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Human-Robot Interaction of an Active Mobile Robotic Assistant in Intelligent Space Environments

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***Abstract*-**This paper presents techniques for system design and human-robot interaction of an active mobile robotic assistant for the elderly people in known, cluttered and dynamic indoor environments. The RFID-based intelligent space is proposed to automatically help users to attain desired services and prevent from possible accidents. A useful human-robot interactive system (HRI) is presented which includes facial expressions, event reminder and two nursing-care functions. An operational scenario is presented for showing how the robot interacts with the user. Experimental results are conducted to show the merits and effectiveness of the proposed techniques.

keywords - Human-robot interaction, intelligent space, mobile robot assistant, RFID.

I. INTRODUCTION

Thanks to significant improvements of medical science and biomedical engineering technology, life expectancy of humans has been lengthened so that home-caring and nursing-caring problems become increasingly important for families with the elderly as well as government agencies. It is predicated that, in Taiwan, the population of senior citizens over 65 years old is 9% by the year 2005, and will be 15% by the year 2020. In Taiwan, current facilities and conditions for the majority of the elderly people who need nursing-care or home-care aids are already rather insufficient, and this situation will be estimated to get worse in the future if the nursing personal still remains in the current status. On the other hand, most of the elderly people prefer to stay at home instead of hospitals because of privacy, safety, comfortable and convenience. Hence, to cope with the home-caring and nursing-caring problems, much effort in the US, German, Japan, Korea, Sweden, Norway, Taiwan, and etc., has been paid to construct several kinds of nursing-care mobile facilities to meet the requirement of the elderly people.

Many mobile robotic assistants constructed to meet nursing-care requirements have been extensively investigated in the past decade [1-5]. In general, mobile robotic assistants can be classified by two categories: passive and active. Active mobile robotic assistants provide safe navigation for leading the users to reach their desired destination by its internal power, whereas passive ones provide only braking functions for the users and move by the pushing force from the users. Active mobile robotic assistants are developed with several functions, such as perception (automatic gathering of environment information), navigation and friendly human-robot interactions. Perception and navigation are often dependent on external sensors, such as sonar, ultrasonic, laser scanner and vision sensors. Similarly, human-robot interactions also require many external sensors, such as vision, smell, textile, and sound and so on. In order to prevent mobile robotic assistants from making error decisions based on erroneous sensor data, a good mobile robot assistant would have redundant sensors. Multi-sensory systems not only increase the fault tolerance, reliability, robustness and precision of the robot perception and navigation, but also enhance the capabilities of friendly interactions between active mobile robotic assistants and users.

Intelligent space is a relatively new concept that was created to effectively use various engineering disciplines such as automation and control, hardware and software design, distributed sensors, actuators, robots, computing processors and information technology over communication networks to make intelligent operation decisions over a space of interest [6]. From this application viewpoint, the intelligent space technology would be promising for assisting the mobile robots and the elderly people, in order to provide convenient and fast services. Moreover, the RFID technology has been widely used for logistics, material handing, personnel monitoring, and other important applications. For active mobile robotic assistants, passive and active RFID systems not only have been successfully utilized for robot localization [7-9], but also have been applied to identify users in order to quickly provide their demanding services.

Several kinds of active mobile robotic assistants have been extensively studied in [10], but little attention has been devoted to human-robot interactions and user-oriented nursing-caring functions. Hence, this paper aims to develop a much better nursing-care scheme and a more practical human-robot interaction system for an active mobile robotic assistant for the elderly and disable people. The contributions of this paper are as follows. First, a human-robot interactive system for the mobile robotic assistant, including face expressions, event reminder, and two nursing-care functions, is constructed. Second, a RFID-based intelligent space technique is proposed to help users to attain desired services and prevent from possible accidents. Third, an interesting operation scenario is presented to show the merits and effectiveness of the proposed methods.

The rest of this paper is organized as follows. Section II presents the architecture of the active mobile robotic assistant. Section III introduces the RFID-based intelligent space. Facial expression, event reminder and nursing-care functions will be described in Section IV. The operation scenario for the elderly

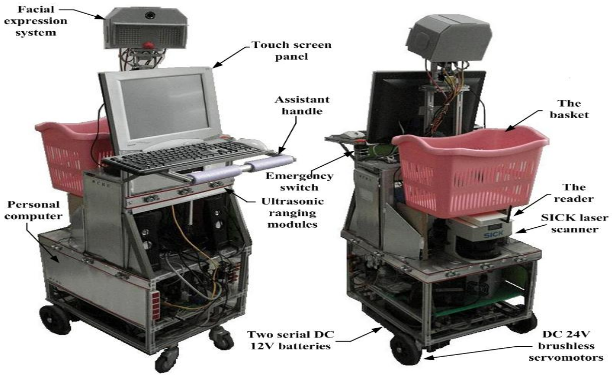

Fig.1. Physical configuration of the mobile robot.

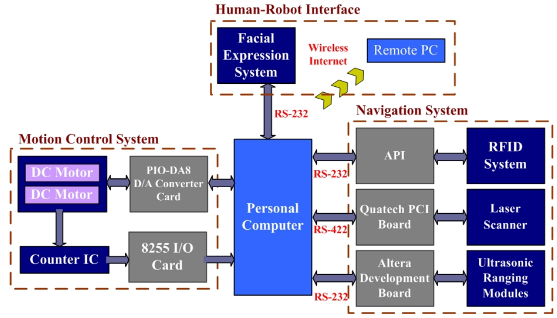

Fig.2. Block diagram of the mobile robotic assistant.

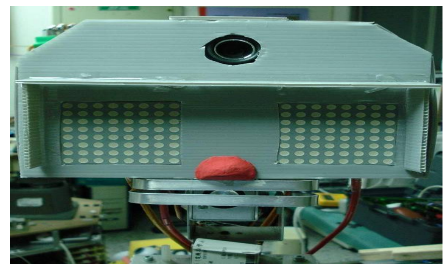
Fig.3. Facial expression system.

people is proposed in Section V. Section VI conducts several experiments to show the effectiveness of the proposed methods. Section VII concludes this paper.

II. SYSTEM DESIGN

A. System Description

Fig.1 shows the physical configuration of the proposed active mobile robotic assistant. The robot is equipped with a personal computer with required input-output devices, a motion control subsystem, a wheeled mobility configuration with differential driving, the SICK laser scanner, 12 ultrasonic SRF05 ranging modules, the radio frequency identification (RFID) system, a power supply subsystem, a facial expression system, a web camera, a touch-screen panel, and a wireless internet card. The length of the robot is 55 cm, the width 44 cm, the height 150 cm and the weight about 60kg. The computing unit of the robot includes a personal computer, one D/A (digital-to-analog) interfacing card (PIO-DA8), one digital parallel 8255 input/output interfacing card, and a touch-screen panel. This computational unit is responsible for real-time sensing, control and executes the algorithm of safe navigation. The touch-screen panel receives the commands from the user and returns them back to the computer. The motion control system requires a DC 24V power offered by two serial DC 12V batteries. Fig.2 introduces the structure of the system.

Two optical encoders mounted on the motor shafts are used to obtain the speed and travelling distances of the vehicle. The environmental information from the SICK laser scanner and the set of SRF05 ultrasonic ranging modules will be transferred to the computer through the RS-422 with Quatech Universal PCI board and RS-232 serial port via ALTERA Nios II Development board, respectively. The RFID system calculates out the initial position and orientation of the robot. Moreover, for the reason of security, several images are taken by the web camera and transmitted to the remote users through the ASUS wireless internet card. The operation system adopted for the personal computer is WINDOWS XP. Its main advantage is that many software packages and peripherals support this kind of operation system, and there have several real-time built-in functions.

The programming language Visual C++ is used to build the human-robot interaction, all navigation algorithms and control codes. This kind of language is pretty decent to users, while writing the algorithm codes. To analyse and synthesize the designed control laws, the software package named Matlab 6.5 provides users good design environments, powerful simulation and design toolboxes in order to accomplish the controller synthesis.

B. Facial Expression System

In order to enhance interactions between the robot and user, it is important to design one lively and friendly interesting facial expression system. Fig.3 depicts the facial expression system has several kinds of facial expression, vocal interaction, and 7 degrees-of-freedom. This kind of facial expression system is improved from its original systematic hardware structure by Dr. Robot Company, which structure is a Logitech web camera, a speaker, three servo motors and two 16×16 LED matrix eyes. Both the host computer and Nios II development board Stratix II edition are connected together to control the facial expression system via RS232 communication. In order to offer the interactions between the user and the robot more naturally, the robot has a facial expression system of some kinds to express its emotion. The moveable joints of the facial expression system are 5 RC servo motors. The eye of the head system is a web camera; it can capture images with the rate of 30 frames/second. The facial expression has two 16×16 LED matrices which can make facial expressions to be lively and vivid, thus increasing the user's enjoyment. However, the real eye of the robot is constructed by one web camera.

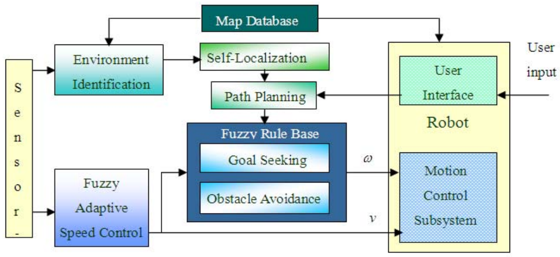

Fig.4. Block diagram of the fuzzy hybrid navigation scheme.

C. Hybrid Navigation

Fig.4 illustrates the basic ideas of using the hybrid navigation method to steer the mobile robotic assistant. The navigation uses nine ultrasonic rangers and a laser scanner to identify the surrounding environment. According to the environment data measured by the sensors and the robot's speed v determined by fuzzy adaptive motion speed controller, the robot employs the behaviors fusion method [10] to inference the output variables ω via fuzzy control logics. The following steps show how to design a hybrid navigation control method.

Step1. Load the specified map data.

Step2. Input the starting and the final pose.

Step3. Plan the path by Dijkstra's algorithm [10].

Step4. Establish line environment model

Step5. Obtain the robot pose by fusing the readings from the RFID, the encoders on the driving wheels, and the laser data. Detect the average distance between the user and the robot by the ultrasonic rangers, and calculate the appropriate speed v of the robot by the fuzzy adaptive speed controller [10]. Measure the obstacle information using the ultrasonic rangers and laser scanner.

Step6. Compute the angular speed ω to determine the vehicle heading by a fuzzy behaviour fusion approach which fuses the two behaviours: goal seeking and obstacle avoidance

Step7. Output the control signals v and ω.

Step8. Repeat Step 4 to Step 7, until the robot reaches the final pose.

D. Teleoperation

Teleoperation indicates operation of the mobile robotic assistant at a remote distance. It is most commonly associated with robotics and mobile robots; for example, two major components of telerobotics and telepresence are visual and control applications. The camera on the robot provides a visual representation of the view from the robot. The client and server require a well-known set of conventions before service be rendered and accepted. This set of conventions comprises a protocol which must be implemented at both ends of a connection. The protocol for teleoperation can be either symmetric or asymmetric, depending on the situation. No matter whether the specific protocol is symmetric or asymmetric, there is a "client process" and a "server process" when a service is executed. Fig.5 describes the flow chart of communication between a server and a client. The host computer mounted on the robot wirelessly communicates with the remote computer, such that the robot environmental position and the pictures caught by the CCD camera are sent to the remote computer in the client control system. The measurements from the laser scanner, the ultrasonic range modules and the RFID system, are also conveyed to the remote computer. Through teleoperation, the operator or any remote user can control the robot easily and effectively, or understand the current situation of the environment surrounding the robot through CCD camera.

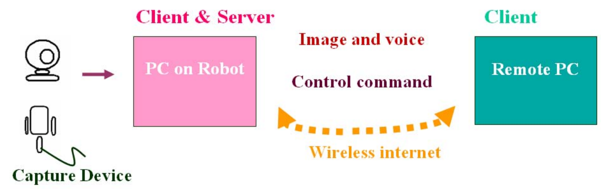

Fig.5. Teleoperation.

III. Intelligent Space

Constructing and applying intelligent environments have received considerable interest in industrial and academic circles. Digital life is the primary issue of intelligent environment research. Intelligent environments, in conjunction with identification technologies, are supposed to enhance our life style. In this subsection, an RFID-based intelligent scheme capable of increasing the efficiency of mobile services is presented. The proposed scheme consists of four mechanisms as follows: the intelligent info-filtering mechanism for tags reading, the secure settlement and payment mechanism, the status-management mechanism of daily commodities, and the management mechanism for operating home appliances. The proposed scheme can integrate RFID and context awareness technologies in ubiquitous environments to increase the efficiency of mobile commerce and probably change the life style in the future.

The range of the intelligent space is quite extensive, such as campuses, Volkswagen transportation system space, shopping mall, workplace, or house. However, this research focuses on and looks after the system at home more. When the intelligent space is used vastly, there are two basic and important aims: the discernment of personnel and things, and its status information; If the system is unable to discern correctly and effectively the personnel or the things in the space, it cannot fetch useful information and use it for optimization, let alone to apply to the operation of the intelligent space. It is by solving the real problem concerning life and improving the quality of the life to study the purpose. As to security question used in the intelligent space, it is important to have the mechanism of protection. To specific service demand of elderly people, it is necessary to design the intelligent operation mode.

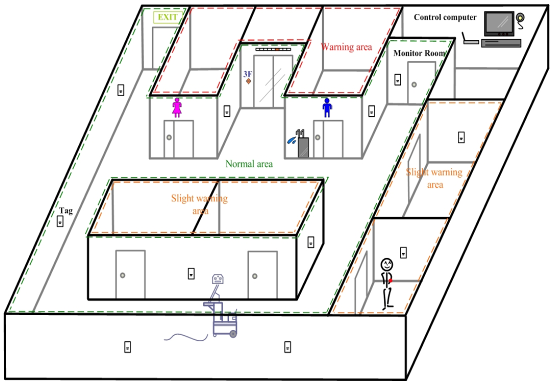

Fig.6. Illustration of an intelligent space.

Except monitoring of the physiological signals, lots of potential security questions exist in the life of the house. The wet and slippery bathroom and kitchen are all potential dangerous places for the elderly people. With the merit of the intelligent space, the ideas capable of protection and distinguishing the personnel and things in the environment of the house can be easily implemented. The discernment of personnel and things is by the RFID system at first. In Fig.6, the intelligent space is divided into several state spaces, each of which has different meaning. The intelligent space system is constructed based on the active RFID technology, wireless network and the knowledge of handling the potential security questions at desired environments. For effective management, the system will divide the intelligent space into several subspaces, every user in the space wears a watch-like tag, and several tags are placed upon some special locations in order to achieve warning, notification, reminding and etc. For example, many tags are installed at some pre-specified locations in the intelligent space, in order to inform the user the space knowledge, and the user will wear a watch-like tag for user identification and emergency.

The operating principle of the intelligent space system is elucidated as follows. While the robot passing by a location, the reader on the robot will receive RF signals from the corresponding tag; if the signal strength is greater than a threshold value, then the space or room corresponding to the tag will be identified for further purpose of essential warning or event reminding. It is worth noting that the threshold value is an important parameter for effective recognition. Tag signals from a user by reader in the intelligent space will be detected to monitor where the user is and take any possible action to cope with possible accidents, for example, the robot will issue an alarming signal to the operator for the occurrence of the long stay of a user in some specific location (i.g., bathroom). More importantly, if the intelligent space system judges via the user's watch-like tag that the user is entering a warning area, then it will show the condition in the operation computer, and then send out the dangerous message to the screen on the robot for reminding the user to avoid possible accidents at the moment. When an accidents or any emergency occur, the user can send out an urgent signal via his or her watch-like tag to the operation computer; after receiving the calling, personnel will give an immediate response to deal with it. On the other hand, if the users have long stays in some space for a long while, the intelligent system is capable of automatically detecting the situation and informing the service people to prevent them from possible accidents.

IV. Human-Robot Interaction

Human-robot interaction (HRI) is especially dedicated to the study of interactions between the user and the active mobile robotic assistant. The basic goal of HRI for the robot is to develop principles and algorithms to allow more natural and effective communication and interaction between humans and robots. Research ranges from how humans will work with remote, teleoperated unmanned vehicles to peer-to-peer collaboration with anthropomorphic robots. Many in the field of HRI study how humans collaborate and interact and use those studies to motivate how robots should interact with humans. The application of the HRI system includes entertainment, education, home robots, companion robotics, rehabilitation and elder care, artificial intelligence, automatic speech recognition, linguistics and telemetric. In order to develop a useful user interface, the scenario-based design is an important object. Scenarios include information about goals, expectations, actions and reactions.

To design the user scenarios, there are three stages: analysis, design, prototype and evaluation. Based on these three design criterion, we constructed the following human-robot interaction system that has facial expression module, event reminder and two nursing-care functions. The events which were already set in the computer database will come into effect and implemented. After the goal where the user wants to go is selected, the mobile robot assistant starts to navigate. The environment data measured during the navigation task, facial expression system will opportunely interact with the user.

A. Facial Expressions

Humans can adopt a facial expression and understand the emotion of each other via certain facial expressions. For making the robot to interact with users more naturally, the robot is designed to simulate several emotions through various facial expressions. In order to increase the interactions between the robot and the user, the robot is equipped with one lively and friendly interesting facial expression system. The CCD camera aims to acquire the user and space images to the remote computer.

The CCD camera catches the states of the user or space at any time, through the vision the remote controllers can understand whether the situation is dealt with in the occurrence of the emergency. The face expression system also matches the voice function established except that there are abundant movements, thereby making the user easily operate the robot. When the user interacts with the robot, the users are often impressed with interesting facial emotions of the robot. Hence, such a system is designed to have facial emotions such as surprising, happy, and disappointed, to gaze around, depressed and etc.

B. Event Reminder

Since the user is recognized using the RFID system, the robot via the speaker reminds him or her of some important events pre-recorded in the system database. Fig.7 depicts the functions of the auto-reminder. The architecture of the auto-minder is divided into three modules: plan manager, space reminder and time reminder. The plan manager is used to integrate the user requirement and determine which reminding function should be enabled, where, according to the database; the space reminder is responsible for reminding the user based on the environment information; and the time reminder reminds the user of the timetable or scheduling of their daily life based on time or events. Fig.8 shows the flow chart of auto-reminder between the user and the robot assistant. The information of the user is stored in the database of the robot. Through the RFID system, the user ID can be effectively recognized by the computer in mobile robot assistant and then transferred to the remote control computer.

The event reminder can prompt the routine directly to the particular user.The robot detects the tag from some user by the RFID system. A new user ID will be transmitted to the host computer and the remote computer at the same time, and the computer will set up this user's database. For effective identification, each user has his or her own tag. The RFID system can locate the robot location in the environment, and can also carry out and distinguish spaces and the elderly people basing on tags.

Every tag has different serial ID number which can be used to distinguish its current room or space. The robot will guide the user to move forward these facilities or space, and then measure this information sent by the mounted tag near the facility. Once the visiting room location is confirmed, the robot will make a brief introduction to the room for the user. If the user wants to go to the lavatory and the floor could be wet, then the robot will automatically remind him or her the situation of wet floor.

C. Nursing-Care Functions

The mobile robot must have nursing care functions to service elderly people. These functions include emergency calling functions, detection of falling down, and monitoring of physiological signals. When the user has accidents or emergencies, he or she pushes the button of the tag on the wrist, and the robot will detect the signal from the user ID; afterwards, the operator will understand through the remote computer and reply the request rapidly. Note that the wrist-type tag is able to detect the function which measures human temperature. When the user dresses on this kind of tag, LED will flash the red light in tag; if not, LED will flash the yellow light in tag. The user can switch the model for walking or following. The use of ultrasonic range modules in the front of the active mobile robot detects the distances between the robot

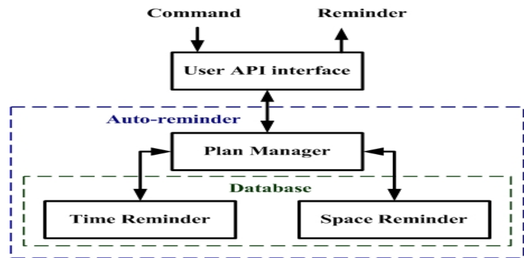

Fig.7. Auto-reminder system.

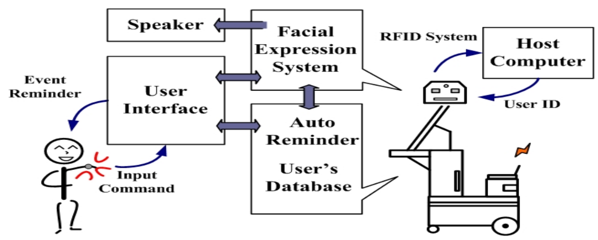

Fig.8. Auto-reminder between the user and the robot.

and the user. If all the ultrasonic readings exceed their threshold values, then the robot will stop, and inform the operation computer to check whether the falling down occurs.

V. Operation Scenario

For the operation problem, the robot provides a graphical user interface to display the environment map such that the user can select the desired destination via touch screen or mouse. At the same time, the robot will interact with the user by many facial expressions and voices. When the user determines the destination, the autonomous navigation mode will be enabled. During the navigation, the robot may perform the function of event reminder which is aimed at assisting the user and sending the image to the operation computer continuously. If there has any danger or accident, the operation computer can control the robot to prevent it from happening. While arrives at the destination, the robot will ask the user if other services are needed; if not, switch over patrol mode; otherwise, associate and wait for the next command with users. For taking care of the elderly people, the mobile robot assistant needs implementing its function properly. The human-robot interface must be convenient to operate and simple to use. The first problem of the mission is where to locate the initial position of the mobile robotic assistant. The global pose initialization problem can be easily done by the intelligent space system. In doing so, the mobile robot has to be placed at some subspace. After receiving an ID of the subspace from the remote control computer, the robot will recognize the environment information and wait for the service request from any user. When the user calls for the service, the computer will detect the tag of the user. The user's ID recorded in the tag will be transferred to the remote control computer with the customer database. The remote control computer will connect with the service robot to transfer the user and subspace information by wireless internet.

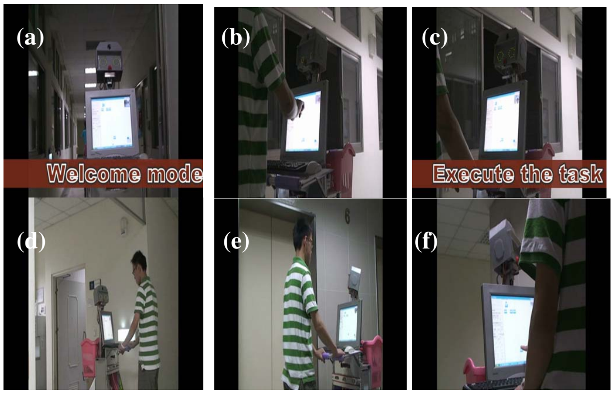

Fig.9. Experimental pictures of the operational scenario.

VI. Experimental Results and Discussion

The experiment environment of the intelligent space was equipped with many tags on the wall. With such an environment, the reader connected with the host computer on the robot will receive tag information to activate operation. The environmental information includes the space state, the room, life requisites, and etc. The experiment was dedicated to the demonstration of the proposed operational scenario in the intelligent space. Assume that the robot has identified the user via the RFID system before experimentation. This experiment started to activate the touch screen which displays the built environmental map and several location options to the user, and enabled the facial expression system and the event reminder to communicate with the user. Note that services can be requested by the user by facial gestures or voices at the same time.

With the commands from the user via touch screen, the robot began to navigate from the selected starting pose to the desired configuration, and told the user that the words of "we are getting started" and "please follow me". Once the robot had arrived at the desired location, the robot informed the user that you are at the destination and checked whether another service is needed. Fig.9. shows the experimental pictures of the operational scenario. In Fig.9(a), the robot got up and displayed the welcome mode. As can be seen in Fig.9(b), the robot moved to select node and the user chose the destination that is the elevator via the touch screen, and the robot interacted with the user via facial expression system and voice simultaneously. Fig.9(c) shows the navigation process. In Fig.9(d), when the robot moved near the lavatory, and detected the tag signal that setting in the lavatory via the RFID system. Afterwards, the robot inquired whether the user needs the service. Fig.9(e) shows the condition when the destination was arrived; the robot interacted with the user. In Fig.9(f), the robot waited for the user, and provided the service again where the user selected the room destination.

VII. Conclusions

This paper has presented techniques for system design, and human-robot interaction of an active mobile robotic assistant for the elderly people. The friendly graphic display with touch panel has been developed such that the elderly people can operate easily and effectively. Much effort has been paid to construct the mobile robot with the capabilities of human-robot interactions, including facial expression, event reminder and nursing-care functions. An operation scenario in the intelligent space with the functions has been presented. In addition to characterizing the regions of the environment, the RFID system can be used to identify the user's status via user's tag ID. After knowing user's identity and through RFID system measuring the user's location, the robot will find and interact with the user via facial expression. Furthermore, for a known user's identity, the robot can serve the function of event reminding. Through experiments, the proposed method has been shown to be capable of achieving satisfactory interactions between the user and the robot.

Acknowledgement

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