Paper:

A Robot Partner Communication System for Smart Home Based on Healthcare as a Service

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Abstract. In recent years, population aging has become a severe social problem. By using smart homes that include robot partners, we can monitor the health of the elderly without additional human resources, but it is a challenge to provide personalized intelligent healthcare services for the elderly. This paper explains a human-centric approach to provide personalized services. From the viewpoint of healthcare as a service, We design a cloud-based healthcare system for smart homes. Next, we explain the system's data structure and information flow, including sensors and service robots. Furthermore, we develop a scenario editor to realize the accessible design of healthcare services. In the demonstration, as a personalized function of essential fall detection, through the scenario editor, we design a situation confirmation function based on robot communication to prove the effectiveness and usability of the system.

Keywords: Healthcare as a Service, Partner Robot, Scenario Editor

1. Introduction

In recent years, population aging has become a severe social problem. Developed countries such as Japan and Germany are faced with an aging population. According to the Japanese government, one out of three citizens will be over 65 by 2025 (Fig. 1) [1]. The proportion of the elderly to the male and female population is 14.6% and 22.6%, respectively, implying there will be approximately 2.3 million older men and 4.7 million older women in the future. It is essential to provide monitoring and health support services to ensure the quality of life of the elderly. In the context of the ever-expanding demand for nursing services, we should pay attention to a severe shortage of professional caregivers. In Japan, according to the Ministry of Health, Labor and Welfare, it is estimated that about 2 million nursing staff will be needed by 2025 [2]. However, at the end of 2016, the total number of the nursing staff was only about 1.66 million [3], so even if it increases 30,000 a year, the expected number of the nursing staff in 2025 will be about 1.93 million.

The research and development of smart homes can significantly reduce the workload of caregivers. Internet of Everything (IoE), including the Internet of things (IoT), known as an advanced paradigm to connect physical and virtual things for enhanced services [4], has been introduced for developing smart homes. However, measurement data are only used for simple safety confirmations, such as human localization and fall detection.

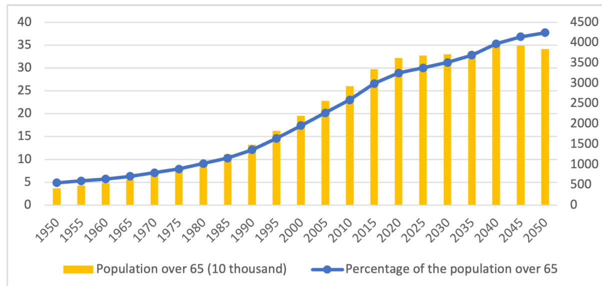

Fig. 1. Trend of older adults living alone

The integration of IoT technology in Healthcare brings several challenges, including data storage, data management, data exchange between devices, security and privacy, and unified and ubiquitous access. One possible solution that can address these challenges is Cloud Computing technology [5].

Healthcare is closer to users receiving health services provided by operators than users getting products from the latter, which aligns with the XaaS concept under the cloud service concept. In the specific application of smart home, the inspiration given by Healthcare as a service (HaaS) is that compared to using intelligent sensors and wireless network technology to obtain accurate user information, we need to care more about how to use this information to improve The user's quality of life (QoL) and guarantee the user's health. Most importantly, Healthcare must be adaptive and must customize its treatments to the needs of the users [6].

Through technical means, we hope that medical staff can participate in the construction of healthcare services in smart homes without learning robots or communication technology. In order to achieve this goal, we build a HaaS-based smart home platform for elderly care. And based on this platform, a scenario editor that can be used without technology is designed.

The rest of the paper is organized as follows: Section 2 introduces the previous work of service robots for elderly monitoring systems and the concept of Information Structure Space. Section 3 shows the structure of the HaaS-based smart home platform and the design of the scenario editor. After the experiment in Section 4, finally, we conclude our studies in Section 5.

2. Related works

We have to consider how to deal with information in order to control multiple robot partners in addition to human detection and behavior monitoring in information service. The environment surrounding people and robots should have a structured platform for gathering, storing, transforming, and providing information, because the information accessibility within an environment is essential for both people and robots. Such an environment is called the informationally structured space (ISS) [8]. The ISS realizes the quick update and access of valuable and useful information for both people and robots on real and virtual environments. ISS can be considered as a typical client-server system where a robot partner or sensor network device is a client (physical node). A physical node uploads information to the ISS server and downloads information from the ISS server. This kind of local information processing is considered as the bottom-up access. On the other hand, the ISS can control or manage each physical node from the global point of view. For example, the ISS can set the sampling interval of each sensor network device according to human states and behaviors in the perception level. This kind of global information processing is considered as the top-down access.

In addition to the necessary database features, the information structure space has the following characteristics.

1. Information Sharing Property: All data is independent of the type of sensor, robot, and development environment.

2. Information interpretability: All data is interpretable between robots and people.

3. Information reversibility: Measurement data is the reciprocal between digital data and symbolic representation.

4. Standardization and Modularity: Based on the idea of HaaS, operators should provide basic modules. In the default state, in order to provide a unified default service, the data should be stored in a standardized form and kept modular for all server equipment and programs to call. (Fig. 2) [7].

5. Adaptability and Maintainability: The format and content of information storage should meet the individual needs of users and be determined according to the physical and transmission environment.

Based on the idea of HaaS and ISS, we built a smart home platform shown in Fig. 3. A variety of different sensors upload data to the cloud server through the network management, and the calculation result of the cloud server is sent to the user's smart device. At the same time, users can view the running status of all devices on the smart device and perform simple settings.

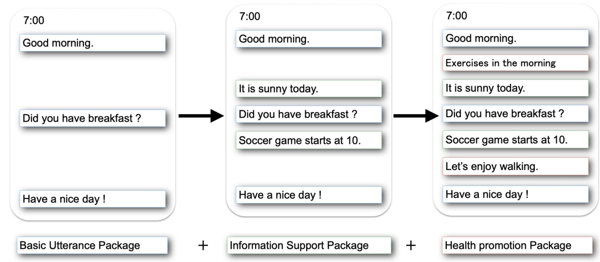

Fig. 2. Organized service packages of ISS

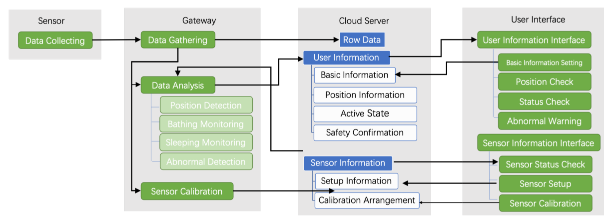

Fig. 3. Smart home system structure including cloud mySQL server, local server and device nodes

3. HaaS-based healthcare robot partner system

We have long believed that a stable elderly care system cannot rely on sensors alone. On the one hand, sensor data and background speculation can only reflect the expected behavior of the system. On the other hand, the scenarios that older people may encounter are diverse. Therefore, we need to confirm the system's judgment by means other than sensors. We call it "sensor + α".

We have developed and used various types of robot partners for elderly care, rehabilitation support, information service, and robot edutainment [9]. In this research, we have developed a robot partner "iPhonoid"(Fig. 4) as the α. we propose this smart device-based robot system [10] to reduce construction costs. iPhonoid consists of iOS devices, robot bodies, micro controllers, and servo motors [11]. iOS devices equip a variety of sensors such as gyroscopes, accelerometers, illuminate sensors, touch interfaces, compasses, two cameras, and microphones. These sensors are sufficient for the robot partner to interact with the elderly.

3.1. System structure

In previous research, we have implemented a smart home monitoring system including sensors, server, and user terminals. In order to control the communication content of the robot in real time, we have added a local server for controlling the robot on the previous system 5.

We subdivide the cloud server into online information database and online scenario database. The former

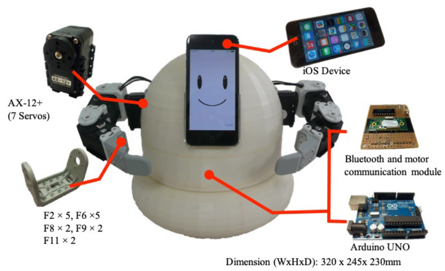

Fig. 4. Construction and individual components of iPhonoid

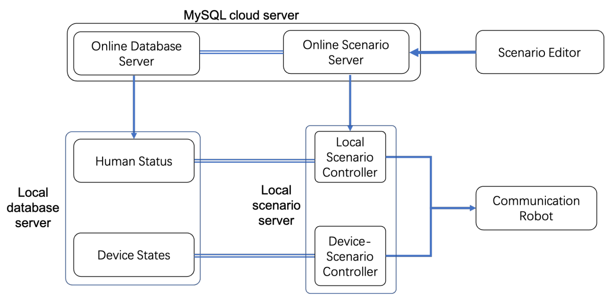

Fig. 5. The structure of cloud-based robot communication system

contains all the information from sensors, networks, and smart devices, as well as the current state of the user derived from the above information. The latter includes all pre-set communication scenarios.

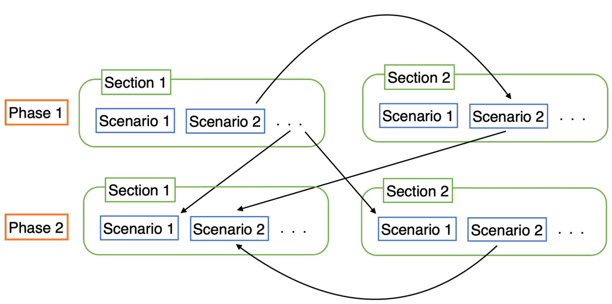

Fig. 6. The structure of cloud-based robot communication system

Correspondingly, the local server is also divided into an information server and a scenario server, which are connected to the two parts of the cloud server through Wi-Fi. The device states module records the operating conditions of all the devices in the current system. Depending on the connection and operating conditions, the services that the system can provide will change through device-scenario controller. The Local scenario controller directly controls the communication content of the robot. According to the current situation, the system will decide what kind of service (such as exercise amount management) to provide to determine the Phase. Each Phase contains several Sections corresponding to different situations under this service (such as insufficient exercise amount reminder, exercise amount reports, etc.), each Section contains several specific scenarios, which include the specific communication dialog, expressions and postures (if necessary) of the robot .

According to the different services provided, each scenario has its own independent Phase_ID, Section_ID, Scenario_ID. The system can skip section and scenarios, and can go back to previous scenario. The next section is transited to the next according to the conditions, e.g., voice recognition and user ’ s interaction.

3.2. Scenario transition system

The scenario transition system can integrate three processing levels for healthcare services according to

1. the types of sensors connected to the network in the data level,
2. measurement results of environmental states and human activities in the information level, and
3. interactive scenarios with a service robot at the knowledge level.

3.2.1. Data level

First of all, we must consider that in different households, the types and quantities of connected sensors and smart devices are different. However, it is obviously unrealistic to independently develop a set of robot communication scenarios for each situation. The Device-scenario controller is designed to solve the above problems.

The enabled state of all scenarios is set as shown in the Table. 1

Table 1. Mode of a scenario

Mode	Explanation
0	OFF
1	Full mode
2	Basic mode

When the user chooses not to enable a certain function, or the device does not meet the enabling conditions, the mode is set to 0. The scenario controller will not select dialogue from the scenario with mode=0. When the function is enabled, mode is set to 1. The scenario controller will select the dialogue normally. In particular, some services require specific sensors or smart devices to provide complete services. When the corresponding device is unavailable, the mode will be set to 2. In basic mode, the system will use other sensors and environmental information to provide the same service as well as possible.

Here I show two examples:

When the mat sensor used to measure the sleep status of the elderly cannot be used, the sleep management function is disabled; when the sensor tag placed in the medicine cabinet to monitor whether the elderly take medicine on time cannot be used, the medical remind function becomes the basic mode: only remind the elderly to take medicines according to the time.

```
if mat_sensor.state == 0 or 99 then
    sleep_management.mode = 0;
else
    sleep_management.mode = 1;
end
```

```
if sensortag_medicine_cabinet.state == 0 or 99 then
    medical_remind.mode = 2;
else
    medical_remind.mode = 1;
end
```

It should be noted that only when the conditions are not met at all, the system will close the corresponding service.

3.2.2. Information level

In order to improve the ease of use and interpretability of the system, all sensor information is not simply stored on the server in the form of raw data, but also includes storage based on events and status. For example, the humidity sensor in the room can report the current humidity in real time, but this value is meaningless to the user. Since a dwelling is considered to be healthy at a humidity of 40 - 60%, we divide the humidity into 1 (too low), 2 (comfortable) and 3 (too high). In this way, we can design new scenarios not based on values, but based on events and states.

3.2.3. Knowledge level

Merely displaying the current state of the user on the user interface cannot be called a service. Only when the system makes full use of these data, and provides the information that users need through communication and other forms based on existing knowledge, is the complete form of the service. The focus of scenario control at the knowledge level lies in the flexible use of this information.

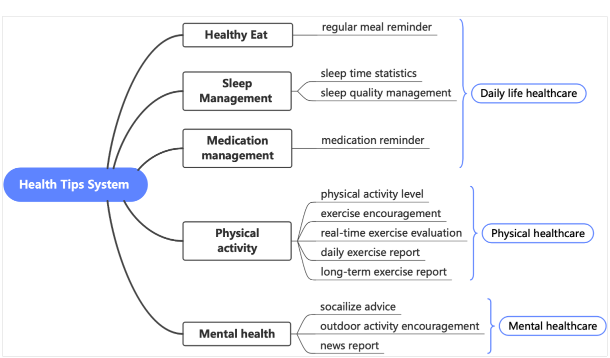

Fig. 7. Functions of healthcare tips system

According to the guidance of medical institutions for the healthy life of the elderly [13], as well as the sensors we can currently use, we have listed some of the health tips functions that can be provided (Fig. 7).

3.3. User friendly scenario editor

Contents design is one of important problems to popularize robot partners in daily use at public areas. Therefore, we develop a human-friendly scenario editor for users unfamiliar to robot technology (RT) and information and communication technology (ICT). Upper right of Fig. 5 shows the scenario editor linking with the cloud database. Specifically, the scenario editor is divided into two parts: the dialog editor and the transition editor, which are respectively connected to the dialog database and the transition database on the cloud server.

We designed the robot user interface with the aim of making it easy for people who are not familiar with robots to operate the robot in a friendly and intuitive manner. In addition, content can be created and managed by downloading content from a database in the cloud and editing it via the iPad, making it possible to create content anywhere with an iPad that can connect to the Internet. Fig. 8 shows the screens of scenario editor.

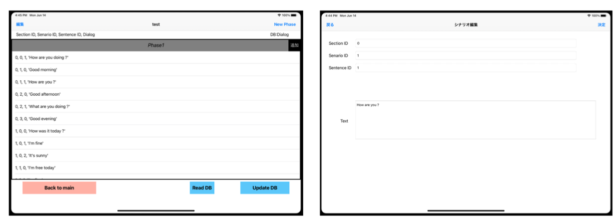

Fig. 8. Screen of scenario editor (Left: dialog list interface; Right: dialog editing interface)

4. Demonstration

In this section, we will use a demonstration of users or service providers create new function through the scenario editor.

We chose to use a set of vibration sensors. This kind of vibration sensor can monitor the movement of people in the room in real time and alert the caregiver when the elderly person falls (Fig. 9) [14]. However, in most cases, the elderly people have the ability to recover on their own after a fall, so alarms are not always necessary. Therefore, we create a status confirmation function through the scenario editor to improve the accuracy of the fall detection.

When we use robot partners, we can perform a second confirmation to further ensure that the user's status is correctly grasped, and seek help according to actual needs (Fig. 10). When the system determines that someone may have fallen, the robot will confirm by voice. If a voice response is received, or the vibration sensor detects human activity again, the system will not alarm. If there is no response for a period of time, the system will contact the caregiver for help.

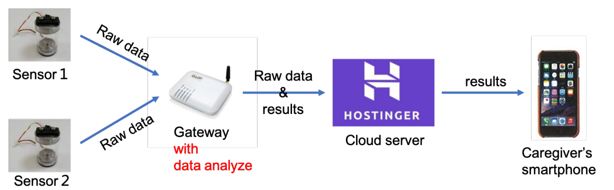

Fig. 9. A basic fall detection function based on vibration sensor

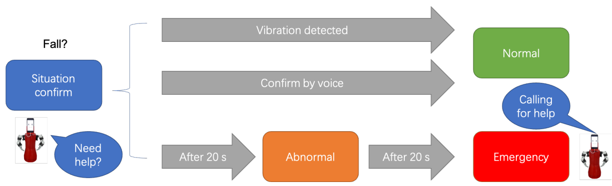

Fig. 10. A robot fall confirmation system demonstration

Table. 2 shows some of the dialogs that may be used in situation confirmation service. and the sentence number includes Phase_ID, Section_ID, Scenario_ID. The scenario in this service is simple, so all dialogs are in the same section. Through the scenario editor, we can easily modify the content of the dialog.

Table 2. Dialog for fall confirmation system

ID	Dialog
(0,0,0)	I heard a loud noise, are you okay?
(0,1,0)	I'm glad you are okay.
(0,1,1)	Please let me know if you need help.
(0,2,0)	Are you falling down? need any help?
(0,3,0)	I can not hear you. I will call for help.

Table. 3 shows the sensors that this service needs to call. The number in parentheses after the sensor represents the sensor number. All information from wireless sensors are numbered 0-99; messages from the system are numbered 100-199; the results from voice recognition are recorded in 200-299. NEW SENSOR Incorporated (NSI) has developed the sensor we use in this study. Under our training, the current vibration sensor can obtain data such as the person's position, current action, and walk steps [15]. For convenience, irrelevant state is not shown in the table. For speech recognition, we use the Speech framework of Swift under the iOS platform. And we have prepared a dictionary of synonyms. Words with the same meaning as Yes will also be detected, and the status of "Voice recognition: Yes" will be changed to TRUE.

When we have prepared all the dialogs and planned which sensors to use in this service, we can start to make the transition table for the status confirmation service. In Table. 4, we show the transition rules in logical language. And Fig. 11 shows the transition rule set actually used to control this process on the iPad APP.

When we upload the dialog and transition to the cloud server by just clicking "Update" on the iPad), and ensure

Table 3. Some sensors and their states used in the fall confirmation system. The number in parentheses after the sensor represents the sensor number; the number in parentheses after the status represents the status number. These two sets of numbers are used in the scenario editor

Information	State 1	State 2
Vibration (70)	Active (1)	Fall (2)
Voice recognition: Yes (200)	TURE (1)	FALSE (2)
Timer (100)	> 20 s (1)	> 40 s (2)

Table 4. Transition table for fall confirmation system

Dialog Old	Dialog Next	Situation
NULL	(0,0,0)	vibration = fall
(0,0,0)	(0,1,0)	vibration = active or voice recognition = yes
(0,1,0)	(0,1,1)	//
(0,1,1)	(0,2,0)	timer $>$ 20 s
(0,2,0)	(0,3,0)	timer $>$ 40 s

that all the sensors that need to be used in this service are correctly connected to the network, this service can be used.

Fig. 12 shows the actual operation of the system after the "Status Confirmation Service" is installed. When the participant fell from the bed to the floor, the robot confirmed it. Since no feedback was received within 40 seconds, the robot sent an alert to the caregiver's mobile phone.

5. Conclusion and Future Works

Based on HaaS, this paper proposed a human-centered smart home system including robot partners. We connected the wireless sensor system with the robot through cloud server, and designed a scenario controller to real-

Fig. 11. All transitions can be check and edit on the scenario editor APP

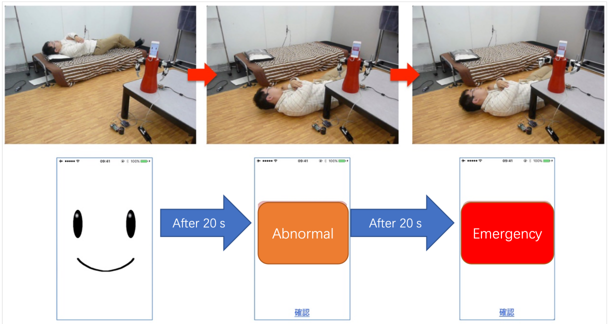

Fig. 12. The robot can correctly issue an fall alarm based on sensor information

ize the healthcare service completed through human-robot communication. We also designed a scenario editor that can be used without any knowledge of RT and ICT, so that users or operators can further customize service functions. Through a demonstration of fall detection + status confirmation, we showed the usability of the system.

Due to COVID-19, we have not yet tested this system in the homes of elderly people, and this will be one of our next phases of work. In addition, we will further improve the performance of the robot under the multi-sensor collaborative work.

Acknowledgements

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