshold conforms to the site conditions and then consider the correction requirements.

Many studies and schemes related to threshold adjustment were referenced in the study, and differences among various methods were compared (see Table 2). Due to the good effect of the application of Exponentially Weighted Moving-Average (EWMA) in business, finance and other aspects, this mechanism is applied to reduce the occurrence of false alarms and the missed alarms. Moderate threshold adjustment is the core of a care facility using an IoT device for monitoring. In the simulation application, such a mechanism not only has a good effect of automatic monitoring for accurate notification, but also accurately guarantees the safety of the person receiving care and provides a good care environment for the family members.

Table 2. Threshold adjustment method table

	EWMA control chart	T-COV control chart	Adaptive threshold method of Monte Carlo
Examples	Sensor fault alarm system in large industrial system	It is used to detect false alarm for coronavirus and gear manufacturing errors	It is used for fault diagnosis of coal-burning turbine in industrial equipment
Advantages	It has been used in various financial and economic fields, and can be accurately and effectively used in various data analysis fields	Compared with the past CT control chart, it has better effect	It has a good performance of identification accuracy for equipment diagnosis in nonlinear state
Disadvantages	It is not suitable for the analysis of small amount of diverse data	Only in a few cases can it give reasonable results of error alarm correction	A large amount of data is needed to train the model and verify the effectiveness of threshold adjustment
Reference	[15]	[16]	[17]

4 Application

In this study, the IoT equipment was divided into physiological equipment, and environmental equipment, and field subdivision was carried out. Taking the clinical situation of the institution as the main analysis target, the physiological and environmental data were collected according to the IoT equipment in the actual field. Physiological equipment includes the sphygmomanometer, forehead thermometer, etc. Environmental equipment includes an intelligent floor mat, control socket, temperature and humidity sensor and multi-communication edge computing gateway. Through the gateway in the clinical field, the data signals of all IoT equipment are integrated. After preliminary data judgment and processing, the data are uploaded to the cloud healthcare information platform for analysis and storage, so as to reduce the cost of IoT equipment construction and provide a more friendly long-term healthcare environment for family members and the elderly.

As shown in Fig. 5, the back-end healthcare information platform presents the measured data with a graphical interface, and analyzes the data according to the different IoT devices used by the elderly. In order to let the nursing staff quickly understand the situation of the institution, we designed some functions for the system interface, including the management of personnel and equipment, as shown in the solid box (A), and with no more than two clicks as the humanized design goal. The section box is the data graph of the environment device. Block B is the sensor data record of the smart mattress, from which we can know the time of the elderly getting up and down the bed and going to the toilet at night. Block C is the use record of the control socket, from which the use status of the socket can be grasped to further understand the practicability of the socket in the mechanism. The dashed box is the data chart of the physiological measurement device. Block D is the sphygmomanometer measurement record. In addition to setting the systolic pressure at 130mmHg and diastolic pressure at 80mmHg in accordance with the latest treatment guidelines provided by the American Heart Association in 2017, the system also considers that blood pressure varies slightly depending on individual conditions. A fixed threshold setting will cause many false alarms or missing alarms, leading to the anxiety of nursing staff. Therefore, the adaptive threshold design is used to adjust the appropriate threshold flexibly, and the FAR and MAR are calculated continuously to get the most appropriate threshold setting. Block E is the measurement data record of the forehead thermometer. According to the body temperature standard of the Ministry of Health and Welfare, a fixed threshold was set, such as the normal forehead temperature between 35.0 and 37.5 °C. This chart can be used to quickly understand the temperature changes of the elderly, allowing caregivers to judge whether the elderly have a fever trend. Caregivers can click on an elderly person's name for detailed data, and use the platform to remotely operate specific IoT devices.

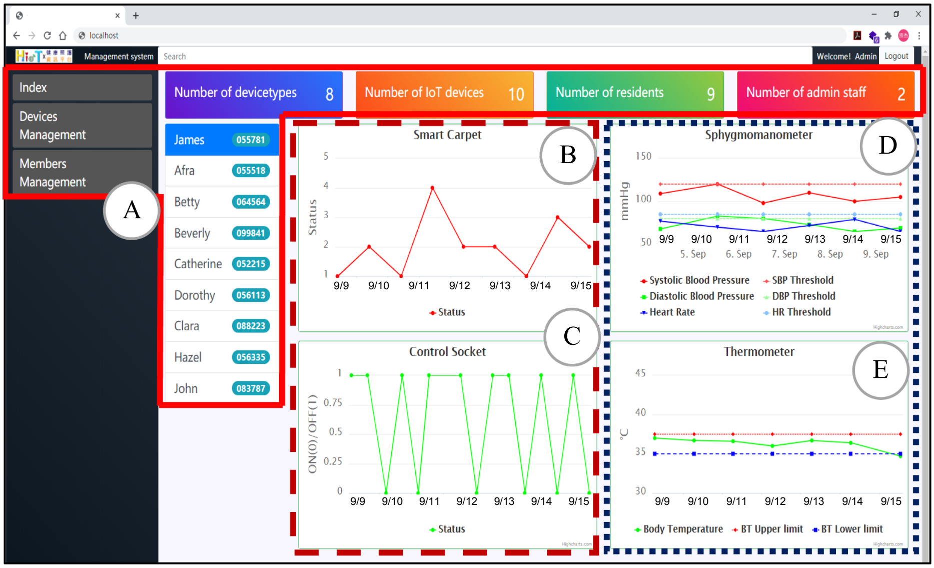

Fig. 5. Data map of the healthcare information platform

5 Conclusion

To ensure that the care system and IoT equipment can help nursing staff, family members and patients, this study designed the IoT environment with innovative concepts. The threshold setting of traditional IoT equipment is fixed, such as the standard blood pressure, blood sugar, heartbeat and other professional biomedical data set by the Ministry of Health and Welfare. In this study, physiological sensing equipment in accordance with medical standards was used, and the flexible adjustment mechanism of environmental sensing equipment was also designed. The data generated in various locations in the institution vary with different environments. For example, the toilet is damp, so the humidity is high; the fire is often used in the kitchen, so the room temperature is high; and the aerosols in the social hall need to be accurately grasped. Therefore, we used the adaptive computing mechanism to set the threshold, so as to get the appropriate notification threshold.

The phased alarm notification mechanism can not only effectively help the elders to get rescue from professional nurses in real time through intelligent notification technology or alarm functions, but also enable the fixed configuration of IoT equipment to be flexibly adjusted according to different factors of time and space through adaptive threshold technology, so as to reduce the interference of false alarms and missed alarms to the nursing staff. In addition, in order to solve the delay and bandwidth problems of data transmission from a large number of IoT devices to the cloud, an edge computing system was added to the gateway in the study, so that the data could be quickly determined and processed by distributed technology and more processing time could be given to nursing staff. When the data changes and tracking are presented in a graph on the care platform, and the care personnel can effectively assist the nursing staff, elders and family members through remote operation and rapid application of the IoT device, so that the patients can get better care and the nursing service efficacy of various institutions can be gradually expanded.

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