Multiple Robotic Wheelchair System Considering Group Communication

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Abstract. In recent years, there has been an increasing demand for elderly care in Japan due to the problems posed by a declining birthrate and an aging population. To deal with the problem, we aim to develop a multiple wheelchair robot system that moves with multiple companions collaboratively. In actual care, we noticed that for a group of four people, which included wheelchair users and their companions they tended to break up into two sets of two (1 wheelchair user and 1 caregiver) to move around or communicate with each other. Based on this observation, we propose a robotic wheelchair system that facilitates coordinated movement between the wheelchairs and the companions while maintaining suitable formations for communication among the group.

1 Introduction

In the last decade, several robotic wheelchairs possessing user-friendly interfaces and/or autonomous functions for reaching a goal have been proposed to meet the needs of an aging society [1],[2]. Although ideally, wheelchair users would be able to go out alone, they are in practice often accompanied by companions such as friends, families and caregivers. Therefore, it is vital to consider how we can reduce the caregivers' load and support their activities, while simultaneously facilitating ease of communication between caregivers and wheelchair users. Moreover, when we observed scenes of actual care, caregivers would take multiple patients using wheelchairs because of safety and efficiency as shown in Fig. 1. In such cases, the caregivers indicated that they could not talk to the caretakers face-to-face and provide good patient care. So a multiple robotic wheelchair system, which can move to facilitate easy communication with companions automatically, is highly demanded in care facilities.

Many kinds of mobile robots that can move multiple companions collaboratively have been proposed. For instance, Urcola et al. propose the methodology that multiple robots take multiple companions in a practical situation [3]. Murakami et al. also propose the methodology that a robot, which does not have a priori knowledge of the companions' destination, can move with companions collaboratively using a destination estimation model based on observations of humans 'daily behaviors [4]. Mobile robots which have companions like the approaches mentioned do not have passengers, so that they do not consider communication between passengers and companions. So, in this paper, we present a

Fig. 1. Scenes in a care facility

methodology for multiple robots that can move with multiple companions collaboratively while considering communication between passengers and companions.

Autonomous mobile robots need to consider changes in circumstances such as passage width as their 1st priority because they have to avoid obstacles. However, when there is enough space, a given group of robotic wheelchairs should consider arranging their relative positions in formations suitable for communication among humans in the group. Takano et al. [5] reported the experimental result that group formations are changed depending on circumstances such as passage width or obstacles. They also found that communication is not facilitated when the wheelchair users were positioned in tandem formations. Therefore we propose a multiple robotic wheelchair system that maintains a suitable formation for communication by considering both companions' positions and wheelchairs' positions/poses.

2 Multiple Robotic Wheelchairs System

Kobayashi et al. proposed a robotic wheelchair that could follow alongside a companion based on tracking the companion's body position/orientation using a 2D Laser Range Sensor (LRS), which was set on top of a pole at the companion's shoulder level and attached to the wheelchair [6]. However, this system has two problems. The first problem is that the companion cannot control the wheelchair for ease of communication because it is difficult for the companion to move straight while talking to the wheelchair user face-to-face. The second problem is that it is difficult to get multiple companions into the group using only a LRS on the wheelchair due to a high level of occlusion. When a companion moves near a wheelchair he/she may occlude others from the sensor over a wide area. To deal with these problems, we setup LRSs in the environment where the wheelchairs are to be used and can get observations of multiple companions with less occlusion. Moreover, we maintain formations between wheelchairs without using the companions' body orientation along a preset path. In a care facility, the number of locations visited (e.g. bathroom, dining hall, or barber room) is limited, so we can consider paths to already be known. To control wheelchairs in this manner, the wheelchairs need to share a map of the surrounding environment and the positional relationship among the group. Therefore we install a system which can obtain a map and the position/pose of the wheelchair using a LRS on the wheelchair. Fig. 2 shows an overview of the system.

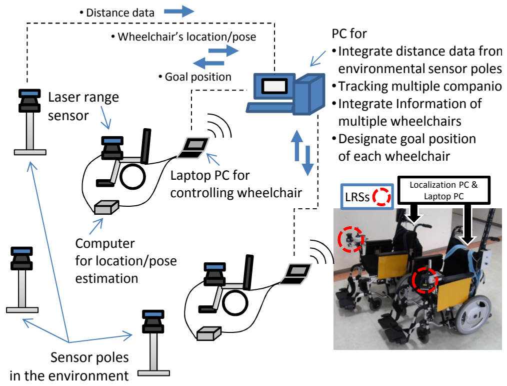

Fig. 2. System overview

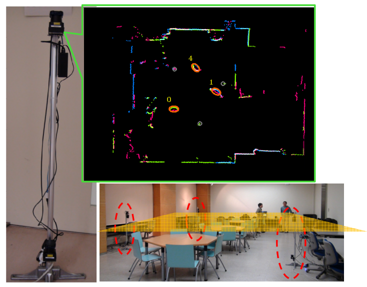

Fig. 3. Observation on sensor poles

We note that in this paper, we use the wheelchair TOWNY JOY X (Yamaha Motor co. ltd.) and the localization system ICHIDAS (Hitachi Industrial Equipment System co. ltd.). Both of them are commercial products. The wheelchair can be controlled by sending 2 channel signals of 0.1-4.9V to set velocity/angular velocity.

2.1 Tracking Companions

We mentioned above that it is difficult to observe multiple companions with a LRS on the wheelchair because of large occlusions. To deal with the problem, we employ sensor poles, which can be put in the rooms without damaging walls or the floor (Fig. 3). We then incorporate them and track companions with less occluded observations.

We apply Kobayashi's companions tracking algorithm [6]. The LRSs on the top of each of the sensor poles are at the shoulder level of the companions. The observed outline shape of the companions' shoulders obtained by the LRSs can be considered as a part of an ellipse. Thus we use an ellipse for the model of the tracking target. Then the system tracks the locations/orientations of companions by applying a particle filter framework [7]. We assume a coordinate system with its X and Y-axis aligned on the ground plane. The model of the tracking target is then represented with the center coordinates of the ellipse (x, y) and a rotation of the ellipse θ. These parameters are estimated in each frame by the particle filter. Using regular particle filters, we represent the posterior distribution by a set of weighted samples that are propagated by a motion model and evaluated by an observation model. Here, we employ a simple random walk model for state propagation, and we evaluate samples based on the observation of the LRSs. Distance data captured by the LRSs is mapped onto a 2D image plane (what we call a "laser image") and then transformed into a Distance Image which is used for evaluating the likelihood of a body. This likelihood is determined by assessing the contour similarity between the model and the companion's upper body as partially observed by the LRSs. At first, an ellipse model of the body contour is sampled as evaluation candidates. Then we select evaluation points

Algorithm 1 Tracking companion

```
Get distance data from LRSs
Map distance data onto laser image
Transform laser image into Distance Image
Generate samples according to likelihoods of previous samples
Propagate each sample
for all samples do
  Calculate positions of evaluation candidate points
  for all candidate points do
    Calculate inner product between the normal vector at the candidate point and
    the vector from the LRS to the candidate point
    if inner product < 0 then
      Employ the candidate point as the evaluation point
    end if
  end for
  Find the maximum distance between the evaluation points and the nearest dis-
  tance data
  Calculate likelihood of the sample by Eq. 1
end for
Estimate current state of the tracking target
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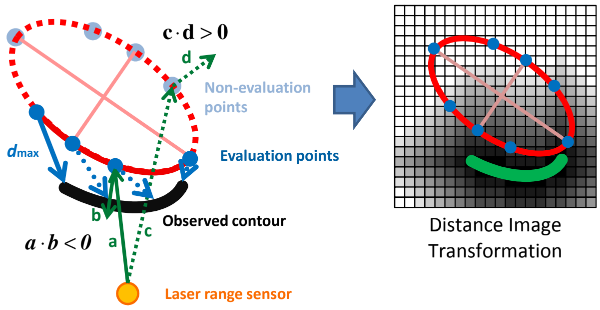

Fig. 4. Overview of algorithm of companions' tracking

from candidates by calculating the inner product between the normal vector at the point and the vector from the LRS to the point. This process is executed by each LRS. Finally, the likelihood of each sample is evaluated by the maximum distance between the evaluation points and the nearest distance data by:

$$w_i = \exp\left(\frac{-d_{\max}^2}{\sigma_d}\right) \tag{1}$$

where w_i is the likelihood score of sample i, and $d_{\max}$ is the maximum distance between the evaluation points and the nearest distance data. At each time instance, once the distance image is generated from the laser image, each distance d_n is easily obtained. σ_d is the variance derived from d_n. These likelihood evaluation procedures are repeated for each sample. This algorithm is shown in Algorithm 1 and Fig. 4.

The system can track a companion in real time with the tracking algorithm outlined above. However, in the case of tracking multiple companions the system cannot perform in real time because of the computational cost for calculating the likelihood of hypotheses as shown by Eq. 1. In practice, the processing time of the likelihood evaluation dramatically increases with the number of people being tracked. To cope with this problem, we use GPGPU to parallelize calculation of the likelihood. Specifically, we parallelize the section from line 6 to line 16 of Algorithm 1.

To evaluate the performance of parallelization, we conducted a person-tracking experiment by using a synthesized laser image sequence simulating multiple people moving around. In this experiment we compared the computation time between the conventional serial computation method and the parallel computation method. The result is shown in Fig. 5. The vertical axis indicates computation time in milliseconds, and the horizontal axis indicates the number of individuals being tracked. The blue dashed line shows the serial computation, while the red solid line shows the parallel computation. According to this result, the parallel computation method can compute approximately 20 times faster than the conventional method.

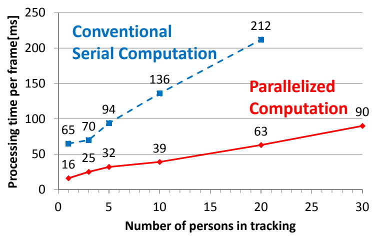

Fig. 5. Comparison of calculation time between "Conventional Serial Computation" and "Parallelized Computation"

2.2 Mapping and Localization

As we indicated above, to be effective, a multiple robotic wheelchair must be able to consider the surrounding environment to determine how it should reach a given destination while considering the positional relations among each wheelchair and companion to maintain a suitable formation for communication. Therefore, we implemented the ability for the wheelchair to estimate its own position/pose. Localization PCs on each of the wheelchairs for processing the neighborhood around the wheelchair using LRSs are attached to the lower part of each wheelchair. First the PC builds an environmental map based on the distance data, and then estimates the position/pose of the wheelchair within a map of the environment.

2.3 Data Integration

Through the methodologies mentioned in Sec. 2.1 and Sec. 2.2, the robotic wheelchair system is able to obtain a position/pose of the wheelchairs and companions simultaneously. The system can then acquire the positional relationship among the wheelchairs and companions to project all of them onto the map. Afterwards, the system can designate the velocity/angular velocity of each wheelchair in order to maintain a formation so that moving while communicating with each other is possible.

2.4 Controlling Wheelchair While Maintaining Formation

The system can obtain the position of each member in the group by applying the data integration mentioned in Sec. 2.4. With this, the system controls wheelchairs on the preset path while maintaining formation. In this paper, for instance, we consider two companions and two wheelchairs as a group.

The outline of this algorithm is shown in Fig. 6.

As the moving the path pl of the group is assigned, each wheelchair is assigned to move along the path pl_1, pl_2 which are the distance d_{pl} away from the path pl. To do so, they calculate the angular velocity ω_1, ω_2 like in [8].

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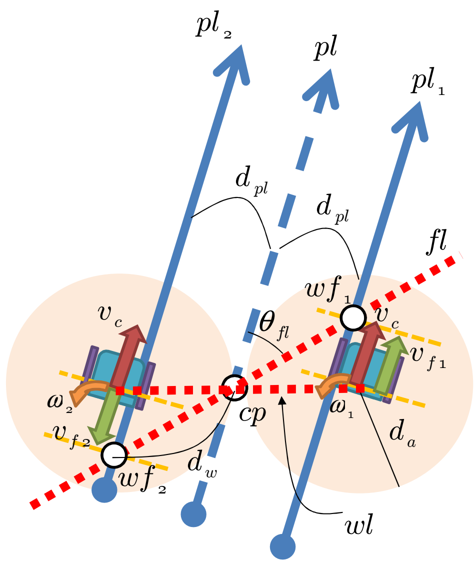

Fig. 6. Controlling multiple wheelchairs while maintaining formation

It is important to control the velocity of each wheelchair to maintain the formation. The calculation procedure of the velocity can be divided into 2 steps. At the first step, we calculate the velocity v_{f1}, v_{f2} which maintains the formation. We denote the point cp as the intersection between the line wl, which lies on the center of each wheelchair's axle, and the path pl. Then we denote the line

fl, which intersects with the path pl at the point cp with the angle θ_{fl}. We then calculate the point wf_1, wf_2, which is on the line fl and the distance d_w away from the point cp. The points wf_1 and wf_2 are the local goal positions which maintain the formation. The velocity v_{f1}, v_{f2} can be calculated according to each distance between the position of the wheelchair at the time and the local goal position. In this algorithm, there are two important parameters to form the positional relationship among wheelchairs. One is the angle θ_{fl} as the formation steering angle. The other one is the distance d_w that determines the distance between wheelchairs. Thus the distance d_{pl} between pl and pl_i can be calculated as $d_w * \sin(\theta_{fl})$. In the second step the system can add the constant velocity v_c if all companions are within the distance d_a from any wheelchairs so that wheelchairs can move forward along a path while maintaining formation when all companions are near the wheelchairs.

3 Experiments

In this section we confirm the effectiveness of our control system, which can control wheelchairs while promoting communication within the group.

In our experiments, we divided 32 participants, all of which are university students, into 8 groups. We asked two individuals to be wheelchair users, and the other two to accompany them. The two wheelchairs went and came back along a predefined path through the course shown in Fig. 7 using the algorithm we described in Sec. 2.4. The path included three lines and two arcs. The length of the path was approximately 18m. We set four LRSs every 10-20m along the path. Each laser range sensor had a field of view of 30m in distance and a 270 degree horizontal angle. The wheelchairs moved using the three formations shown in Fig. 8. In the whole experiment, we set the parameters $d_a = 120$cm, $v_c = 30$cm/s.

For the purpose of facilitating inter-participant conversation, we set a task to the participants whereby they needed to collaboratively work on a quiz. At the start of the experiment, each participant was given a card with a food item printed on it (e.g. carrots, chicken, potatoes). At a point set along the route of

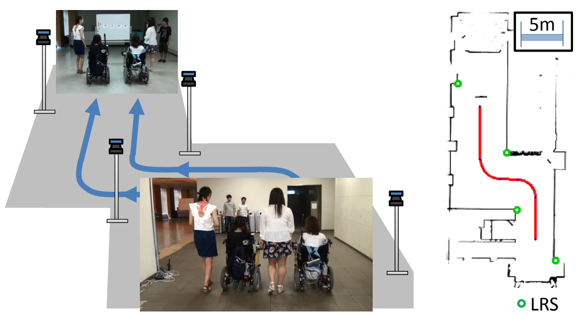

Fig. 7. Experimental settings

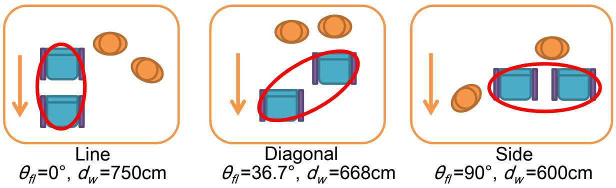

Fig. 8. Formations in the experiment

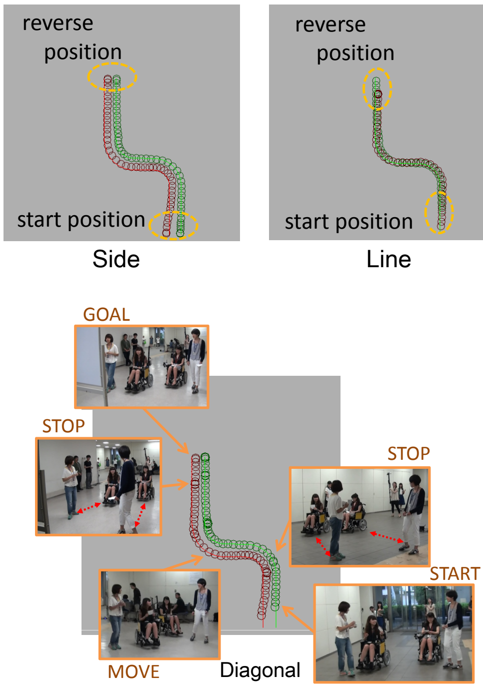

Fig. 9. Paths, trajectories and scenes of the experiment

the experiment, several cards printed with the names of seasonings (e.g. curry paste, soy sauce, miso) were pinned to a whiteboard. The participants needed to figure out what they could cook, given the food items and their choice of a seasoning. They would then give us their answer (e.g. chicken curry) at the end of the experiment. After that, we asked the participants to answer the question, "How did you feel about the formation throughout the experiment?" using the 7 levels on the Likert scale.

The trajectories and scenes in the experiment are shown in Fig. 9. We can see that the wheelchairs move correctly along the preset path. The radii of circles in Fig. 9, which are sampled points of trajectories, are 40cm and are on the paths.

We can also see that the wheelchairs maintained proper formation even when the companions were away from the wheelchairs and stopped. An average of the distance errors between target points and wheelchairs' positions in all cases was less than 30cm. This error did not affect communication among the group.

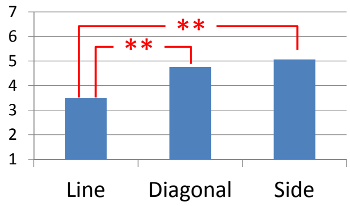

Fig. 10. Result of the questionnaire on ease of communication using different formations

Fig. 10 shows the results of our questionnaire on how the participants felt about the ease of communication using each of their assigned formation. The vertical value indicates the average of the answer. The result is statistically significant in our variance analysis at a 1% level. The difference between the average of the Line formation and the average of the Diagonal formation is significant. In addition, the difference between the average of the Line formation and the average of the Side formation is also significant at a 1% level. Moreover, we can see the average score of the Line formation is less than the neutral score 4 so that the Line formation is not favored by participants. The average score of the Diagonal/Side formations is greater than the neutral score 4 so that the Diagonal/Side formations are favored by participants. By regarding this result, it is clear that moving in the Diagonal/Side formations are effective for the purpose of promoting communication among the group.

4 Conclusion

In this paper, we proposed a multiple robotic wheelchair system that can move with companions collaboratively while maintaining a formation that can promote communication among them. To realize the system, we propose an approach where the system can track multiple companions by extending an existing tracking algorithm and employing a system, which can estimate the location/orientation of the wheelchair. These two components were integrated so as to control multiple wheelchairs while maintaining formation. We then conducted an experiment to evaluate the effectiveness of the system.

Nevertheless, we still need to address the problem of determining the initial position of each companion. We will strive to overcome this by distinguishing the members of the group and pedestrians automatically. We will also aim for more control of the wheelchairs by using the orientation of the companions' body in the future.

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