# User-friendly Autonomous Wheelchair for Elderly Care Using Ubiquitous Network Robot Platform

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## ABSTRACT
The importance of assistive robots for elderly people is increasing to match the needs of rapidly aging world societies. This paper develops a wheelchair robot to support the movement of the elderly to decrease caregiver workloads from the perspective of physical load and time consumption. We observed the behaviors of caregivers at a private residential care home when they are wheeling elderly people in wheelchairs. The behavior includes appropriate utterances for reducing the anxieties of senior citizens based on properties of place, e.g., “Here the path is a little narrow” while passing a narrow space or “Now let’s go into elevator.” They also adjusted to the wheeling speed preference of each individual because their preferred speeds were different. We implemented these two functions for elderly care using the Ubiquitous Network Robot Platform that allows the management of users and environment properties. Experimental results with elderly participants at a pseudo resident home show that the seniors prefer a wheelchair robot on which the above functions have been implemented.

### Author Keywords
Autonomous Wheelchair; Human-Robot interaction; Ubiquitous Network Robot Platform

### ACM Classification Keywords
I.2.9. Artificial Intelligence: Robotics

## INTRODUCTION
As the number of senior citizens continues to increase in many countries including Japan, Italy, and Germany, assisting them is one of the major purposes of robotics research field. Such physical assistance as walking aid [1, 2] and carrying baggage [3] are especially promising applications for assistive robots.



Recent research has also focused on the social acceptance of assistive robots due to the advances in their development. Even if stable and safe wheelchair robots are realized, integrating them in the world is difficult without acceptance by the actual users: elderly people. Such a gap between researchers (or engineers) and users is always experienced when new technologies are introduced to the world.

User-friendliness is one key for acceptance from elderly people. Assistive robots must consider both their individual properties and their preferred interaction style. For example, the walking speeds of seniors vary widely and tend to be slower than younger people. Therefore, assistive robots that accompany users need a function to adjust their moving speed based on each elderly person’s preference. Moreover, a past research work reported that elderly people prefer a conversational robot more than a non-conversational one [4]. Such behavioral considerations are useful to design assistive robots for the elderly.

We are developing a moving support system using a wheelchair robot for the benefit of the elderly. We analyzed the typical behaviors of caregivers in a private residential care home. Such behaviors include appropriate utterances to reduce the anxieties of the elderly that reflect the places and changing wheeling speeds based on individual preferences. To implement typical behavior in a wheelchair robot that adapts to such personal properties as a preferred walking speed, we employed a Ubiquitous Network Robot Platform (UNR-PF) service, which manages interaction between users and wheelchair using UNR-PF. It also manages environment information such as the spatial attributes of a corridor; the robot used this information to make appropriate comments to reduce stress, as caregivers do (Fig. 1). We experimentally evaluated the effectiveness of these functions with elderly participants at an experimental private residential care home facility.


**Fig. 1 Wheelchair robot with an elderly person**

## RELATED WORK

Assistive robots for elderly people are seeing greater development in the world. For example, researchers have developed them as walking aids [1, 2]. Mutlu et al. developed a conveyance robot to assist hospital staffs, which indirectly assists elderly people [6]. Developing a wheelchair robot is one straightforward approach to physically support elderly people [7]; such basic navigation methods as path planning [8], obstacle avoidance [9], and simultaneous localization and mapping [10, 11] are stabilizing due to the hardware and software advances of wheelchair robots. Therefore, researchers are focusing on various stages of research, e.g., such as a user interface as a voice interface [12] and a brain machine interface [13] for easily controlling wheelchair robots, comfortable driving by considering human perceptions [14], and safe autonomous navigation for multiple wheelchairs [15].

Related to the development of such physical assistant robots, social robots, which focus on effective communication with the elderly, are also becoming a major topic in this research field. For example, social robots have been developed for healthcare assistance that give verbal instruction to provide reminders about medicine schedules [16, 17]. Paro, a seal robot, is used for therapy purposes in elderly care homes [18]. Iwamura et al. investigated the effectiveness of the conversation and the appearances of a physical assistant robot for elderly people [4] and concluded that seniors prefer a conversational robot as a shopping assistant partner.

Similar to these related works, in this research we investigate the effectiveness of a wheelchair robot that provides moving support to elderly people instead of caregivers through an experiment with actual elderly people. One of the unique points of our research work is its investigation of the perception of elderly people about two implemented functions that were designed by observing the behavior of actual caregivers for such moving support as speaking behavior for wheelchair robots. Past related works developed several wheelchair robots to provide moving support [7], but they did not focus on such perceptions.

## SYSTEM DESIGN AND OVERVIEW

### Design Policy for a Wheelchair Robot

We investigated how actual caregivers interact with the elderly at a private resident home (Good Time Living Kōrigaoka, Osaka) to design the functions for our wheelchair robot. About 100 elderly live in the home, among whom 20 only use wheelchairs every day.

The minimum number of daily wheelchair trips for a person in the home was 10: six times between the bedroom and the dining area (three round trips for meals), twice between the bedroom and the bathroom, and twice between the bedroom and the recreation room. Therefore, at least 20*(10-times) wheelchair uses for the moving support of elderly people occur in this home.

We observed how the caregivers wheeled the elderly people around the home. From ten observations of a 11-m hallway between an elevator and a dining hall/cafeteria, the average wheeling speed was around 600 mm/second, which resembles the slow walking speed of an adult. Caregivers often made comments based on the locations or about arriving at or waiting for the elevator or entering the cafeteria/recreation room, even if the elderly people did not respond.

After observing the caregiver behaviors during the moving support, we discussed them with the home's administrator. Even though the caregivers carefully maintained a slow wheeling speed, we learned that some of the elderly people desire an even slower wheeling speed because they want to move at their own walking speed. The administrator also emphasized that caregivers must engage in small talk to help reduce the anxiety of the seniors, even if they failed to respond.

Based on these observations, we implemented two functions to realize a friendly wheelchair robot for moving support: 1) adaption of moving speed based on individual preference and 2) small talk about position-related events.

### System Overview

We used an UNR-PF to manage the preferred speed of the individuals as a personal characteristic and environmental information to support position-related events to implement the observed functions. Fig. 2 shows an overview of the system, which consists of three components: user interface (UI), UNR-PF, and a wheelchair robot. The details are described as follows.

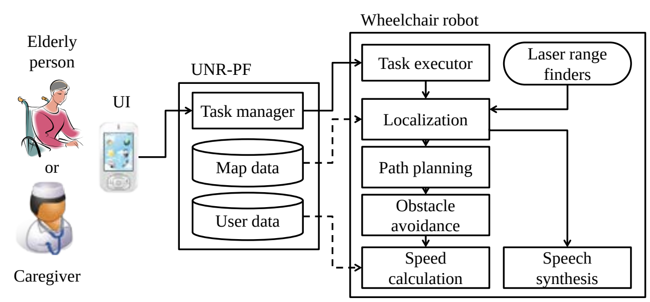


**Fig. 2 System overview**

#### *User Interface*

We used an Android tablet (Nexus 7) to control the wheelchair robot. The user interface consists of three panels: settings, user selection, and navigation (Fig. 3). By using a "login" system, the system automatically retrieves and changes the moving speed of the wheelchair robot to the preferred speed of the user who is riding on the robot wheelchair. Destination options are displayed by simple icons that the elderly or the caregivers can touch to select a target location.


**Fig. 3 UI to determine wheelchair location**

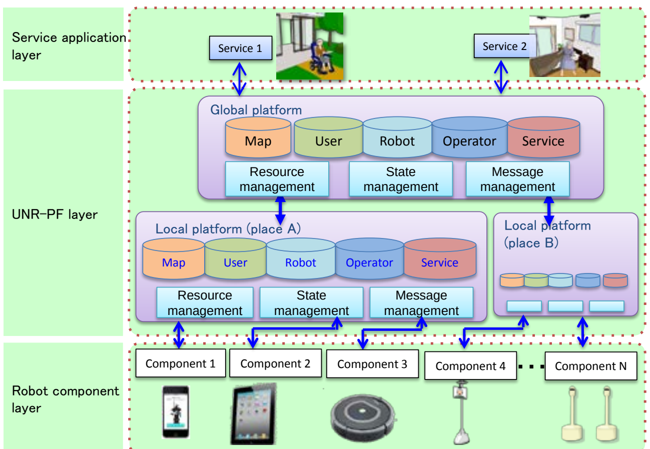


**Fig. 4. UNR-PF overview**

*UNR-PF*

The UNR platform is an open standard infrastructure for networked robot services [5]. Its salient point is that it focuses on abstraction over the underlying low level robotic hardware layer to develop robotics services, unlike other common libraries and middleware such as ROS and RTM. Even if such systems enable robotics researchers to develop functions for robot control, it remains difficult to manage robot service applications with different kinds of robots/sensors. To bridge the gap between robot development and service applications, our UNR platform design has three layers: service application, platform, and robot component (Fig. 4).

To achieve interoperability with different robots and sensors by sharing information among the robots and the service applications, the specifications of the data structures and the interfaces must be standardized. Even though part of the UNR platform has already been proposed to several organizations as international standards, the standardization details are beyond the scope of our research focus (see [5] for details). We used the UNR Platform to connect the wheelchair robot and a client user interface system and to manage both the elderly and environment information.

*Wheelchair Robot*

In this work, we used a differential drive robotic wheelchair from Nissin Medical Industries (NEO-PR45, Fig. 1), which is equipped with three laser range finders (Hokuyo UTM-30LX). It is 59-cm wide, 85-cm-tall, and 104-cm-long and we set it to move forward at a maximum velocity of 900 mm/sec and at 30 degree/sec. The forward acceleration and the rotation are 600 mm/sec$^2$ and 30 degree/sec$^2$, respectively. The laser range finders are used for localization and obstacle detection. For safe navigation, we implemented a time varying dynamic window (TVDW) [9] and used speech synthesis software, XIMERA [19], for the robot's speech.

For speed adaption and speaking behavior, the wheelchair robot changes its moving speed using the preferred speed information from UNR-PF to realize the first function. For the second function, the robot makes pre-defined small talk based on its position and registered map information in UNR-PF around narrow spaces and slopes. The robot also uses the elderly person's name who is riding in the wheelchair and informs her of departures and arrivals.

## EXPERIMENT

### Hypotheses and Prediction

We implemented two functions on our wheelchair robot by referring to the actual caregiver behaviors. If these functions are prepared well, we believe that the elderly will more positively evaluate the robot than a robot without them.

As an alternative method, we used a wheelchair robot without our implemented functions that was designed based on the observations of caregivers. The safety functions are the same as the developed system. The moving speed is 600 mm/sec, which is the average speed of the caregivers measured at the private residential care home. We also prepared a caregiver condition to compare the evaluations with the robots as an additional alternative method. Based on the above idea, we made the following predictions:

Prediction 1: The wheelchair robot with the implemented functions will be rated higher in terms of comfortable moving speed than the wheelchair robot with an alternative method.

Prediction 2: The wheelchair robot with the implemented functions will provide more enjoyment during movement than the wheelchair robot with an alternative method.

### Participants

Twenty eight elderly people (14 women and 14 men, who averaged 74.0 years old, S.D 6.85) participated in the experiment. 10 people, who require daily care, are living in private residential care homes; five usually use wheelchairs. One or two senior staff members from the care home also participated in the experiment to support the elderly people who are living in the home.

### Environment

We conducted the experiment in an experimental residential care home facility that consists of a bedroom, a bathroom and a lobby. The room sizes and designs are the same as the actual care home where some of the participants are actually living. Fig. 5 shows a map of the environment.

### Conditions

We used a within-participant experiment design to evaluate and compare the effects of the implemented functions.

#### *Simple navigation condition*

In this condition, the wheelchair robot automatically moved with the participants who are riding on it after selecting the target location by UI. As written above, the wheelchair's usual speed was 600 mm/sec. The robot did not use its speech synthesis function. Fig. 6 shows a wheelchair robot moving around in the experimental environment.

#### *Proposed condition*

In this condition, the wheelchair robot also automatically moved after selecting the target location by UI. It speaks based on the robot's location. We adjusted the usual speed to each participant's preferred speed that was measured at the beginning of the experiment (details are described below).

We set two kinds of place information in this environment: a narrow place at the bedroom's door and a slope in front of the bathroom. This information was sent to the robot from the UNR-PF using the robot's position, and then the robot says pre-defined dialogues before passing these places. For example, the robot said, "here is relatively narrow" before passing the bedroom's door, and "now we are going slightly uphill" at the beginning of the slope. Fig. 1 shows a scene where a wheelchair robot speaks before passing the door.

#### *Caregiver condition*

In this condition, a caregiver wheeled the participants as the caregivers usually do. Therefore, this condition reproduces a daily situation of the elderly who are using wheelchairs and need help to move around.

If the participants were living in the care home, a staff member of the home wheeled them in the experiment in the usual fashion; we did not specify moving speed or conversation behavior. For the rest of the participants, the experimenter wheeled them at around 600 mm/sec, which is the average speed at which the caregivers wheeled the elderly people, as measured by the private resident home. The experimenters talked to the participants using similar contents to the *proposed* condition that was described above.

In Fig. 7, a caregiver is pushing a participant in a wheelchair.

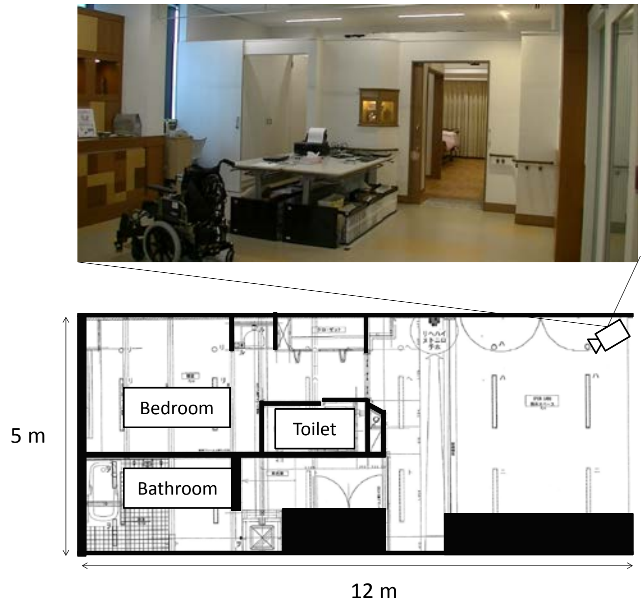


**Fig. 5 Environment**

**Fig. 6 Wheelchair in simple navigation condition**

**Fig. 7 Caregiver condition**

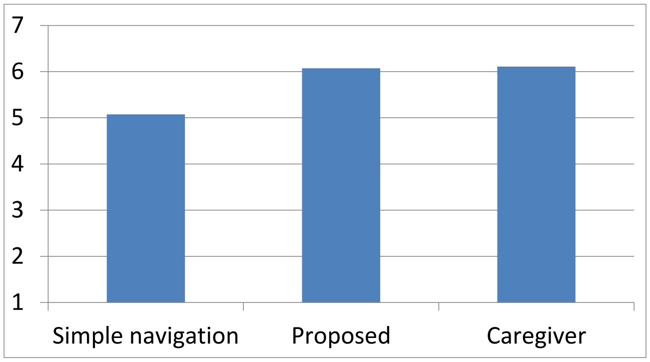


**Fig. 8 Comfort of moving speed**

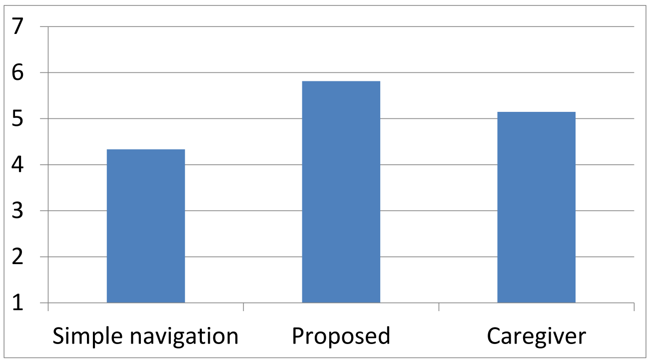


**Fig. 9 Enjoyment during movement**

### Procedure

Before the first session, the participants were given a brief description of our experiment's purpose and procedure. We also determined their preferred speed; the participants rode in the wheelchair robot at three different speeds: 300, 600, and 900 mm/sec. Most of the preferred speeds reported by the participants are used for controlling the wheelchair robot under the *proposed* condition. Seven participants preferred 300 mm/sec, 19 preferred 600 mm/sec, and two preferred 900 mm/sec.

Since the experiment had a within-participant design, each participant participated in three sessions of different conditions. The order of the conditions was counterbalanced. Staff members remained in the environment for safety and to record videos. The participants filled out a questionnaire after each session.

The experiment's route was designed based on the daily situation of a representative elderly person who is using a wheelchair at the private resident home in the evening. She leaves her bedroom to go to the bathroom to take a bath and returns to her bedroom. Since this is an experiment, the wheelchair robot makes a round trip between the bedroom and the bathroom.

### Measurements

We measured two items in this experiment: comfort at the preferred moving speeds and enjoyment during the movement. All questionnaire items were evaluated on a 1-to-7 point scale.

## RESULTS

### Verification of Prediction 1

Figure 8 shows the result of the comfort of the moving speed. We conducted a one-factor within subject ANOVA and found a significant difference among the conditions (F (2, 52) = 10.419, $p<.001$, partial $\eta^2=.286$). Multiple comparisons with the Bonferroni method revealed significant differences: *caregiver* > *simple navigation* ($p$ = .001) and *proposed* > *simple navigation* ($p$ = .001). No significance was found between *caregiver* and *proposed* ($p$ = 1.0). Therefore, prediction 1 was supported.

### Verification of Prediction 2

Figure 9 shows the result of enjoyment during the movement. We conducted a one-factor within subject ANOVA and found a significant difference among the conditions (F (2, 52) = 12.026, $p<.001$, partial $\eta^2=.316$). Multiple comparisons with the Bonferroni method revealed significant differences: *caregiver* > *simple navigation* ($p$ = .029) and *proposed* > *simple navigation* ($p$ <.001). A significant trend was found between *proposed* and *caregiver* ($p$ = .096). Therefore, prediction 2 was supported.

## DISCUSSION

### Limitations

Since this study was conducted for moving support at an experimental residential care home in Japan, we cannot generalize about our predictions from it. Even though this experiment was held in a realistic situation with participants who used the wheelchair robot, it was conducted within the framework of an academic study. The elderly participants only used the wheelchair robot a few times. Thus, the effect shown in the experiment would probably be moderated if they got accustomed to the wheelchair robot: the diminishment of any novelty effect. For example, the robot needs to change its words to avoid negative impressions caused by repeating the same speeches. The preferred speed of individuals might also change based on experiences with the wheelchair robots. These limitations of our study will be tested in the future, perhaps with the realistic deployment of wheelchair robots in society.

## CONCLUSION

This paper investigated whether elderly people prefer a wheelchair robot that makes comments based on place while providing moving support and changes its moving speed according to individual preferences. To implement these functions, we used a wheelchair robot and UNR-PF, which can manage individual properties and environment information for robot services. We conducted an experiment with elderly people at an experimental residential care home that consists of a bedroom and a bathroom. The elderly people more highly evaluated a wheelchair robot with the implemented functions than a wheelchair robot without them; we found no significant differences from the questionnaire results between caregiver support and the wheelchair robot with our implemented functions.

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