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Prototype Design of Medical Round Supporting Robot "Terapio"

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***Abstract*— We have developed a new type of robot which accompanies the healthcare professionals making medical rounds in patient's bedrooms at hospitals. This novel robot mainly executes two tasks: the carrying armamentarium of round medical supplies and the recording electronic health data on rounds. An omni-directional mobile mechanism and a human tracking control system to follow a specified medical professionals realize smooth transfer movement from the nurses' station to patient's bedroom. Electronic health data on rounds is automatically recorded by using a CCD camera and a voice recorder. When the robot is connected via a cable to a medical data server in nurses' station, the robot transmits the patients' data to the server and receives new patients' information.**

I. Introduction

In view of population aging with a low birthrate in Japan and elsewhere, healthcare professionals are in short supply and unevenly distributed, and thus demand for robots as alternatives to humans for performing simple tasks is increasing. Although increasing numbers of medical institutions have introduced electronic medical records, there are a variety of issues, such as inconvenience of data recording and high cost. Use of robots that support medical care data management and delivery of armamentarium at the medical front so that humans can concentrate on tasks requiring knowledge, skills, and experience is expected to contribute to enhancement of the quality of healthcare services. R&D of assist robots in the healthcare field includes the RP-VITA of iRobot Corporation, which is a remote presence robot for telemedicine; the MKR-003 of Murata Machinery, Ltd., which is an autonomous mobile robot[1] that uses a known environmental map for autonomous navigation to deliver drugs etc.; HOSPI developed by Panasonic Corporation that autonomously navigates based on an in-hospital map, including the use of elevators to move around in multi-story buildings, and is mainly used for delivering drugs[2].

We are developing a robot for making rounds that performs mainly two tasks[3]: delivering armamentarium and communicating healthcare data. We have developed Terapio, a next-generation robot that replaces conventional medical cart used by healthcare professionals during their rounds in a hospital. Terapio assists healthcare professionals in delivering armamentarium and recording round information (See Fig. 1).

Terapio is a mobile robot that tracks a person and is equipped with a differential drive steering system for both quiet operability and smooth omnidirectional mobility, and can overcome difference in level on floor. It recognizes the environment and autonomously tracks a specified human while avoiding obstacles. Using a ring-shaped power assist handle of Terapio, an operator can control Terapio accurately with slight force when it is necessary to move Terapio by directly touching it. Terapio also records patients' personal data and vital signs data and displays data, including the course of health record. By connecting Terapio to a data server via a cable at the nurses' station, it is possible to transmit and receive data on rounds and to manage patients' data in an integrated manner. In terms of its exterior design and color scheme, Terapio is suitable for use at medical institutions. The touch panel on the top of Terapio is for manipulating the robot and data on rounds. It is designed such that an operator and patients can recognize the robot's status and actions by the expressions shown on the display that change according to the robot's operation modes, which are power assist, tracking, and rounds.

II. Integrated System of Medical Round Robot

II-I Overview of Medical Rround Robot System

Terapio's principal role is to support healthcare professionals when they see patients in bedrooms for examination and treatment. Typically, in hospitals at present, carts are used for transporting armamentarium and the used items to be disposed, at the nurses' station and patient's bedroom. Terapio, with autonomous, omnidirectional mobility, abilities to track a specified person and avoid obstacles, and a power-assist drive, well performs transportation. Terapio has storage spaces for armamentarium, items for recycling, and items for disposal, respectively. It also displays data on rounds and manages data by employing computer memory functions, including recording of patients' data, display of their medical histories, and recording and storage of audiovisual data. The LCD display on the top of Terapio serves as its "face" and its expression changes by changing the shape of its "eyes." Unlike the metallic, cold impression of a cart, these eyes give Terapio

Figure 1. Supporting environment of medical round robot Terapio

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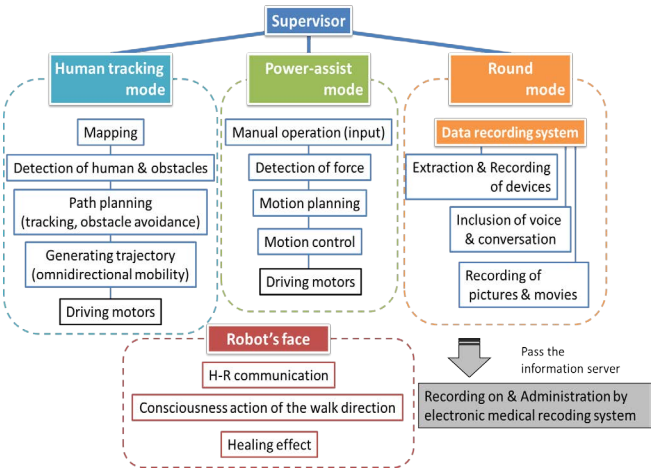


Figure 2. Integrated Robotic system and round operation flow

a human-like, friendly, communicative persona. This touch-panel display is also used for switching the robot's operational modes. To assist the work on rounds, Terapio has an extendable arm with light, CCD camera, and microphone devices. The touch panel is used for operating the shutter of the camera to take still pictures of the portion of the patient's body that is subject to treatment. Fig. 2 shows the flow of Terapio's integrated system. The robot's operation modes, which are autonomous tracking, power assist, and rounds, are switched by the supervisory controller.

The round support in a series of assistive motion for medical doctor or nurse is shown in Fig. 3. For example, in the case of round supporting for only one patient bedroom, robot movement modes: 1-4 as follows will be sequentially changed to achieve the required each assist task.

1. *Server connection mode* to receive and send the electronic medical chart by connecting with the main information server with LAN wire-line at the nurses' station.
2. *Human tracking mode* to follow the specified user from the nurses' station to the patient bedroom with collision avoidance for the people and the other obstacles.

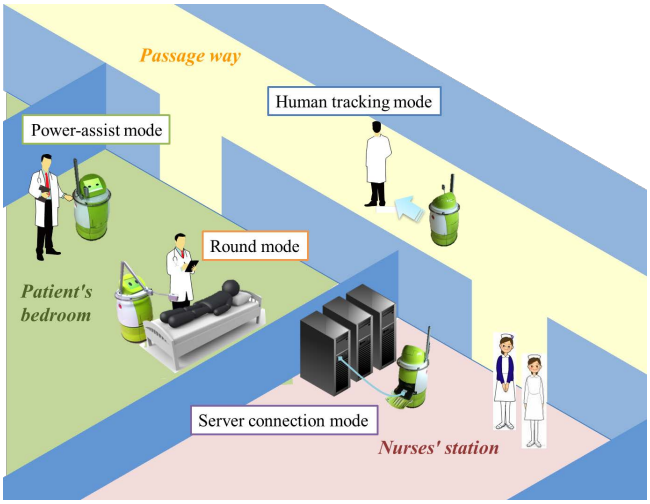


Figure 3. Round assistive motion circulation of Terapio

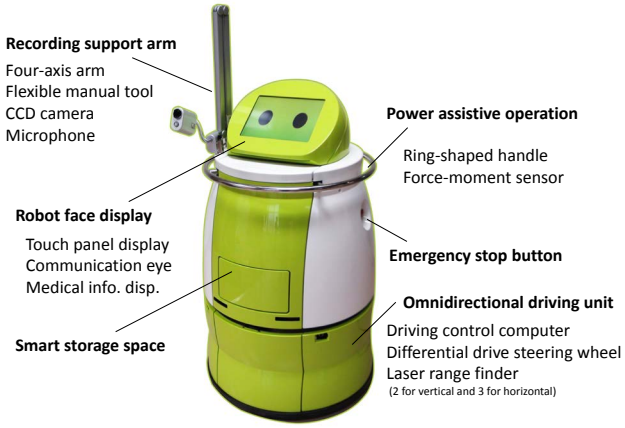


Figure 4. Hardware construction of Terapio

TABLE I. PRIMARY SPECIFICATION

External dimensions	Maximum width: 720 Body height: 1100 (include arm: 1340) unit: mm
Weight	80 (kg)
Driving system	DDSS, 4 wheels: omni-directional drive
Max. velocity	translation: 1.3 (m/s), rotation: 2 (rad/s)
Climbing ability	+5 (deg)
Over level difference	15 (mm)
Sensors	CCD camera: 1, LRF: 5, Force sensor: 1
Rating capacity of force sensor	Horizontal direction: 200 (N) Torque: 4 (Nm)
In-out devices	Touch panel monitor, Assistive handle, Speaker, Microphone, CCD camera
Communication facility	Wire type LAN with information server
Battery capacity	24 (Ah), (20 Hr rate)
Continuous working time	Usual case with waiting and traveling: 7 hours Continuous traveling case: 1.5 hours
Weight capacity	20kg, 1. Main storage: general medical round supplies of 5 packages 2. Sub storage A: spare consumable supplies 3. Sub storage B: extra unopened supplies for recycle use, control PC, power supplier system 4. Sub storage C: used supplies
Functional arm	Total 5 DOF: horizontal 2-axis and vertical 3-axis (with an added flexible end effector)

3. *Power assist mode* positioning the robot in proper location for medical care assist with applied slight force by the user hand at the patient bedroom.
4. *Round mode* to display the electric patient information, to take in and out the medical supplies package, to record the vital data, conversation, photos and movies for medical procedure.

II-II Total Hardware Construction

Overview of the autonomous tracking and power assist mobile robot Terapio with main round supporting function of transporting work of medical information and supplies

package is shown in Fig. 4. Here, TABLE 1 presents the primary specification about Terapio. Considering the safety and practical operability at the human-robot symbiosis environment of the nurses' station, the passage way and the patient bedrooms in hospital, Terapio's outer shape and the outer size are designed as the cylindrical geometry and height =1,100 (mm), width =720(mm), weight =80(kg) respectively. Relatively lightweight and compact body equipped with large-capacity storage is realized. Total five laser range sensors are implemented to scan the around and floor environment. The installation of the prior information for the movement environment map such as floor layout is not need by default, because Terapio always follows the user by the specified human tracking function in the travelling between nurses' station and patient bedroom.

As seen from Fig.1 in the situation of positioning Terapio into the proper location for medical care supporting, the ring-shaped power assist handle is attached around its body to ensure high operability with omni-directional movement. To realize the high stability of the robot behavior with user operation, omnidirectional driving system of DDSS: differential drive steering system which we have developed in recent years[4] is adopted and its four wheels are implemented. Seamless switching access for the each mode of the tracking, medical round and power assist is achieved by the main computer installed supervisory control system. Main PC generates the robot driving control input by using the information from the power assist force sensor as shown in Fig.5. Then the another drive system PC received the control input from the main PC and the laser range finder scanning data, and sends the driving input into servo motor amplifier.

Terapio design shaped cylindrical geometry makes well effect of visual perception for the omnidirectional robot

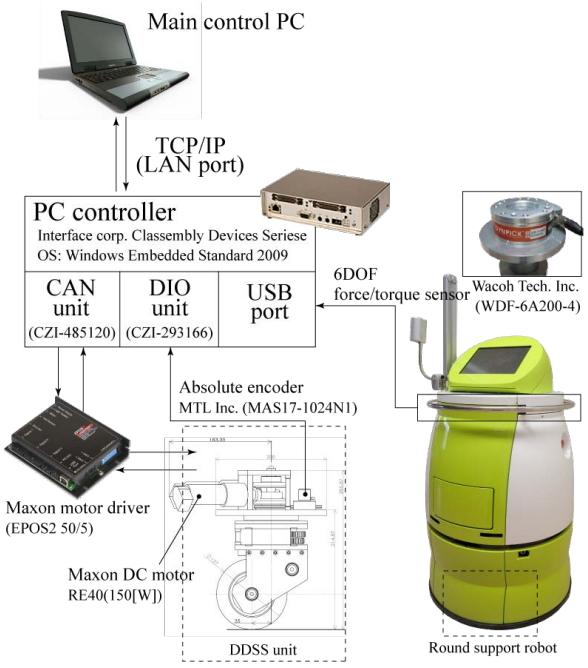


Figure 5. System configuration of mobility

behavior such as sideways and rotational movements. The round information management task can be operated by using the touch panel display and LAN wire-line connection as the external input interface and the communication device.

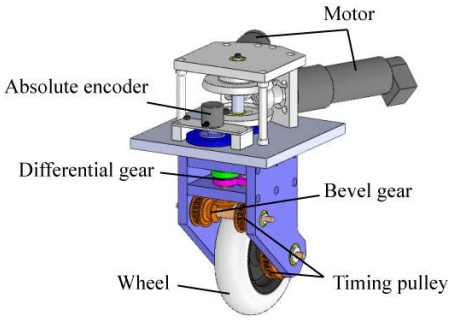
III. PRIMARY MOUNTED FUNCTIONS

III-I Omnidirectional Mobility

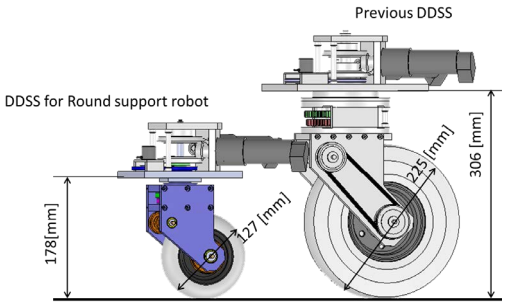
An omnidirectional mobile system which is useful for movement in confined spaces is adopted for Terapio. Thus, Terapio can move in any direction and its movement is not limited to movement in the direction in which it is facing.

III-I-i Drive system: differential drive steering system

Omnidirectional wheels are widely used for mobility aids Fig. 8: Environmental mapping and human tracking by using laser range horizontal finder and transportation equipment. Our laboratory has recently developed a differential drive steering system (conventional DDSS[4]), which is shown in Fig. 6(b) right, for omnidirectional drive. The new DDSS which shown in Fig. 6(a) uses smaller caster wheels and spur gears for quiet operation and enhanced travel and rotational performance. The synchronized use of two motors for rotational and driving operations has enabled reduction of motor capacity and increase of operational efficiency.



(a) Newly constructed DDSS



(b) Comparison of conventional and Terapio's wheels

Figure 6. New DDSS: differential drive steering system for omnidirectional robot movement

III-I-ii Omnidirectional power assist

In addition to the omnidirectional mobile system, Terapio is equipped with a power assist control system with which a human can move the robot with slight force by operating the

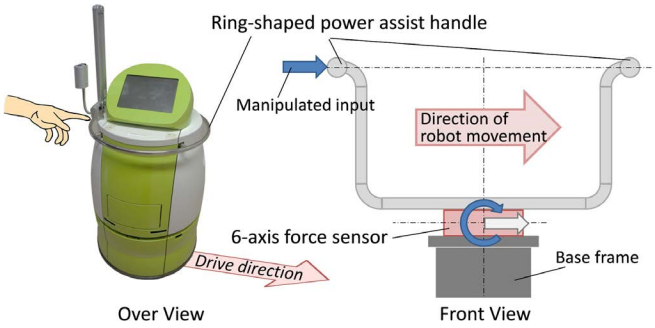


Figure 7. Omnidirectional power assist

ring-shaped power assist handle mounted on the circumference of the robot.

The ring-shaped power assist handle encircling the circumference of the robot as shown in Fig. 7 enables omnidirectional operation of the robot. Six-axis force sensor mounted on the base frame beneath the handle detects force data, from which the direction in which the operator intends to move the robot is assumed, enabling smooth, omnidirectional power-assisted travel driven by the new DDSS.

It would be impracticable for an operator to move a robot that weighs approximately 80(kg), including the items it carries, without assistance, but the use of the power assist system realizes easy operation. As the omnidirectional power assist system allows an operator to move the robot delicately and accurately with slight force, it is useful, for example, when moving the robot closer to a patient bed in a ward.

III-I-iii Tracking to a specified human

Horizontal laser range finders: LRFs are mounted at three locations on the exterior of Terapio to ensure that it remains in close proximity to the operator (doctor or nurse) and tracks that human while capturing data on him/her and multi-angle environmental data [5, 6]. Moreover, tilt laser range finders are mounted on two locations at the front of the robot, enabling detection of any difference in floor surface levels and steps.

Terapio tracks the human in accordance with the operational flow shown in Fig. 8 and moves in patient's bedrooms at the translational speed of 0-1.3 (m/s) and the rotational speed of

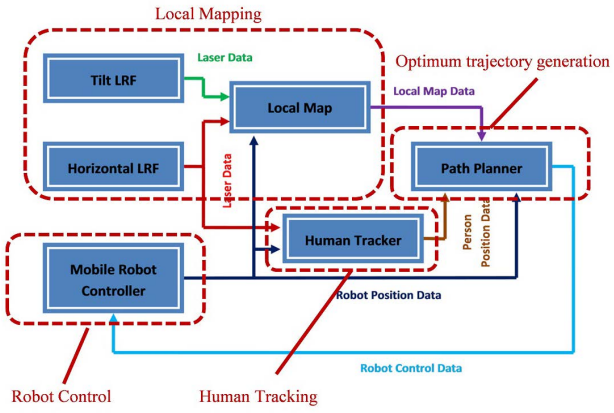


Figure 8. Environmental mapping and human tracking by using laser range horizontal finder

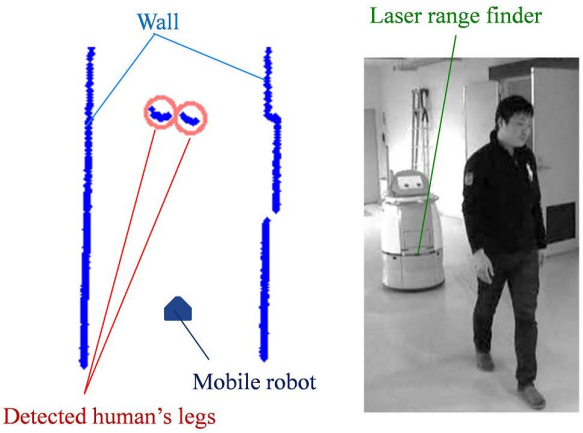


Figure 9. Specifeid human tracking experiment

0-2.0(rad/s). Fig. 9 left shows an example of data obtained by horizontal LRFs and plotted. In this example, the legs of the human being tracked and the walls are detected. One pair of 2 vertical LRFs also can detect obstacles and difference in level on the floor in aisles and bedrooms and then avoid them.

III-II Functional Arm Unit

Terapio has the multi-linked arm of 5DOF with horizontal 2-axis and vertical 3-axis witch implemented CCD camera, spot light device and microphone for the assistive recording on the medical round. The end effector of the robot arm consists of the accordion type flexible structure to ensure high operability with the user. Still images of the patient's affected part can be captured easily by pressing the shutter button on Terapio face displayed motion image from the CCD camera. This arm is replaced compactly as shown in Fig. 10 left during the human tracking and power assist modes, not medical round mode. On the other hand, Fig. 10 right shows maximally-extended arm attitude to 1.1(m) on the round, and positional relationship between Terapio, patient bed and the user.

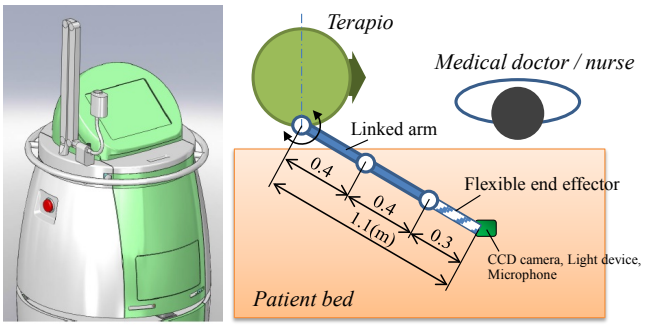
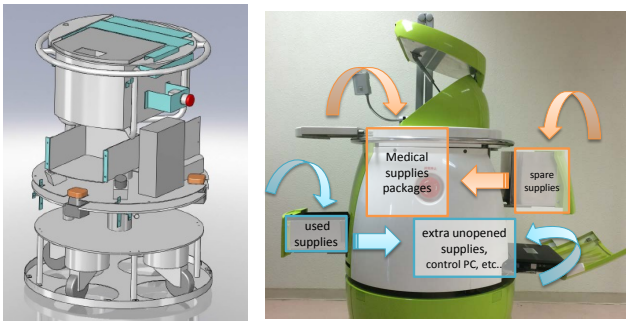


Figure 10. Functional arm and extension range

III-III Storage of Medical Supplies and Waste Materials

It is necessary to transport the medical supplies packages and also waste equipment at the round work. Furthermore the storage space layout, mainly proper height must be designed for human use without workloads related to the user positon to take in and out the medical stuff. On the round service, the user puts the medical supplies packages on the slide table of Terapio first, and the after, takes out only the necessary equipment from the package and uses for the care work. Therefore, main storage construction with pull-in/out slide

table was designed for easily accessible to take into supplies packages when the robot face opens above as shown in Fig. 11 (b). The slide table sets lower the robot face can be used as care work space and top cover of the storage. The user can see the display of Terapio to check the electronic patient information, because the robot head part could be close while pulled out the table. Here the table height is decided to set above the fence of the bed. By taking doctors and nurse views into account, the each storage for the used medical supplies and recyclable item is set lower position than the main storage from the aspect of good hygiene, and the other stuff for the round can be put into large storage on the back of Terapio.



(a) Interior configuration (b) Storage layout

Figure 11. Medical supplies and waste materials storage

II-IV Robotic Communication Face

As a robot operating in coordination with humans, Terapio is equipped with an LCD display to show simple expressions with which people can feel empathy. Expressions are shown by the "eyes," which are a combination of 2 spheres created by computer graphics as shown in Figs. 12, 13. This face design is based on the knowledge of baby schema in the field of cognitive psychology which is closely related to the cuteness

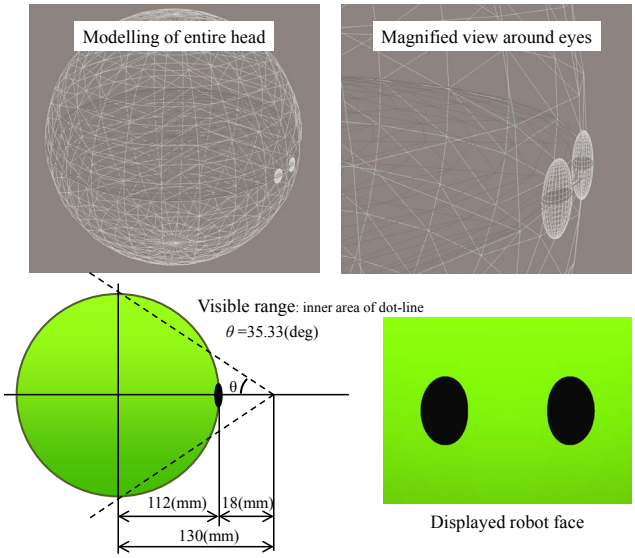


Figure 12. Modelling and rendering of robotic face

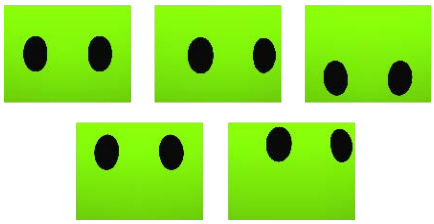


Figure 13. Gaze state into various directions

Figure 14. Rendering of blink action

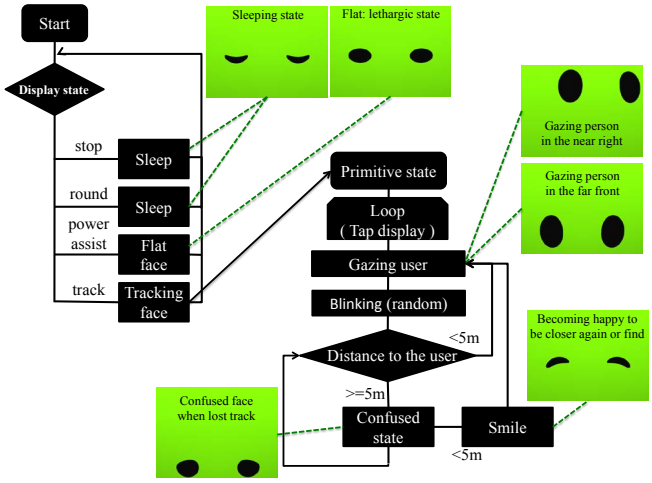


Figure 15. State transition diagram of face change

and the balance between the facial parts and shape such as infants[7, 8]. Gouraud shading applied to the spheres makes Terapio's face appear to be round. Then, the robot gazes at a person nearest to the robot. This behavior makes users to believe the robot has an intention to communicate with the user[9]. Terapio also "blinks" naturally to communicate that it is in a normal condition. The robot's blinking occurs at random timings, and it indicates the robot is alive as shown in Fig. 14. It is designed that Terapio blinks about 10 times per minute and each blink lasts 0.25 second, similar to average blinking of humans. The timing of blinks is at random with normal distribution model of the mean 6.4(s) and the standard deviation ±2.4(s)[10], so that humans perceive that Terapio blinks like a human.

Terapio tracks the user and is programmed to change expressions according to circumstances shown in Fig.15. If Terapio loses track of the user, it shows a sad expression and if it finds the use again, it makes smile. Simple change in the shapes of the eyes gives humans latitude in interpretation and is expected to encourage an emotional rapport building between humans and the robot. A human who encounters Terapio perceives that the robot recognizes him/her and is trying to communicate with them and then he/she tries to communicate with the robot.

II-V Round Data Recording and Management System

In the rounds mode, the display on the top of Tarapio is an interface for a doctor or a nurse to enter data on rounds and to display patients' medical histories. With Terapio, it is unnecessary for healthcare professionals to carry paper documents or portable information terminals to record data on rounds and there is no need to install information equipment in each patient's bedroom to manipulate medical data. The proposed system for recording and managing rounds data offers enhanced information management security by requiring the authorization of individuals.

This system allows healthcare professionals to enter data on vital signs measured on each round, such as body temperature, maximum and minimum blood pressure, pulse, urine output, fluid replacement volume, and drainage volume, and also to check data on allergies and medication of patients in advance. As soon as Terapio is switched to the rounds mode, it starts recording audiovisual data and the operator can shoot a still image by operating the touch panel. Such data captured during rounds is managed as patients' data, together with data on vital signs entered in the robot, and after rounds once the robot is connected to the information management server in the nurses station via a cable, data is transferred to the server for storage and management.

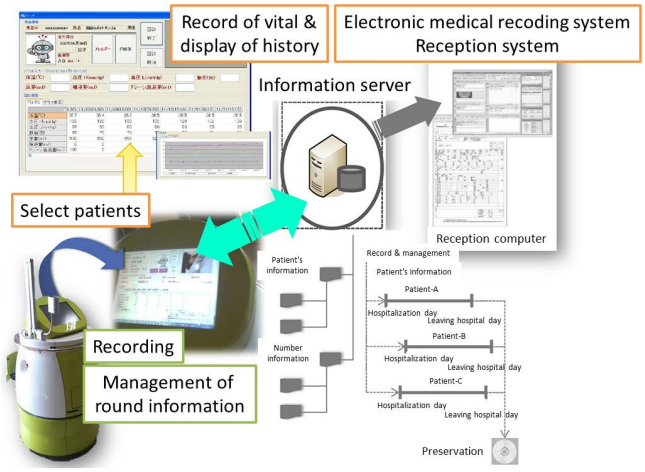


Figure 16. Intercommunication between Terapio and information sever

Figure 17. Intercommunication display view

IV. Conclusion

A prototype of an autonomous mobile robot, Terapio, has been developed to assist healthcare professionals making medical rounds in hospitals. Terapio is characterized by its functions to transport armamentarium, record the rounds data, and communicate with humans by showing facial expressions. In view of its functions and integrated system, Terapio is expected to contribute to reduction of the workload of healthcare professionals. We intend to improve key technologies for automatic tracking, power assist control, and omnidirectional drive systems, and are currently working on Terapio's practical test and the performance evaluation.

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References

[1] T. Suzuki, M. Takahashi, K. Yoshida: "Development of Au-tonomous Omni-directional Traction and Transfer Mobile Robot", Journal of The Robotics Society of Japan, vol. 27, no. 8, pp.942-949, 2009

[2] R. Murai, T. Sakai, Y. Kitano: "Autonomous Navigation Technology for 'HOSPI,' a Hospital Delivery Robot System", Collection of Manuscripts for the 55th Japan Joint Automatic Control Conference, CD-ROM No. 1K303, 2012

[3] K. Terashima, S. Takenoshita, J. Miura, R. Tasaki, M. Kitazaki, et al.: Medical Round Robot -Terapio-, Journal of Robotics and Mechatronics No.26(1) pp.112-114, 2014

[4] Y. Ueno, H. Kitagawa, K. Kakihara, K. Terashima: "Devel-opment of the Differential Drive Steering System Using Spur Gear for Omni-Directional Mobile Robot", Transactions of The Japan Society of Mechanical Engineers Series C, vol. 78, no. 789, pp. 1872-1885, 2012

[5] I. Ardiyanto, J. Miura: "Real-time Navigation using Ran-domized Kinodynamic Planning with Arrival Time Field", Robotics and Autonomous Systems, vol. 60, no. 12, pp. 1579-1591, 2012

[6] K. Koide, J. Miura, J. Satake: "Development of an Attendant Robot with Human Tracking Functions", ROBOMEC, 2013

[7] Lorenz K.: The innate forms of potential experience. Zeitschrift für Tierpsychologie, 5, 235-409.

[8] Glocker ML, Langleben DD, Ruparel K, Loughead JW, Gur RC, Sachser N.: Baby Schema in Infant Faces Induces Cuteness Perception and Motivation for Caretaking in Adults. Ethology, 115(3), 257-263, 2009

[9] Y. Murofushi, N. Isobe, R. Tasaki, K. Terashima, M. Kita-zaki: "Shugo-robot face", Proceedings of IEEE Virtual Real-ity, pp. 179-180, 2013

[10] Doughty, MJ.: Further assessment of gender- and blink pattern-related differences in the spontaneous eyeblink activity in primary gaze in young adult humans. Optometry and Vision Science, 79(7), 439-447, 2002