2015 IEEE International Conference on Advanced Intelligent Mechatronics (AIM)
July 7-11, 2015. Busan, Korea

Immersive VR Interface for Informationally Structured Environment

Yoonseok Pyo[1], Tokuo, Tsuji[2], Yuuka Hashiguchi[1], and Ryo Kurazume[2]

***Abstract*— This paper presents a new immersive VR interface bridging cyber and physical worlds for Cyber Physical System (CPS). Informationaly structured environment (ISE) has been proposed in service robotics so far. In ISE, environmental information such as positions of objects, furniture, humans, and robots is gathered by embedded sensor networks and stored in a database structurally. A service robot is able to utilize these information anytime and anywhere by connecting to the network. In this paper, we introduce the ISE architecture named ROS-TMS and a new cyber-physical interface for ROS-TMS. The proposed system consists of an immersive wearable display, a stereo camera, an optical tracking system, and an environmental simulator, and is able to present forecasted images with high reality based on the structured information in ISE.**

***Index Terms*— Cyber Physical System, Service robot, Immersive display, Environmental simulator**

I. INTRODUCTION

CPS (Cyber Physical System) is a system to develop an efficient and affluent society by solving various issues in real world utilizing a great amount of computer resources in cyber world. After the NSF has identified the CPS as a key research area in 2006, this concept has been attracting much attention and a number researches have been presented so far. In recent years, the concept of IoT (Internet of Things), which connects all the objects and machines through the internet and controls them efficiently, has been becoming very popular. Besides, the CPS is to forecast an ideal world based on a wealth of sensory information obtained through IoT and huge computer power in cyber world, and plan and execute optimum strategies for realizing the ideal physical world.

On the other hand, the concept of an informationally structured environment (ISE) or an intelligent space (IS) has been proposed so far in the robotics research field. In this concept, rich information about a daily life environment where a service robot performs a variety of service tasks to humans is acquired using embedded sensors and sensory networks, and stored in a database structurally. All the required information to perform proper service tasks by a service robot, such as position of objects, furniture, human, or robots, are provided on-demand from a database anytime and anywhere by connecting to the network.

[1] Yoonseok Pyo and Yuuka Hashiguchi are with Faculty of Information Science and Electrical Engineering, Kyushu University, 744, Motooka, Nishi-ku, Fukuoka, 8190395, JAPAN {pyo, hashiguchi}@irvs.ait.kyushu-u.ac.jp

[2] Ryo Kurazume and Tokuo Tsuji are with the Department of Information Science and Electrical Engineering, Kyushu University, 744, Motooka, Nishi-ku, Fukuoka, 8190395, JAPAN {kurazume, tsuji}@ait.kyushu-u.ac.jp

A number of studies for the ISE has been presented so far, including the "Smart room" (Media Lab at MIT), "Intelligent room" (AI Lab at MIT), "Robotic room" (The university of Tokyo), "Intelligent space" (The university of Tokyo), etc. and various new researches have been reported to this day actively [1–9]. The concept of the ISE is very closely related to the CPS mentioned above in terms of the purposes and means.

We also have been proposing a framework for the ISE named Town Management System (TMS) so far [10]. In this system, a variety of information regarding objects, furniture, humans, and robots which is acquired by distributed cameras, laser range finders, and RFID tag readers is stored to a database and provided according to the request from a service robot. We have been developing API libraries of the TMS and releasing them.

In 2012, we started to develop a new version of TMS named ROS-TMS, which adopts Robot Operating System (ROS) [11] as a middleware. Owing to the ROS, we can integrate a variety of sensors and robots adaptively to a variety of environments. We have been developing more than 95 modules for the ROS-TMS so far such as sensing system or motion planning for a service robot [12].

In this paper, we propose a new ISE platform for an indoor environment based on the ROS-TMS technology. This platform consists of several humanoids-type and wheeled-type service robots, a wheeled chair robot, a robot refrigerator, furniture such as desk, chair, bed, bookshelf, cabinet, etc., and various embedded sensors. The position and translation of objects, furniture, humans, and robots are detected and tracked by laser range finders, an optical tracker, RGB-D cameras, RFID readers in intelligent cabinets and robot refrigerators, etc. and stored to the database in ROS-TMS.

In addition, we also propose a new immersive VR interface for the developed ISE platform which bridges cyber world and physical world intuitively. The events which will occur in real world are predicted and simulated though a computer simulation according to the sensory information acquired by distributed sensory networks. The simulation results are displayed immersively by a wearable VR interface. Therefore, the person wearing this system has an experience for the simulated events in cyber world with a high realistic manner before it will happen actually in real world. In other words, this system is a potent interface of the CPS which bridges cyber and physical worlds.

The remainders of the paper are organized as follows. In Section 2, some related works for an immersive VR interface in the robotics field will be introduced. In Section 3, we will introduce a ROS-TMS and ISE platform for an indoor environment. A new immersive VR interface for the ISE will be proposed in Section 4.

II. Related work

An immersive VR interface has been mainly utilized in the research on tele-robotics. Several applications using an immersive VR interface have been presented, for instance, an intuitive operation of a surgical robot such as da Vinci Surgical System (Intuitive Surgical, Inc.) [13], surgical simulator [14], motion control of a space robot [15] and a rescue robot [16].

An immersive VR interface can be categorized into two groups. Surround screen projection system such as CAVE [17] utilizes multiple screens and projectors, and display whole directional images to walls, a floor, and a roof independently of a user's line of sight. On the other hand, a wearable device such as Google Glass or Epson Moverio overlays a VR image onto a real image directly using transparent glasses, and have been attracting much attentions since they have a high affinity for AR (Argumented reality), MR (Mixed Reality), or First Person Vision. In recent years, new wearable devices such as Oculus Rift have been produced as a wearable immersive VR interface. These devices consist of a small display and an IMU (Inertial Measurement Unit), and synthesize a virtual image corresponding to the head direction. Thus, these wearable devices are simple and low-cost comparing to the system with large screens and projectors, and thus very popular in recent years.

Immersive Virtual Robotics Environment (IVRE) [18] at Johns Hopkins University utilizes Oculus Rift and ROS, and demonstrates a collaborative task with a robot and a human in a virtual world. However this system is mainly for a safe path/motion planning through virtual single human-robot interaction, and human-environment interaction including multiple objects, robots, and humans proposed in this paper has not been considered.

III. Informationally structured environment platform

A. ROS-TMS

We have been developing an informationally structured environment architecture named ROS-TMS [12]. The ROS-TMS is a mechanism which connects various sensors distributed in an environment such as laser range finders, cameras, RFID tag readers, or proximity sensors, various robots, and a database based on Robot Operating System (ROS) [11]. The ROS-TMS is able to acquire, store, and analyze environmental information, and plan and control robot motion adaptively. ROS is an open source middleware which absorbs differences of various sensors and robots, and provides uniform interface to users. In ROS-TMS, each controller of a robot and a sensor is implemented as a node (a process for a particular task) in ROS and thus the communication between nodes and addition and removal of a new node are quite simple and easy. Figures 1 and 2 show a concept of ROS-TMS and its architecture.

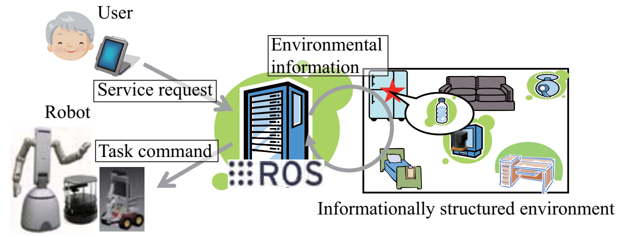


Fig. 1. Concept of ROS-TMS. ROS-TMS connects various sensors, robots, and a database based on Robot Operating System (ROS) in order to provide proper service tasks for users.

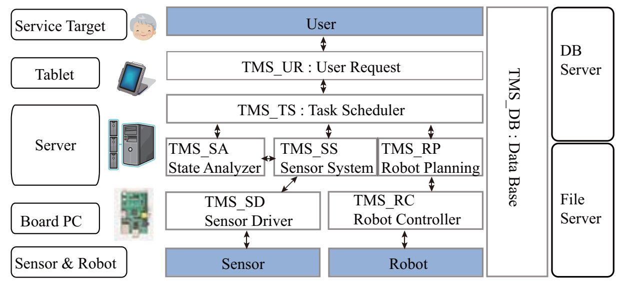


Fig. 2. ROS-TMS architecture. ROS-TMS consists of more than 95 modules including sensor processing, robot planning, user interface, and a database. See the wiki page for more information [12].

We have developed a number of nodes for ROS-TMS and released them [12]. These nodes can be categorized into the following modules.

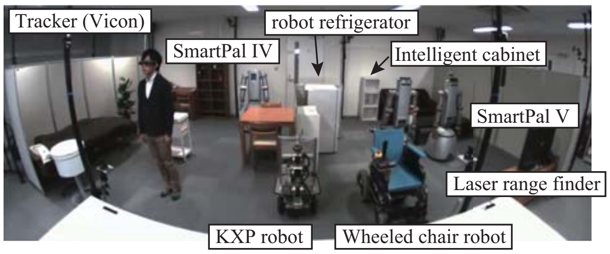
- TMS_DB Environmental databases using MySQL
- TMS_UR User interfaces using wearable devices or mobile devices
- TMS_TS Task schedulers based on ROS SMACH
- TMS_SA State analyzer
- TMS_SS Sensor fusion module
- TMS_RP Motion planning module for service robots
- TMS_SD Sensor drivers
- TMS_RC Robot controllers

B. Indoor ISE platform for daily life environment

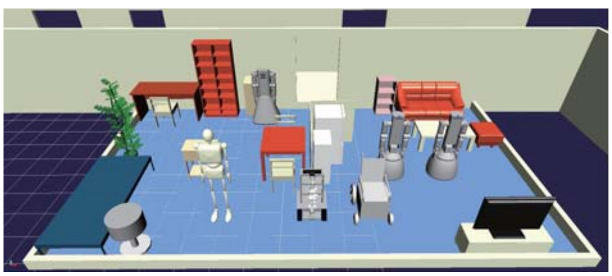
Figure 3 shows the developed indoor ISE platform simulating a daily life environment and the environmental simulator (Choreonoid [19]). Choreonoid is an integrated robotics GUI environment with a dynamics engine, which allows users to add their own functions as plugins on the basis of various basic robotics functions. We utilize Choreonoid and its motion planner plugin named GraspPlugin [20] to simulate the indoor ISE platform. Using the GraspPlugin, various robot motions can be designed with a simple manner considering their physical properties and mutual interference. Collision detection function is also provided by GraspPlugin.

The indoor ISE platform consists of several service robots (SmartPAL IV and V (Yaskawa Electric), KXP (Katana, Pioneer 3 AT), Kobuki (Yujin Robotics), a wheeled chair robot, and a robot refrigerator), furniture (desk, chair, bed, bookshelf, cabinet, etc.), and embedded sensors. The position and translation of objects, furniture, humans, and robots are detected and tracked by laser range finders (UTM-30LX-EW, Hokuyo Automatic), an optical tracker (Bonita, Vicon), RGB-D cameras (Kinect, Xtion), RFID readers in intelligent cabinets and robot refrigerators, etc. and stored to the database, TMS_DB.

Based on the environmental data stored in TMS_DB, the physical simulation can be conducted using Choreonoid in the virtual environment which reflects the real situation in the indoor ISE platform exactly. Therefore, the developed indoor ISE platform and the Choreonoid simulator can be considered as a physical and cyber systems in the CPS, respectively.



(a) Informationally structured room



(b) Simulated room (Choreonoid)

Fig. 3. Information structured room (physical system) in an real environment and simulated room (cyber system) in Choreonoid simulator.

Figures 4, 5, and 6 show the examples of the object detection function in TMS_SS. Objects placed in the intelligent cabinet or on a table are detected as follows [21]. In the intelligent cabinet, a RFID tag reader is installed under the base plate and the object is identified by reading a RFIDtag attached on the bottom of the object. The position of the object is measured by four load cells which support the base plate as shown in Fig. 4,. The name and the position of the detected object are registered in the TMS_DB and displayed in Choreonoid (Fig.5) in real time. On the other hand, the object placed on the table is scanned by the Xtion mounted on a humanoid robot (SmartPal V, Fig.7) and labeled by the database using CSHOT [22].

When a user request is detected by TMS_UR, Choreonoid refers TMS_DB and simulates a safety motion by a service robot which will not collide with the environment using the GraspPlugin. Robot motions designed above are transmitted to the motion control nodes in TMS_RP and TMS_TS, and service tasks such as a fetch and carry task by a service robot and a robot refrigerator, or a transportation task using a wheeled chair robot are executed. Figure 8 shows the fetch

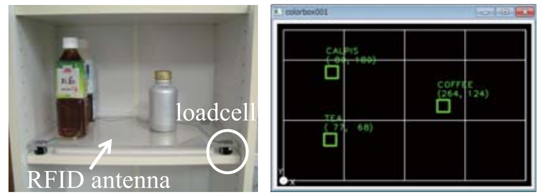


Fig. 4. Object detection using Intelligent Cabinet [21]. The names and the positions of objects are detected by a RFID tag reader and load cells.

Fig. 5. Detected objects in the Intelligent Cabinet. Real and cyber worlds are synchronized in real time.

and carry task controlled and processed by the task scheduler ”SMACH” [23] in TMS_TS.

IV. Immersive VR interface bridging cyber and physical worlds for CPS

A. System configuration

This section introduces an immersive VR interface bridging cyber and physical worlds to realize the concept of CPS. This system consists of an immersive VR display (Oculus Rift DK2, Oculus VR, Fig. 9), a stereo camera (Ovrvision, Wizapply, Fig. 9), an optical tracking system (Bonita, Vicon, Fig. 10), and an environmental simulator (Choreonoid, Fig. 11).

The immersive VR display (Oculus Rift DK2) is a wearable display which enables a binocular stereo by displaying left and right images individually. A three-axis attitude sensor

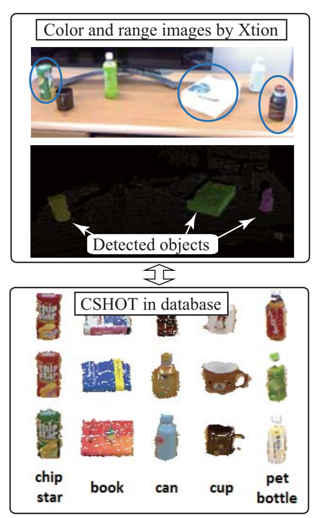


Fig. 6. Object detection on a table using a RGB-D sensor (Xtion) and CSHOT descripter.

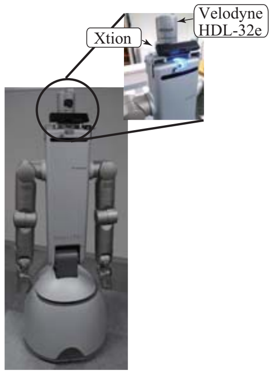


Fig. 7. Xtion mounted on the humanoid robot (SmartPal V). A laser scanner (Velodyne HDL-32E) is also attached.

is also installed in it. The head orientation measured by the three-axis attitude sensor is sent to the PC. On the other hand, the position of the immersive VR display in the room is tracked by optical markers and the optical tracking system (Bonita) with the accuracy of less than few millimeters (Fig.9). Based on the position and orientation information of the immersive VR display, the VR images of the room from the same view point are synthesized and displayed on the immersive VR display. Figure 12 shows the graphic pipeline using Oculus Rift DK2, Bonita Vicon, and Choreonoid.

The scene is firstly modelled using environmental information stored in the TMS_DB, then the OpenGL-based graphics engine in Choreonoid synthesizes distorted stereo images by calling a distortion function in libOVR (LibOVR 0.4.4, Oculus VR). Finally, stereo images are displayed on the left and right displays in the Oculus Rift individually.

The stereo camera (Ovrvision) is mounted on the front chassis of the Oculus Rift and captures images from the same viewpoints of the person wearing the Oculus Rift. Captured stereo images are displayed on the left and right images of the Oculus Rift individually, and thus we can see the surrounding real images without detaching the Oculus Rift.

Figure 14 shows some synthesized stereo VR images for Oculus Rift and real images captured by the stereo camera when the person wearing the system walks through the room as shown in Fig. 13. In these examples, there is no serious time-delay and both images are almost synchronized.

We can see that proper VR images which are quite similar to real images are created and displayed at any position in the room according to the change of head position and orientation even if the person wearing this system walks anywhere in the room.

B. *Time shift effect*

The most important characteristic of the proposed system is the so-called time-shift effect. We can show the highly realistic VR images forecasted by the Choreonoid simulator. The simulation is executed based on the current real status of objects, furniture, humans, and robots sensed and stored by the ROS-TMS.

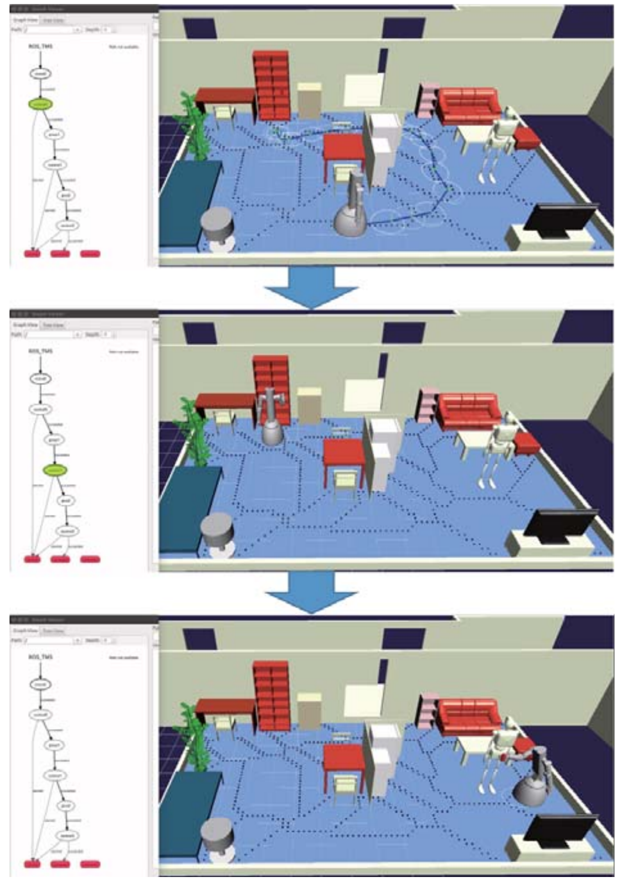


Fig. 8. Fetch and carry task by service robot. Robot motions are planed and executed by ROS-TMS. Left column shows the current state in a whole procedure executed by SMACH state machine. Dotted lines indicate the designed trajectory of the service robot.

Figure 15 shows the examples of the time shift effect by the proposed system. The left column of Figure 15 shows VR images from the eye position of the person who ordered a fetch and carry task to the service robot. The robot performs the service task as shown in Fig. 8. The designed trajectory of the service robot can be seen as dotted lines depicted on a floor in Fig. 15. Moving objects can be reflected on the simulator in real time if these objects are detected by embedded sensors such as LRFs and cameras. Note that these images are synthesized before the service task is actually executed by the service robot. With this system, we can see the forecasted synthesized images beforehand and confirm whether the planned service action is safe and proper or not. with our own eyes. If these actions are not appropriate, we can stop and rearrange the service action to be safe. Real images taken by the stereo camera when the service robot executes the planned service task actually are shown in the right column of Fig. 15.

V. CONCLUSION

This paper introduced the informationally structured environment architecture named ROS-TMS and the indoor platform for Cyber Physical System, CPS. Then we proposed

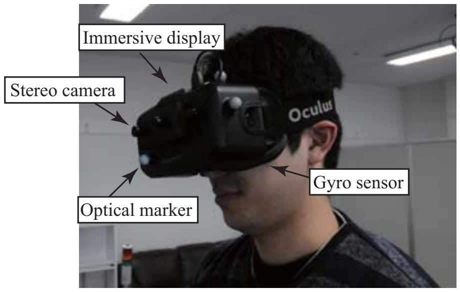


Fig. 9. Immersive VR display device consisting of Oculus Rift DK2 (immersive stereo display), Ovrvision (stereo camera), and Vicon Bonita (optical position tracker)

Fig. 10. Optical position tracking system (Bonita, Vicon)

the new immersive VR interface using Oculus Rift, Bonita Vicon, and Choreonoid simulator which bridge cyber and physical worlds to realize the concept of CPS. As a typical example of the CPS, we demonstrated the time shift effect by the proposed system. The proposed system is one of the examples of the CPS implementation, which forecasts an ideal world, designs the optimum strategy, and presents the predicted results with high reality using the immersive VR display.

The current system is, however, not practical for natural human-system interactions due to its size. The proposed system can be applied with smart glasses such as Moverio (Epson) or Google glass by overlaying simulated images on real scene.

This research is supported in part by a Grant-in-Aid for Scientific Research (A) (26249029) and the Japan Science and Technology Agency (JST) through its "Center of Innovation Science and Technology based Radical Innovation and Entrepreneurship Program (COI Program)."

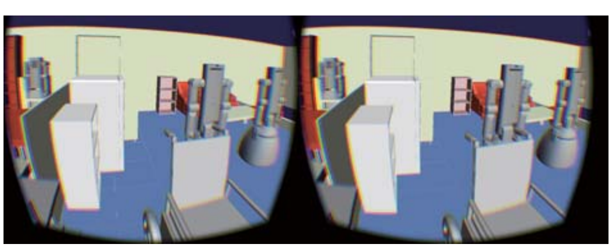


Fig. 11. Synthesized VR stereo images by Choreonoid

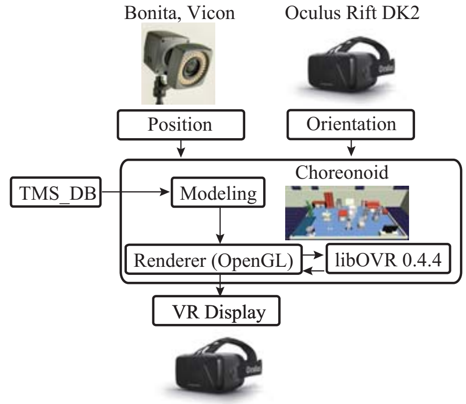


Fig. 12. Graphic pipeline of the proposed immersive VR interface. The position of the VR display is tracked by an optical tracker (Bonita, Vicon) and the pose is sensed by a three-axis attitude sensor in Oculus Rift DK2. The VR stereo images of the real world from the current position of the user are synthesized and displayed on the immersive VR display in real time.

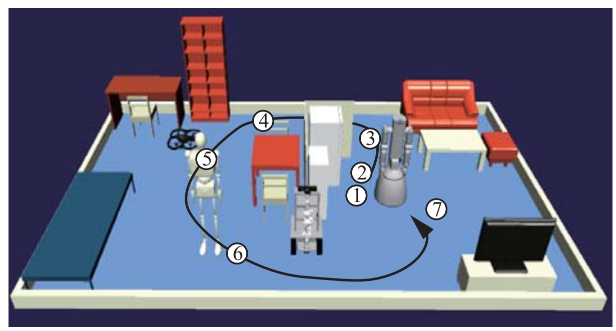


Fig. 13. Walk-through path in a room

REFERENCES

[1] Hiroshi Noguchi, Taketoshi Mori, and Tomomasa Sato. Automatic generation and connection of program components based on rdf sensor description in network middleware. In *IEEE/RSJ International Conference on Intelligent Robots and Systems*, pages 2008–2014, 2006.

[2] Yuka Kato, Toru Izui, Yosuke Tsuchiya, Masahiko Narita, Miwa Ueki, Yoshihiko Murakawa, and Keijyu Okabayashi. Rsi-cloud for integrating robot services with internet services. In *IECON 2011 - 37th Annual Conference on IEEE Industrial Electronics Society*, pages 2158–2163, 2011.

[3] Horst-Michael Gross, Christof Schroter, Steffen Muller, Michael Volkhardt, Erik Einhorn, Andreas Bley, Tim Langner, Christian Martin, and Matthias Merten. I'll keep an eye on you: Home robot companion for elderly people with cognitive impairment. In *IEEE International Conference on Systems, Man, and Cybernetics*, pages 2481–2488, 2011.

[4] Moritz Tenorth, Alexander Perzylo, Reinhard Lafrenz, and Michael Beetz. The roboearth language: Representing and exchanging knowledge about actions, objects, and environments. In *IEEE International Conference on on Robotics and Automation*, pages 1284–1289, 2012.

[5] Young-Guk Ha, Joo-Chan Sohn, and Young-Jo Cho. Service-oriented integration of networked robots with ubiquitous sensors and devices using the semantic web services technology. In *2005 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pages 3947–3952, Aug 2005.

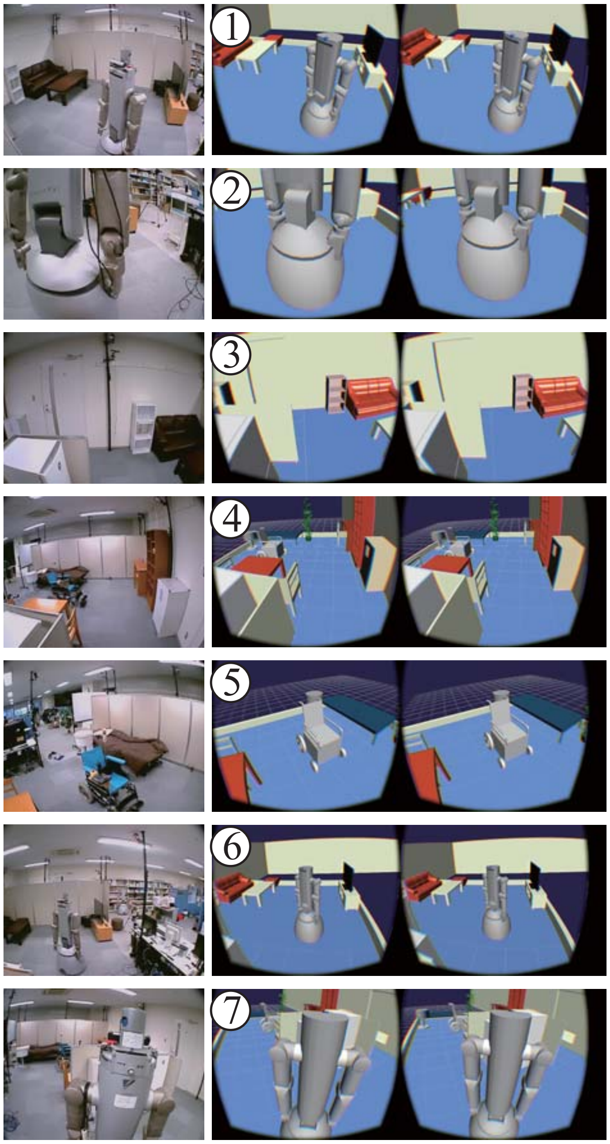
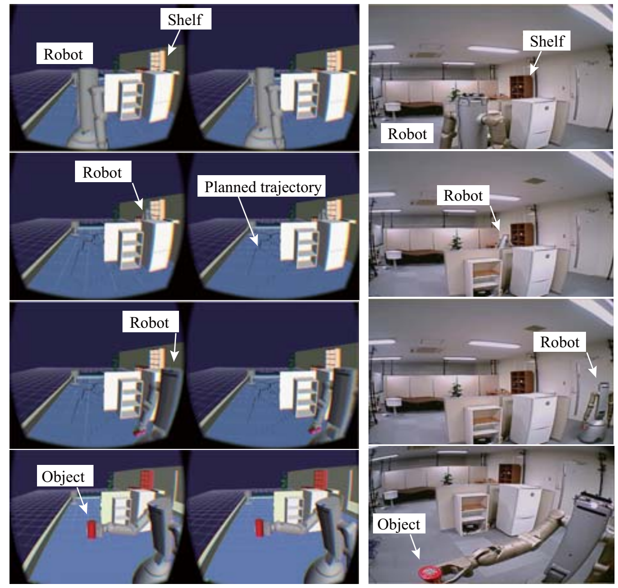


Fig. 14. Walk-through images of a room displayed on the stereo screens of Oculus Rift. VR images from the current view points (right column) which are quite similar to real images (left column) are appropriately synthesized.



(a) Virtual task planned previously (b) Actual task

Fig. 15. VR and actual images for fetch and carry task. Real task is executed after the task is confirmed to be safe and executable previously using the Choreonoid simulator.

[6] Md. Jayedur Rashid, Mathias Broxvall, and Alessandro Saffiotti. A middleware to integrate robots, simple devices and everyday objects into an ambient ecology. *Pervasive and Mobile Computing*, 8(4):522–541, 2012.

[7] Miki Sato, Koji Kamei, Shuichi Nishio, and Norihiro Hagita. The ubiquitous network robot platform: Common platform for continuous daily robotic services. In *2011 IEEE/SICE International Symposium on System Integration (SII)*, pages 318–323, Dec 2011.

[8] Abdelghani Chibani, Yacine Amirat, Samer Mohammed, Eric Matson, Norihiro Hagita, and Marcos Barreto. Ubiquitous robotics: Recent challenges and future trends. *Robotics and Autonomous Systems*, 61(11):1162–1172, 2013.

[9] Abdelghani Chibani, Antonis Bikakis, Theodore Patkos, Yacine Amirat, Sofiane Bouznad, Naouel Ayari, and Lyazid Sabri. Using cognitive ubiquitous robots for assisting dependent people in smart spaces. In *Intelligent Assistive Robots*, pages 297–316. Springer, 2015.

[10] Ryo Kurazume, Yumi Iwashita, Koji Murakami, and Tsutomu Hasegawa. Introduction to the robot town project and 3-d co-operative geometrical modeling using multiple robots. In *15th International Symposium on Robotics Research (ISRR 2011)*, 2011.

[11] Morgan Quigley, Ken Conley, Brian Gerkey, Josh Faust, Tully Foote, Jeremy Leibs, Rob Wheeler, and Andrew Y Ng. Ros: an open-source robot operating system. In *International Conference on Robotics and Automation, ser. Open-Source Software workshop*, 2009.

[12] `https://github.com/irvs/ros_tms/wiki`.

[13] John F. Boggess. Robotic surgery in gynecologic oncology: evolution of a new surgical paradigm. *Journal of Robotic Surgery*, 1:31–37, 3 2007.

[14] Morten Bro-Nielsen, Joseph L Tasto, Richard Cunningham, and Gregory L Merril. Preop endoscopic simulator: a pc-based immersive training system for bronchoscopy. *Stud Health Technol Inform*, 62:76–82, 1999.

[15] `http://www.engadget.com/2013/12/23/nasa-jpl-control-robotic-arm-kinect-2/`.

[16] Henrique Martins, Ian Oakley, and Rodrigo Ventura. Design and evaluation of a head-mounted display for immersive 3d teleoperation of field robots. *Robotica*, FirstView:1–20, 1 2015.

[17] Carolina Cruz-Neira, Daniel J. Sandin, and Thomas A. DeFanti. Surround-screen projection-based virtual reality: The design and implementation of the cave. In *Proceedings of the 20th Annual Conference on Computer Graphics and Interactive Techniques*, SIGGRAPH '93, pages 135–142, New York, NY, USA, 1993. ACM.

[18] `http://cirl.lcsr.jhu.edu/research/human-machine-collaborative-systems/ivre/`.

[19] Shin'ichiro Nakaoka. Choreonoid: Extensible virtual robot environment built on an integrated gui framework. In *Proc. of the 2012 IEEE/SICE International Symposium on System Integration (SII2012)*, pages 79–85, 2012.

[20] `http://choreonoid.org/GraspPlugin/i/?q=en`.

[21] Oscar Martinez Mozos, Tokuo Tsuji, Hyunuk Chae, Shunya Kuwahata, Tsutomu Hasegawa, Ken'ichi Morooka, and Ryo Kurazum. The intelligent room for elderly care. In *1The fifth International Workshop on the Interplay between Natural and Artificial Computation (IWINAC2013)*, 2013.

[22] Federico Tombari, Samuele Salti, and Luigi Di Stefano. A combined texture-shape descriptor for enhanced 3d feature matching. In *Image Processing (ICIP), 2011 18th IEEE International Conference on*, pages 809–812, Sept 2011.

[23] Jonathan Bohren, Radu Bogdan Rusu, E. Gil Jones, Eitan Marder-Eppstein, Caroline Pantofaru, Melonee Wise, Lorenz Mosenlechner, Wim Meeussen, and Stefan Holzer. Towards autonomous robotic butlers: Lessons learned with the pr2. In *International Conference on Robotics and Automation*, 2011.