Ubiquitous Knowledge-based Framework for Personalized Home Healthcare Systems

Yen-Lin Chen and Yo-Ping Huang
Dept. CSIE and EE
National Taipei University of Technology
Taipei, Taiwan, ROC.
ylchen@csie.ntut.edu.tw,
yphuang@ntut.edu.tw

Hsin-Han Chiang
Dept. EE
Fu Jen Catholic University
New Taipei City, Taiwan, ROC.
hsinhan@ee.fju.edu.tw

Tsu-Tian Lee
Dept. EE
Chun Yuan Christian University
Chung Li, Taiwan, ROC.
ttlee@cycu.edu.tw

***Abstract*—In this paper, a personalized home healthcare system with the ubiquitous knowledge-based framework is presented. This system aims to facilitate the in-person service of healthcare and mobility support. To this end, an efficient rule-based reasoning model and flexible knowledge rules are constructed for providing the necessary physiological support and medication treatment procedures. Among the utilized sensing and control technology, software modules, video camera sensors, communication devices, physiological sensors, and a robotic walking support platform are integrated in our system. The proposed system can offer high flexibility and further meet the demands in the practical healthcare support for different patients and caregivers by updating the knowledge rules in the inference mechanism. The various experimentations can demonstrate the system feasibility and interaction with users under numerous healthcare tasks, intelligent personalized services, remote healthcare and walking support and monitoring.**

Keywords-Personalized healthcare systems, knowledge-based framework; mobility support and monitoring, ubiquitous systems.

I. INTRODUCTION

Nowadays, many developed countries are facing the growing trend of population aging. The emerging contradiction between per-capita medical resources and the growing demand for people health care is increasing. To this end, the application-oriented healthcare systems for the elderly and the patients with chronic disease have become a vital research field. The growing advancement of information and communication technology (ICT) raises the healthcare technique and management to the solution for contemporary family life. Healthcare systems such as wireless emergency telemedicine systems, infant-monitoring systems, mobile healthcare systems, home emergency rescuing systems, handheld electronic patient records, and mobility support robotic systems are widely used to diagnose, treat, and manage human health to enhance the efficiency and quality of healthcare services [1-5].

According to various patients of health, age, and disease, personal demands may differ in providing healthcare services under different settings of treatment or nursing. Therefore, to achieve the flexible home healthcare system for caring for patients, multiple sensors and devices as well as the customized functions for caregivers should be integrated while considering various healthcare demands. For instance, the physiological data of patients can be measured and combined with the video stream so that possible irregular health status can be possibly detected and prevented by caregivers or nursing staff [6]. Though the integration of multiple sensors and intelligent systems technology, the research of healthcare systems emerges the topic called the “ambient intelligence” [7-10], which includes the applications of sensor data fusion and processing, ambient event recognition, affective ubiquitous computing, and intelligent automation. To enhance the daily life quality of patients within a spread environment, so far, the presented healthcare systems are mostly designed for specific healthcare functions and treatment tasks on the basis of predetermined diseases or medication needs for patients [11-13]. However, this approach may limit the application flexibility in adapting adequately to diverse demands and various healthcare services among caregivers and patients.

In this paper, a personalized home healthcare system with the knowledge-based framework is presented. The system framework incorporates 5 major components: a physiological sensing and treatment-monitoring module (PSTMM), a real-time video codec component (RTVCC), a monitoring information transmission module (MITM), a robotic walking support and monitoring component (RWSMC), and a remote patient care and monitoring component (RPCMC). All of the proposed components in our system are reusable, configurable, and extensible so that system developers or caregivers can effectively and rapidly implement or modify the home healthcare systems to satisfy various personalized demands of patients and caregivers from the aspect of ubiquitous healthcare service.

Based on the design concept of modular architecture, the developed system can fulfill the extensible, reusable, and configurable features of the ubiquitous healthcare systems for patients with diverse health status (e.g., health, age, and disease). Furthermore, the proposed system can provide remote video-monitoring functions on the mobile handled devices of caregivers. By updating the knowledge rules in the inference engine, the proposed system can offer high flexibility for improving and extending the system further to satisfy new patient and caregiver healthcare and monitoring demands. The experimental results indicate that the proposed system demonstrates the effective potentiality for our systems with the

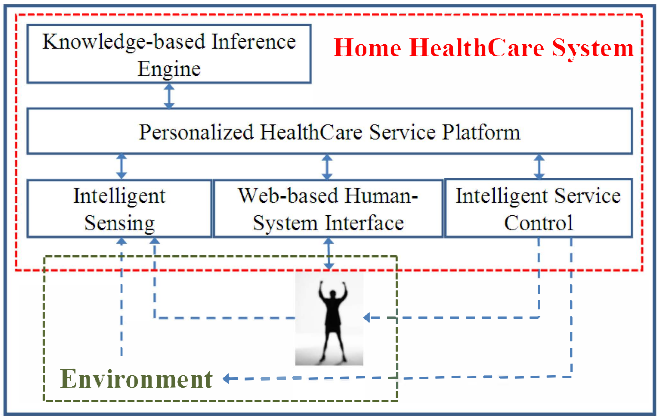


Fig. 1. Proposed home healthcare system framework.

patients and caregivers under various home healthcare conditions.

II. Home Healthcare System Framework

The interaction framework between the user and the proposed home healthcare system is presented in Fig. 1. Through the service platform, all the components can be connected so that each component can communicate with one another. Based on this designed framework, the home healthcare system gathers the health status of user via intelligent sensing modules, receives the user input from human-system interface, and sends all the information to the knowledge-based inference engine to determine the most appropriate service to be provided. According to the inferred results, the system will activate the healthcare services, including interaction with user via interfaces, mediation and treatment monitoring procedures, and walking support capability via the intelligent service control. The design framework is accomplished by integrating the components and modules which are individually introduced in the following sections.

A. Physiological Sensing and Treatment Monitoring Module

To facilitate the application of the corresponding modules and components of the proposed healthcare system, the PSTMM is designed to provide portable and efficient interfaces to acquire and retrieve patient physiological data from sensors. This module also has the interfaces to monitor the patients' treatment processes and physiological statuses. Thus, the alerts can be provided through different server-side systems and remote mobile terminal devices. According to the inference results from the knowledge-based system, the PSTMM provides a set of crucial functions and three software interfaces for recording, monitoring, and alerting caregivers on patient physiological statuses and treatment processes:

1) Physiological data input;

2) Physiological data input/output;

3) Physiological and treatment display.

The first interface supplies the functions for acquiring the patients' physiological data from domestic physiological measurement devices. Then, by using the second interface, the acquired patient physiological data and treatment records of rehabilitations can be recorded in XML-formatted documents with timestamps. In the final interface, these data records can be stored in file archives or transmitted to communication devices for caregivers' remote observation through cooperated correspondence with the MITM. The archived patients' physiological data and treatment records can also be retrieved and observed by caregivers through the local server-side archives, as well as remote handheld devices or Web browsers.

B. Real-time Video Codec Component

To monitor and record a patient's rehabilitation in various home settings and provide convenient caregiver observation, the proposed RTVCC encapsulates the real-time monitoring video compression and decompression technique. In addition, RTVCC integrates and implements the crucial functions and software interfaces for video-monitoring applications used as software components. Three major software interfaces are implemented for conveniently supporting the functions of recording and retrieving patient monitoring videos:

1) Video frame input;

2) Compressed video bit-stream input/output;

3) Video frame display.

First, the video frame input interface should provide functions acquiring video frames from the camera sensors mounted in monitoring regions, as well as compressing the acquired video frames into bit-streams. The compressed video bit-stream input/output interface provides a set of functions for storing and loading compressed monitoring video bit-streams into file archives (such as hard disks and cloud storages) and transmits and receives compressed video bit-streams from file archives or remote network transmission devices (such as Internet and mobile communication networks) by correspondence with the monitoring information transmission module. In coordinating with the service platform and other components and modules, the RTVCC is responsible for providing convenient and portable interfaces to record and retrieve the patient's videos for Web-based interfaces such as mobile terminal devices and Web browsers. Accordingly, using a video frame display interface, the archived or remotely transmitted compressed video bit-streams can be decompressed and retrieved using the display devices of the local server-side system, client-side handheld devices, or Web browsers; thus, caregivers can ubiquitously monitor the patient's care activities and status using various remote devices from far places.

C. Monitoring Information Transmission Module

The MITM is designed with the major function which can transmit the patients' monitoring data to caregivers' remote browsers and monitoring devices. The transmission data includes patients' monitoring video streams, patients' physiological data records, patients' treatment records, and patients' warning statuses. For transmitting the patients' monitoring video streams, the MITM transmits the compressed monitoring video bit-streams, which have been inputted in the video stream buffer using the real-time video codec component, to the remote terminal devices through the wireless communication network devices based on the RTP transmission protocol. During the transmission process, first the MITM loads the desired patients' physiological data or treatment records from the archive device, and then transmits these data or records to the remote terminal devices through the wireless communication network devices through the TCP/IP protocol. On the other hand, the MITM can inform the caregivers of patients' health status by using the alert notification message which is transmitted to the caregivers' remote Web-based servers or handheld personal communication network devices.

D. Robotic Walking Support and Monitoring Component

The developed RWSMC provides the service of walking support with remote monitoring and controlling functions for a home environment. This component is also capable with interactive services according to user requests and task properties. In the walking support service, the robot assists the user in walking and adapts its controlling behavior to the user's controlling characteristics such as step speed and direction intention. In addition, the robot can sense its environment and change its controlling behavior to improve the user's safety. For instance, if there is an obstacle or a narrow corridor in front of the robot system and the user's intention is to go straight, the robot system can adjust its characteristics in speed and orientation so that the collision accident can be prevented. The robot platform initially parks in the specified space. In the call-and-come service, when a requested signal is acquired in the home server, the robot system will navigate to the user location which can be arbitrarily designated on the environment map interface by the user. The home server also provides a gesture-based interaction scheme between the human and the robot system for calling. Moreover, while finishing service, the robot system can be guided to a specific parking space in the home environment map under remote control of a user. The home server connects to the robot system via wireless communication network, and plays a role of the human-robot interaction and monitors the operation status. The operation status can be monitored by using the RPCMC. On the other hand, the caregivers can access the monitoring video stream through the MITM.

E. Remote Patient Care and Monitoring Component

The proposed RPCMC primarily provides the required functional interfaces for caregivers to request and retrieve patient-monitoring video streams, physiological data, and treatment records from the aforementioned modules and component. Four major functions are designed in the RPCMC to acquire and retrieve the patient's monitoring data through caregivers' remote mobile devices or Web-based browsers:

(1) Video monitoring;

(2) Physiological data records;

(3) Treatment record monitoring;

(4) Warning status monitoring.

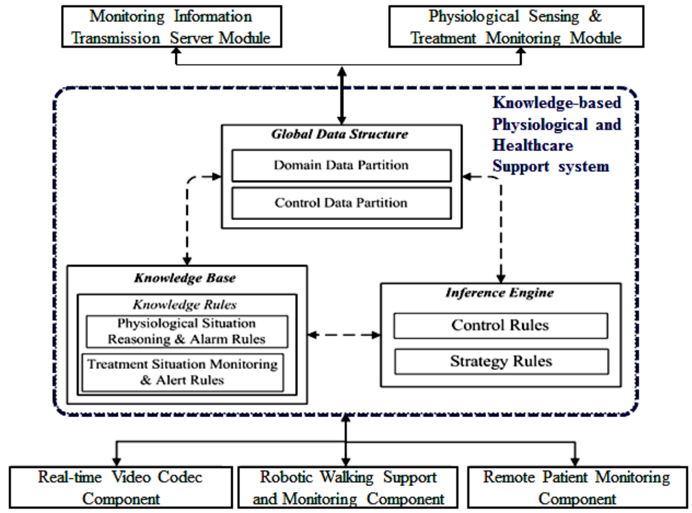


Fig. 2. Integration diagram of the knowledge-based physiological and healthcare support system with the developed modules and components.

The compressed monitoring video bit-streams can be transmitted from the personalized home healthcare system to the Web-based and mobile communication network devices via the RTP protocol. After that, the video bit-streams are decompressed and then displayed on the handheld mobile devices or Web-based browsers with the client-side RTVCC. Patient physiological and treatment data records archived in the home healthcare system can also be retrieved by using the RPCMC through wireless communication network via the TCP/IP protocol. Moreover, the retrieved patients' physiological data and treatment records in XML-archived format are then parsed and displayed on caregivers' mobile devices or Web-based browsers by using the client-side RPCMC. Besides, when an alert message of a patient's warning status is sent to caregivers by the home healthcare system, the RPCMC can access this message from wireless communication network via the TCP/IP protocol and display the patient's physiological warning status on the handheld device or Web-based browsers through the connection with the PSTMC.

III. UBIQUITOUS KNOWLEDGE-BASED SYSTEM

The ubiquitous knowledge-based system for physiological support and medication treatment in the proposed home healthcare system is shown in Fig. 2. This system is constructed by integrating the component-based modules, a partitioned global data structure, and a knowledge base in terms of rule-reasoning scheme, and an inference engine with control and strategy rules. The knowledge-based system can determine physiological situations and treatment procedure of patients by interacting with the aforementioned modules and components in Section II.

A. Knowledge-based System Structure

A three-layer rule-based reasoning model is adopted in the proposed knowledge-based system, as depicted in Fig. 2. This rule-based model comprises knowledge, control, and strategy rules to determine the appropriate physiological and medication services from the software modules and physiological sensing data such as body temperature, heart rate, blood pressure, blood oxygen values, breath meters, and ECGs. The rules in the knowledge base can be updated in the inference mechanism so that the healthcare system can further provide high flexibility and adaptation to various care demands of patients and caregivers. In the knowledge base, the knowledge rules include the physiological condition determination rules and the medication action monitoring rules. On the basis of different physiological characteristics and therapies of patients, these rules can be accordingly designed to perceive typical physiological signal features and then to infer the corresponding caring and treatment procedures.

The inference engine composes of the control rules and the strategy rules. The control rules determine which physiological features and medication procedures should be analyzed and evaluated, which subsequent healthcare process should be performed, and which events should be activated. The strategy rules are to decide the evocation process of a particular set of control rules, and then decide the execution order for the rules based on the physiological features and medication procedures. In addition, to facilitate the rule-based reasoning scheme in analyzing patients' healthcare events, our inference approach adopts a global data structure, which contains domain and control data partitions, to maintain the processing information of the processed physiological features and medication procedures, as well as immediate control statuses. The domain data partition includes the information of the physiological features and medication procedures from the software modules and physiological sensor information which are processed by the physiological and healthcare monitoring modules. The control data partition includes the information on the statuses of the extraction and identification processes and detailed records on any results maintained in the global data structure.

B. Knowledge-based Home Healthcare System Process

In the knowledge-based system, the dominant data representing the physiological and healthcare process in terms of the textual components are categorized into two types:

1) Physiological support contents: These contents are specified in the physiological measurement procedure and feature the patients' physiological data which are measured from physiological sensors and the walking support robotic platform.

2) Medication and treatment contents: These contents reveal the related data and records which are specified in the patients' medication and treatment procedures.

For offering the proper healthcare service for patients, the following major functions describe physiological monitoring and treatment events involved in the designed knowledge rules, the corresponding modules, and the mentioned features:

- **Normal circumstance**: The favorable health status including normal walking support operation is exhibited from the video stream and the physiological records of the patient. Besides, the patient can follow the personalized medication and treatment plans.
- **Irregular healthcare status alert:** First, if the patients miss some regular physiological measurement procedures under a particular period of treatment or walking support operation, the proposed system will alert them and the corresponding caregivers till the regular physiological measurement and support procedures have been completed. Next, if the patients neglect the planned medication procedures after a period, the proposed system then alerts them and the caregivers till the required medication procedures are completed. Third, if some unexpected hygiene procedures of the patients manipulating the system are detected for a particular period, the patients and caregivers will be alerted. Our system will provide the correct procedures to guide the patients to accomplish the required hygiene procedures. Finally, the system will also alert the patient and caregivers if some required feeding procedures for patients are not properly carried out for a particular period.
- **Abnormal health status alarm**: First, if the abnormal features of heart rate, blood pressure, or ECG of patients are detected, our system will immediately send the alarm to the doctors and caregivers for required emergency procedures. Second, since the body temperature of patient can reveal some abnormal health status and represents the deterioration of the physiological body conditions, the proposed system can alert the caregivers or doctors to prepare the further diagnoses and healing procedures. Finally, the patient's breath rate or blood oxygen saturation value reflects abnormal conditions. This indicates that the patient's physiological cardiorespiratory conditions may deteriorate, and the system will give alarm to the doctors and caregivers to perform diagnoses and care procedures.

IV. RESULTS

The prototype home healthcare system was implemented based on the proposed knowledge-based framework as mentioned in above sections. The current implementation of the system integrates four CCD cameras to facilitate the patient-monitoring of four separate video-monitoring settings, the walking-support robotic platform with remote monitoring functionality, measuring patient physiological data using measurement devices, transmitting the videos, physiological data, treatment records, and warning messages to Web-based server and wireless and handheld devices.

The system core of the proposed prototype service system platform is implemented on an ARM-based embedded platform (TI Marvell PXA310) due to the advantage of an efficient economical solution for portable and handheld systems. This platform consists of one Marvell PXA310 ARM-based general-purpose processor with a 624-MHz operational speed, and includes 256 MB of flash ROM memory for storing the embedded Linux OS kernel, Qt-based GUI system, and 128 MB of DDR memory. The peripheral devices including the video-sensing devices, the physiological sensor modules, the wireless network communication module, and the robotic platform are integrated to accomplish the ubiquitous support of home healthcare system. Regarding to the efficiency of documenting the monitoring video records of patients, the real-time of video streams are acquired from cameras and processed

Fig. 3. Web-based interface for the remote monitoring in the proposed system.

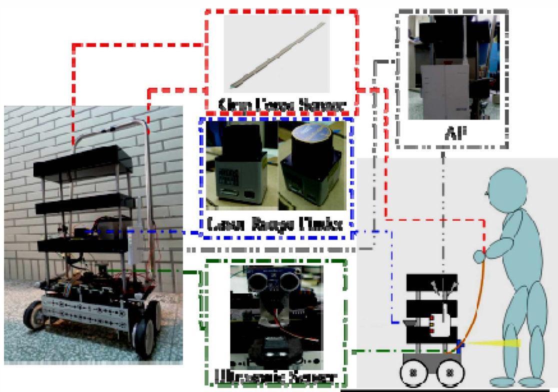


Fig. 4. Implemented robotic platform for walking support service in the proposed healthcare system.

in 30 frames per second. Each image is compressed and recorded in the healthcare service platform with the form of CIF with 352 × 288 pixels and true color. Besides, the personalized handheld devices are also adopted for the caregivers to remotely monitor the patients' health status or treatment conditions. In the current implementation for remote monitoring of patients, the utilized mobile devices consist of a dual-core Samsung Cortex-A9 ARM-based processor with 1.2-GHz computational frequency and 1 GB of DDR memory. Figure 3 presents the remote monitoring interface on the service system platform.

The designed robotic platform for walking support of patients has a suitable size and weight for the personalized healthcare environment. Figure 4 shows the hardware architecture and the prototype of the proposed walking-aid robot system. The on-board embedded system integrates a 400 MHz real-time processor running the VxWroks real-time operating system (RTOS), a reconfigurable FPGA, and 128 MB of DRAM. The laser scanner is mounted in front at 45 cm from the floor pointing horizontally. The laser is connected via serial (RS232) interface, and measures environment information ahead. The ultrasonic sensor is installed at the back of the robot, connected via digital I/O port, and measures the relative distance to a user. The robot wheels are driven by DC motors, which are connected via digital I/O port. The motor encoder information is available for dead reckoning. The grip force sensors are used to measure user's intention. A wireless module with Ethernet port is available for communicating with the home server.

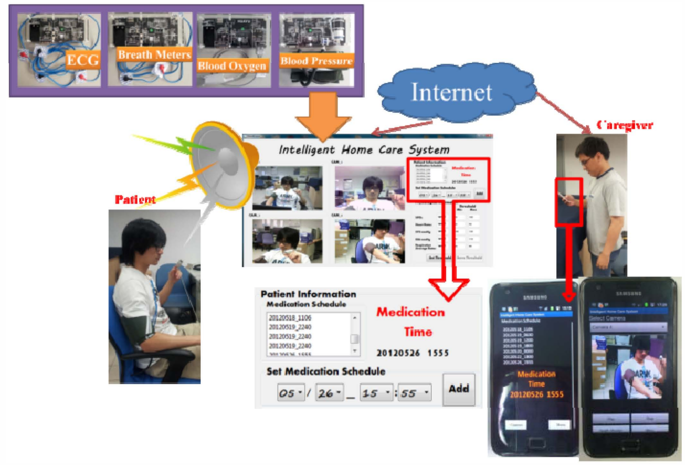


Fig. 5. Illustrations of the ubiquitous monitoring and alerting of patients' treatment and care scenario.

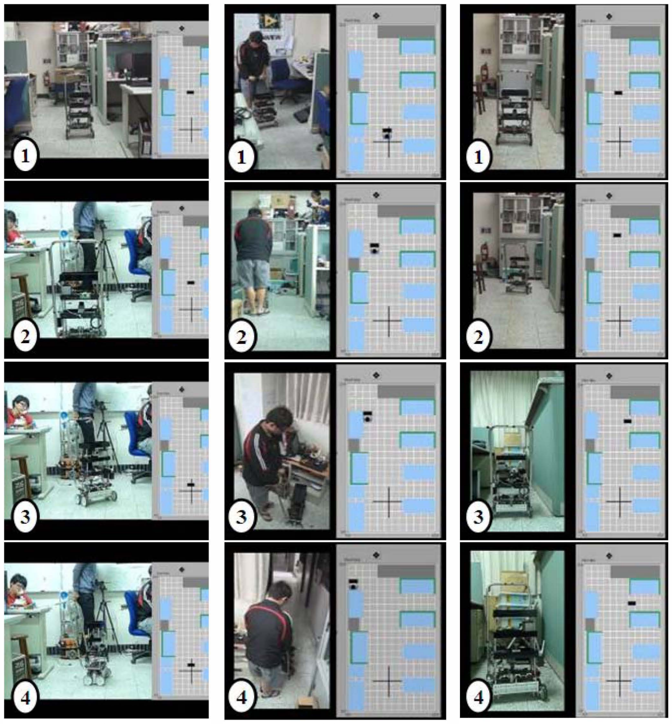
Based on the aforementioned knowledge-based healthcare system with the hardware/software implementation, we briefly introduce the application scenarios for the ubiquitous healthcare services in the following sections to demonstrate the system feasibility and effectiveness.

A. Ubiquitous Monitoring and Alerting of the Patient's treatment and Care Situations

Figure 5 depicts the ubiquitous monitoring and alerting of the patient's treatment and care processes, including regular physiological measurement, medication, hygiene, and feeding procedures. Initially, the patient is assumed to perform the recuperation and follow the treatment schedule which has been established from the caregiver. The proposed system activated the irregular status alert to the patient and the caregiver since a missing of the required medication treatment was detected after a particular period. The alert message with the patient's treatment records also was sent to the caregiver. Moreover, in this application scenario, the proposed system can provide physiological states and alarms, as well as offer real-time video-monitoring functions for caregivers to perform immediate cares for patients. Caregivers can inspect a patient's monitoring videos to understand the body conditions, and whether the patient's home care activities are appropriately conducted, to facilitate the healthcare service and conditions of the patient. If the patient's physiological measurement sensors of heart rate and blood oxygen values unexpectedly fall, the caregiver will immediately receive the alarm of abnormal alarm through the handheld devices. On the other hand, if the alarm is caused by the imprecise placements of the patient's physiological measurement modules, the caregiver can use the real-time monitoring interface to guide the patient restore the physiological sensors and the rehabilitation processes

B. Ubiquitous Monitoring of the Patient's Walking Support Situations

In this application scenario, the robotic platform initially parked in the specified space. In the call-to-come service, when a requested signal was acquired in the home server, the robot



(a) (b) (c)

Fig. 6. Experimentations of RWSS and map updating. (a) Call-and-come trial. (b) Walking support trial. (c) Auto-parking trial.

system navigated to the user location which can be arbitrarily designated on the environment map interface by the user. Moreover, while finishing service, the robotic platform was guided to a specific parking space in the home environment map under remote control of the patient of the caregiver. The control design for the robot system includes obstacle avoidance behavior and navigation behavior. The design methodology applies adaptive fuzzy control design which incorporates expert knowledge and user-adaptive learning strategy into the controller design process. The utilized model-free approach learns from user's walking behaviors in the way the reactive behavior controller can resolve different situations against static and dynamic obstacles, and drive the robot system to the goal position under the navigation task. To serve as walking support, a shared control approach is activated so that the user can activate the goal direction control through grip force sensors on the handlebar. To ensure the user's safety, the user input is smoothed and filtered to reduce the effect exerted from walking and is scaled according to the walking speed. The experimentations for walking support, call-to-come, and autonomous parking maneuvers are carried out in a home healthcare environment, as shown in Fig. 6. With the aid of map-based navigation, it can anticipate an add value of the robot for the real-end users. Besides, our proposed system provided a remote monitoring and can be accessed by the caregiver through the handheld devices.

V. Conclusions

This paper presents a personalized home healthcare system based on a ubiquitous computing and efficient knowledge-based framework. With the aid of sensing and control technology, our system can fulfill the application-oriented demands in personalized healthcare support according in various caring and nursing domains. In order to effectively determine the corresponding treatment procedures, the knowledge-based system with the physiological and medication monitoring scheme integrates an efficient rule-based reasoning model and flexible knowledge rules based on our developed software and hardware modules. By means of the developed software components and modules, our system is able to provide the real-time monitoring functionalities of patient activities and behaviors in homelike environments, as well as to remotely monitor physiological situations, treatment and care records, and warning conditions of patients. The experimental sets have presented persuasive results by offering significant flexibility for facilitating and extending the system further to adapt to the patient and the caregivers diverse, ubiquitous healthcare and personalized demands.

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