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Robotic Service Coordination for Elderly People and Caregivers with Ubiquitous Network Robot Platform

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***Abstract*— This paper proposed a method for deploying robotic service coordination for elderly people and caregivers. By showing two kinds of robotic services for them in real environments, we explain what important designs to deploy robotic services are. For this purpose, we utilized an infrastructure, called Ubiquitous Network Robot Platform (UNR-PF), allowing robot service coordination with robots, smartphones, sensor networks. Three layered architecture of UNR-PF supports developers of personalized robotic services and their coordination to utilize different types of hardware according to characteristics of users. In the case studies of elderly care, robotic services should consider different types of hardware (e.g., wheelchair type) due to characteristics of users; it makes difficulties for design of robotics services.**

I. Introduction

Robotic services consist of various robotic components, such as sensor devices, actuation devices (i.e., robots) and smartphones as both sensor and interaction devices, and service applications that provide people with particular services in real world environments by controlling such devices. Robotic services are expected to be an important factor to support daily life in the real world, particularly for super-aging society.

Japan had become super-aging society. In such society, one of important social problems to be solved is to encourage elderly people in social participation, especially for those who are living alone or who require nursing care. In this context, robotic services are being expected for elderly care purposes from the viewpoints about physical/mental support for such elderly people (Figure 1).

Figure 1 Illustrations of robot services for elderly people

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In fact, many researchers have developed to support elderly people from physical/mental support viewpoints For example, from the viewpoint of physical assistance, Dubowsky et al. have developed a robotic aid system which supports elderly people’s mobility and monitoring [1]. Graf have also developed an adaptive guidance system for robotic walking aids [2]. Kulyukin et al have focused on carrying baggage services, and then they developed a mobile cart robot which works on a shopping mall to support shopping physically. Mutlu et al. developed a conveyance robot to assist hospital staffs, which is an indirect assistance for senior citizens [3].

From the viewpoint of mental care of elderly people, several robotics research works have also been conducted. For example, Paro is one of famous robotics products which used for mental care for elderly people in nursing homes [4]. Several robots, which do conversations as reminders of medicine schedules, are also used for mental cares of them, and used for preventing them from forgetting to take medicine [5][6]. Iwamura et al. have investigated the influences of appearances and chats of interactive robots toward the impressions that elderly people receive under shopping support situations [7].

However, though several robotics services are achieved in the level of “research,” they are still a little far from “commercialization.” To solve problems related to super-aging society, it is important to deploy various robotic services into real world environments. For this purpose, developers should consider how to organize different kinds of robots for various services because appropriate robot hardware varies depending on users’ characteristics. Infrastructures for developing robotic components and managing their resources and assigning them for service applications should be commonly used among developers and operators to provide variations of robotic service applications in particular service environments.

Though ROS [8] and RTM [9] have been developed as middleware to accelerate developments of robot systems, they however have mainly focused on relatively low-layer levels (robot component layer of UNR-PF) that enable control of robotic components, not strongly focused on robotic service applications. Coordination between robotic services should also be supported, because it is still difficult to realize a standalone robot that can provide multiple services only by itself.. For this purpose, to realize service coordination among multiple robots, following four topics should be addressed, such as, definitions of common representation for robots, classifications of robot abilities, managements of available robot resources, and sharing knowledge between different robots. Some of related works achieved robotic service coordination by using networked robot systems [11] [12].

Moreover, RoboEarth [13] and CoTeSys [14] realized information sharing among different types of robots. But, these trials are relatively focused on multiple robot coordination of information sharing, not strongly focused on an infrastructure which enables developers to easily realize robot services in real environments.

From these considerations, we have developed a robotic service framework, ubiquitous network robot platform (UNR-PF) [14], to enable developers to realize various robotic services applications easily. UNR-PF is consisted of three layers: service application layer, UNR-PF layer, and robot component layer. The service application layer is not depended on devices (i.e., robots) so that application developers can just focus on the design and development of robotic services by ignoring limitations of robot hardware. The UNR-PF layer is designed to connect both application and robot component layers properly by considering characteristics of person, robots and environments.

In this paper, we introduce the background and details of UNR-PF and then describe two examples of real robotic service coordination. First one is a shopping support in a shopping mall (Figure 2). This service includes multiple robots and smartphones. Elderly easily uses shopping support applications through smartphone and interacts with the robots. Second one is a robotics support in nursing home for both caregivers and elderly people. This project is in progress. The system uses semi-autonomous wheelchair robots as a mobility support and depth sensors for watching safety in the middle of the night. In both examples, UNR-PF realized robotic service coordination with multiple robots considering personal characteristics of users.

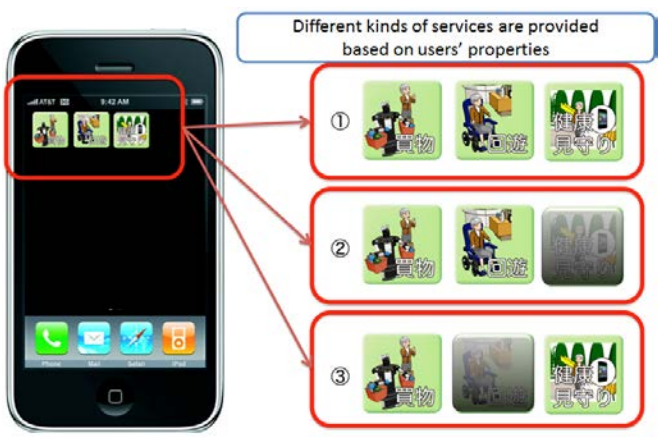

Figure 2 Robotic service selections via a smartphone

II. UNR-PF

As robotic services grow large, robotic systems also become complicated and then development of such a system also becomes harder and harder. Similar to traditional software engineering, people in robotic technology started to seek modularity and reusability of basic functional components and then invested development of common libraries and middleware [8, 9, 15, 16].

Nowadays, robot developers can share functional modules for robotic devices on common platforms and rapidly develop working robotic systems by adopting existing functional modules in combination with their own software. Such modularized development process has accelerated the development of standalone robots as well as individual functional components; however, there exist gaps between development of robots and service applications. Another abstraction layer for service development is required in addition to the component oriented development.

In our previous project, six kind of robotic services have been investigated as case studies for verification of technologies and service coordination, such as shop guidance, shopping support, touring support, active hearing, community building support and health care services. Requirements for common functions arose from those case studies (Table 1), and then the specifications of such functionalities have been proposed as middleware architecture called UNR Platform (UNR-PF).

UNF-PF is a common infrastructure that supports development of robotic services as applications of networked robot technologies. The requirements for the platform are mapped into the following four categories.

1. Multi-Robot Management: a mechanism to assign suitable robots to the demands of services and users.

2. Multi-Area Management: a mechanism to share spatial information of multiple areas such as map information including dynamic location information of moving entities and service oriented information in addition to static spatial structures of the service environments.

3. User Attribute Management: to support the daily activities of various users, especially the elderly and disabled, it is important to understand users' abilities and required supports such as moving assistance, preference for visual communication than aural one, etc. Platform should allocate robotic devices suitable for each user's preference while a service does not notice of it.

4. Service Coordination Management: to execute a number of services across multiple areas, platform should provide mechanisms for managing the state of service execution and that for sharing information among services.

Figure 3 shows a structure overview of the UNR-PF. Following subsections describe the architecture, its internal components, relationship with several international standards, and then introduce current status of the implementation.

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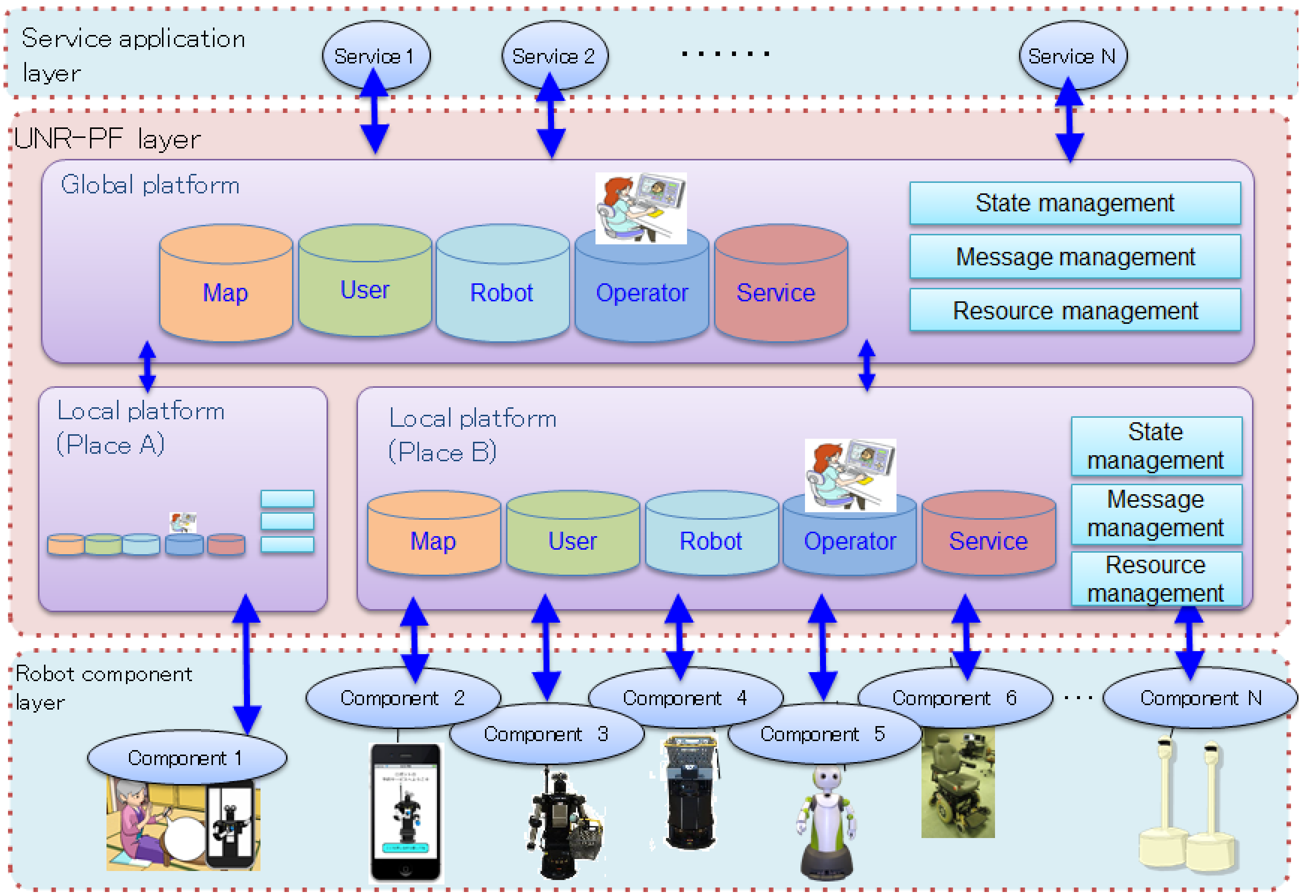

Figure 3 Overview of UNR-PF

A. *System Architecture and Deployment*

The middleware consists of two platform layers: a local platform for the robotic system in a single area and a global one for the robotic system that ranges over multiple areas covered by a number of local ones (Figure 2). These platforms serve as a middle-layer between the layer of service applications and that of robotic components including smartphones, agents sensor networks, etc.

B. *Internal structure of the platform*

First, service applications and robots in each environment are connected to UNR-PF and register with it. The applications and robots discover each other on the UNR-PF and start interacting among themselves.

UNR-PF itself is composed of two platform layers: a local platform (LPF) and a global platform (GPF). LPF is a platform for the robotic system in a single area; GPF is a platform for the robotic system that ranges over multiple areas covered by a number of LPFs. These platforms serve as a middle-layer between the service application and the robotic component layers.

The platform is equipped with five database functions and three management functions to provide common services to the service applications and robots. The database functions consist of robot, map, user, and operator registries, and service cues. The management functions consist of state, resource, and message managers (Table 2).

Table 1 Basic HRI component arose from case studies

HRI Component	Description
System information	Provides the information of the system such as status of the system and position of the physical unit.
Person detection	Detects number of people.
Person localization	Detects position of people.
Person identification	Identifies IDs (names) of people.
Face detection	Detects number of human faces.
Face localization	Detects position of human faces.
Sound detection	Detects number of sound sources.
Sound localization	Detects position of sound sources.
Speech recognition	Recognizes person’s speech.
Gesture recognition	Recognizes person’s gesture.
Speech synthesis	Generates robot speech.
Reaction	Performs specified reaction.
Navigation	Moves to specified target location.
Follow	Follows a specified target object.
Move	Moves to specified distance or curve.

Table 2 Details of each registry and manager of UNR-PF

	Description
Robot registry	It contains information about the robots available in area(s), such as robot IDs, shapes, mobility capability, and transporting capacity. The platform refers to this database to assign robots in a LPF suitable for service applications.
Map registry	It provides map information of the service execution environment, including the floor properties and information about movable and no-go zones. The map registry in GPF provides positional relations among single areas covered by LPFs to improve service linkage between areas.
User registry	It manages information about service users to provide appropriate services and robots to users. This database contains the attributes of each user, such as user ID, call name, degree of walking ability, and sight and hearing abilities.
Operator registry	It manages information about the operators of robots and/or services. The database contains the available skills of all operators with their operator IDs. Therefore, service applications can hire operator assistance, if required, by the resource manager described below.
Service registry	It manages the invocation of services. This database contains the ID of each registered service and information about conditions when invoked by the platform. When a service application registers itself to the platform, its ID and initiation conditions are stored in the service queue.
State manager	It subscribe to the message manager for state notifications registered in the service queue. When the manager receives a state notification, it determines if the state complies with the start conditions in the service queue. If it does, the manager sends a message to the service application to start the service.
Resource manager	It manages the assignment of such resources as robots and operators. After receiving a command execution message from a service application, it refers to the robot, user, and operator registries to reserve a suitable robot and an operator who can operate the service and the robot depending on the situation.
Message manager	It exchanges between service applications and robotic components are handled by message managers through a common interface. When the GPF manager receives a message from a service application, which is typically a request for a command execution, it refers to the registered profiles of the robotic components and delivers it to the suitable ones.

C. *Standardization*

To share information among the robots and the service applications and achieve interoperability among different robots, the specifications of the data structures and interfaces should be standardized. In parallel to the prototype development, the key elements of the platform technologies have been proposed to several organizations as international standards. Four key elements of the prototype system, such as map information, location information, common interfaces, and platform architecture, have been standardized.

Map information is standardized in the Open Geospatial Consortium (OGC), a consortium for standards associated with geographical information. Our request for extension of the CityGML specifications for allowing maps to contain robot-specific information has been accepted and issued as an example of application domain extension (ADE) of CityGML version 2.0.0 in April 2012 [17].

To exchange location/pose information among various networked robot elements and robotic services, this standard proposes a new framework for robotic localization (RoLo) for the representation and treatment of location information specific to robotic usage.

A standard specification for describing and exchanging location and pose information for robots has been issued as the Robotic Localization Service (RLS) specification and updated as RLS 1.1 in August 2012 [18].

The standardization of common interfaces between service applications and robotic functional components is treated in OMG as the Robotic Interaction Service (RoIS) Framework specification. The initial version of the specification has been issued as RoIS 1.0 in February 2013 [19].

The common platform architecture was discussed in the International Telecommunication Union Telecommunication Standardization Sector (ITU-T), study group 16 (SG16). The recommendation, initially called F.USN-NRP, was accepted as a standardization work item in 2011 and has been released as F.747.3 in March 2013 [20].

III. Service Application I: Shopping Support in a Mall

To evaluate the effectiveness, we have conducted a case study with elderly people. This service application provides a touring service that was provided through three areas: the elderly person's home, the shopping mall, and the operator center.

Figure 4 shows an overview of the case study which uses a humanoid robot. In this service application, firstly a user makes a shopping list by using smartphone. When the user visits the shopping mall, the service localizes the user's position by using environmental sensors then a humanoid robot approaches to the user and greet to the user. Then, the humanoid robot carries baggage and starts following the user during shopping.

Figure 5 also shows another variation the case study in which a wheelchair robot is used for elderly people who have walking difficulty. In this service application, firstly a user reserves the shopping support service by using smartphone, too. When the user visits the shopping mall, the service estimate arrival timing by using GPS information via smartphone, then makes a wheelchair robot go to the entrance of the shopping mall with appropriate timing. As a result, the user can use the appropriate wheelchair robot for his/her shopping. We finally developed software which enables users to select possible services depending on user's characteristics (Figure 2).

Figure 4 A shopping support with a humanoid robot

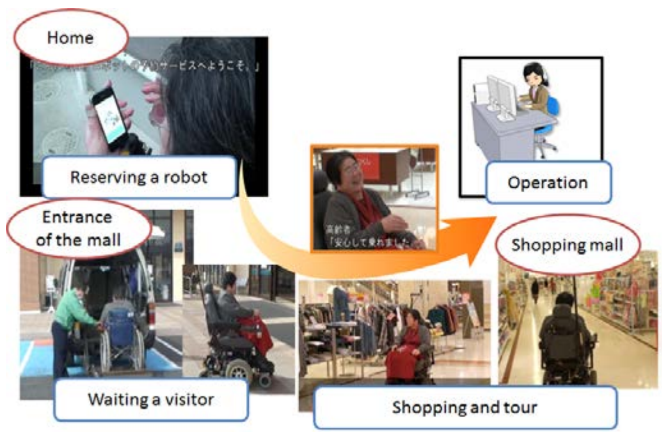

Figure 5 A Shopping support with a wheelchair robot

IV. Service Application II: Transfer Support and Watching of Falling Out of a Bed in a Nursing Home

Due to increase in the number of elderly people, elderly care is becoming an important social problem in Japan. In particular, hard works of caregivers and acute shortage of caregivers are major problems in elderly care. Decreasing the workload of caregivers by using robotic services would help them to increase the quality of elderly care, and consequently elderly people would be able to get more health. Moreover, use of robotic services would be easy and comfortable for elderly people more than asking a help to caregivers in busy.

From these considerations, we are starting a new project which uses robots and sensing technologies to decrease workload of caregivers by supporting transfers of elderly people and watching them of falling out of their beds in midnight at a nursing home. For this purpose, UNR-PF is also used for managing robotic components and service applications by considering users characteristics such as nursing care level (a degree of care-requirements in Japan).

A. *Transfer Support*

Figure 6 illustrates an overview of our transfer support service application. Semi-autonomous wheelchair robots are used to support transfer of elderly people in a nursing home. For elderly people who have walking difficulty, transfer support is quite important to their life, especially from the viewpoint of preventing homebound of elderly people.

However, in transfer support, a caregiver basically needs to move together with an elderly person by pushing wheelchair. Although transfer support is important for healthcare for elderly people, it is true for care givers that its workload is high, particularly from the viewpoint of total time spent at work. For this problem, we proposed the use of semi-autonomous wheelchair robot which transfers elderly people safely with decreasing workloads of caregivers. On behalf of care givers, it enables robot operators or families of elderly people to support locomotion of wheelchair robots, and talk with them via networks.

We designed semi-autonomous wheelchair robots use its own sensors such as laser range finders and environmental sensors such as 3D depth sensors installed in order to understand environments, such as avoiding people in a corridor while navigation. Moreover, UNR-PF provides information about environment properties such as floor characteristics and personal properties such as the nursing care level of users to adapt the behaviors of wheelchair robots. Operators can watch the status of elderly people and the wheelchair via network, and they can talk with elderly people or control wheelchair under transfer support. Even if a problem happens to an elderly people riding on a wheelchair, operators can instantly inspect the situation via network. We are planning to extend our past tele-operation mechanism which enables one operator to control five robots [21].

Figure 6 Overview of transfer support by wheelchair robots

B. *Watching of Falling Out of a Bed*

Figure 7 illustrates an overview of our watching service application. Depth sensors in a room are used to detect dangerous scenes such as falling out of a bed. For elderly people, such accidents sometimes happen while they are sleeping. Another problem related to falling out of a bed is delay of finding of people. If such accident happens in midnight and missing them long-time, it causes critical injuries for them.

This problem happens not only in nursing homes but also in their homes, therefore it is one of main concerns of families of elderly people. Currently, floor sensors around a bed are used to detect such accident but such sensors often miss-recognize the situations (e.g., when an elderly person gets down of the bed to go to a restroom at night, the sensors detects pressures and then sends a warning notification to caregivers) and expensive running cost are often problems for caregivers.

To solve such problems, we proposed use of depth sensors to recognize both dangerous situations and safe ones accurately. Current depth sensors are relatively inexpensive and non-contact sensors, therefore use of depth sensors is appropriate from the viewpoint of cost merits.

For this purpose, we consider to use infrared-type depth sensors such as Kinect to recognize situations where elderly people falling out of beds. Moreover, such sensors can also be used to observe daily activities of elderly people in environments; long-term data analysis would be helpful to detect anomaly situations such as wandering in the environment. We have already developed a system which estimates future behaviors or positions of pedestrians by using stored trajectories [22], we are planning to extend the system to recognize and estimate behaviors and positions of elderly people. Finally, the system can send warning notifications to caregivers via network when the systems recognize or estimate dangerous situations, so that the caregivers can effectively support them.

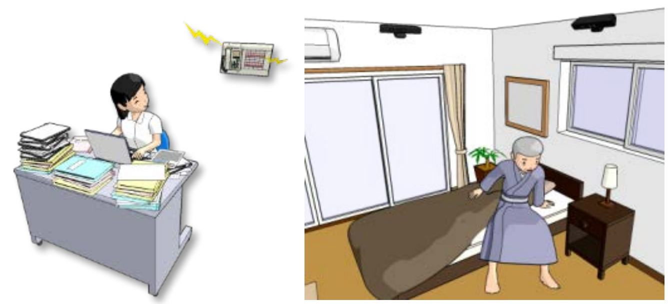

Figure 7 Overview of watching support

V. Conclusion

This paper reports an overview of UNR-PF which is an infrastructure to realize coordination of robotic services. We also showed several case studies of robotic services for elderly people and caregivers in real environments developed with the three-layered architecture supported by UNR-PF.

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