Formation-Based Tracking Method for Human Following Robot

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Abstract— Mobile robots are widely used in real-world applications, and the interactions between a person and a robot are important. Following a person is one of the interaction functions of mobile robots. To implement this function, most robots track the person from behind. In this case, the person experiences two inconveniences. First, the person often looks back to check whether the robot is following her or him well. Second, it is difficult to operate the robot immediately. In this study, we develop a method that helps a robot follow a person without these inconveniences. A set of candidate goal positions are determined based on the location of a person and the density of obstacles. These positions include a preferred location and a safe location. The robot tracks the goal position that is decided by considering obstacles around itself. This method was tested in a simulation environment. Two performance metrics were defined, and the effectiveness of this method was verified using the metrics.

I. INTRODUCTION

As robotic technology develops rapidly, studies on human-robot interaction (HRI) are being conducted actively. Among the various types of robots, mobile robots are widely used in human life. A mobile robot can help people with a variety of tasks, such as cleaning, delivering food, and carrying baggage. Especially, mobile robots that carry heavy loads while following people can be practically useful. Such robots provide convenience to people in places such as shopping malls and airports, where people need to carry large pieces of luggage. Gita robots by the Piaggio group \cite{1} or electric carrier robots by Horizn Studios \cite{2} are such robots.

In implementing the function of following person, the robot typically follows a person from behind \cite{3}, \cite{4}. In this case, the person feels two inconveniences. First, the person feels insecure about whether the robot is following her or him well. Therefore, the person must check the robot from time to time. Second, it is inconvenient for the person to manipulate the robot immediately. There are situations in which the person takes out or puts his belongings on the robot or commands the robot to stop or wait.

In order to address these inconveniences, we introduce a model of formation in which a robot follows a person while avoiding obstacles. The formation is arc-shaped with a set of goal positions based on the location of the person. This formation connects a preferred location to a safe location. The preferred location is set as a location where the person can see and manipulate the robot directly. The region behind the person that the person has just passed is designated as the safe location. The goal position is determined considering the surrounding obstacles. If there are no obstacles, the goal position is set to the preferred location. If multiple obstacles are detected around the robot, the goal position is set to the safe location.

We verified the effectiveness of this method in a simulation environment. Two performance metrics (formation-to-robot distance and difference of orientation) were defined. These metrics provide a quantitative assessment of whether the robot tracks the formation well while avoiding obstacles. The proposed method can be applied to mobile robots that follow people in the real-world environments for various purposes.

This paper is organized as follows. Section II introduces related works in which a robot follows a person. In Section III, we describe a method of creating and tracking the formation between a person and a robot considering obstacles. The simulation experiment and its results are presented in Section IV. A conclusion is given in Section V.

II. RELATED WORK

Human-following technology, with which a robot follows a person, is the study of proximate interaction in HRI technology \cite{5}, which means interaction with the robot in the same space \cite{6}.

A. Human Following Research (Proximate Interaction)

A variety of mobile robots have been used in human-following research. A method in which a drone follows a person has been studied \cite{7}. In another study, the authors researched a method for a pet robot to find a suitable position to interact with a human \cite{8}. In order to reduce risks to soldiers, robots have been developed to follow them and substitute for them in certain dangerous missions \cite{9}.

Generally, when a robot follows a person, it is typical to position the robot at a certain distance behind the person. Research has been conducted to model a relationship between a person and a robot by using virtual springs, so that the robot can follow the person more smoothly \cite{10}. In \cite{11}, \cite{12}, the relationship between a person and a robot was modeled using a potential field. These studies considered only one goal position for following a person from behind. In the present study, various goal positions are constructed using a formation.

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B. Formation Control of Multi-Agent Systems

Formation control of multi-agent systems is the method of tracking specific positions with a formation [13]. According to this control method, a robot maintains a formation by following the posture of the leader robot at a certain position [14], [15]. However, the following robot responds sensitively to small movements of the leader robot. If this method is applied to track a person, it would be difficult to maintain a stable formation owing to frequent movements. In addition, if obstacles exist in the moving direction of the following robot, the robot cannot avoid them.

C. Graph-Based Distributed Approach

A graph-based distributed approach is suitable for robots to follow people considering obstacles [16], [17]. In this approach, a certain shape of formation is set based on the leader. This formation is modeled as a virtual path with a certain structure. The follower robot uses this path to avoid obstacles and maintain its formation. This method makes it easy to follow the leader steadily while considering obstacles.

Therefore, in the present study, we propose a method to track a formation based on the graph-based distributed approach. A virtual path is formed based on the position of a leader, which is the user in the present study. This virtual path is referred to as the formation. This method is effective for stable control when maintaining the formation between a person and a robot.

III. Formation Modeling and Tracking Method

The proposed method enables a mobile robot to follow a person while avoiding obstacles in human-populated environments. In addition, the person can easily see and manipulate the robot. We propose a method to construct and track a formation. First, the approach underlying the proposed method is introduced. Second, a formation and its model are proposed. Finally, a model of the risk that a robot encounters an obstacle is introduced.
The person and the robot. It is expressed by (3).

\[ g^y(\eta) = -p^y(1 - \eta)^k \]

\[ g^x(\eta) = p^x - (2 \cdot p^x)(\sqrt{1 - \left( \frac{p^y}{p^y} \right)^2}) \]

(1)

where \( k \) is a weighting factor for safety. If \( k \) is 1, the goal position is distributed evenly between the preferred location and the safe location. The higher \( k \), the more the goal position is distributed near the safe location. Therefore, if \( \eta \) is equal and \( k \) is high, the goal position is set close to the safe location. This value can be chosen differently depending on a probabilistic model case of obstacle appearance in a specific environment. Figure 3 shows the distribution of goal positions according to \( k \).

C. Risk Modeling between Robot and Obstacle

\( \eta \) represents the risk of collision with obstacles. This risk denotes the number of obstacles present in the sensor’s measurement range (density). This is represented by the blue area, as shown in Fig. 4. For this calculation, a 2-D laser scanner mounted in front of the robot is used. The formula for calculating \( \eta \) is as follows:

\[ \eta = 2(\sum R_{\text{ran}} - R_{\text{sen}}(i)) \frac{1}{n} \]

(2)

where \( n \) is the number of lasers, \( R_{\text{sen}}(i) \) is an input variable that represents the sensor length of one laser scanner. In this formulation, \( i \) represents the sensor index.

\( \eta \) is the normalized value (\( \eta \in [0, 1] \)). In order to normalize \( \eta \), the maximum range of \( R_{\text{sen}}(i) \) is specified to \( R_{\text{ran}} \). \( R_{\text{ran}} \) is set to \( R_{\text{max}} \) by default. When \( U_{\text{len}} \) is smaller than \( R_{\text{max}} \), \( R_{\text{ran}} \) is set to \( U_{\text{len}} \). \( R_{\text{max}} \) is a constant and the maximum measurement range of \( R_{\text{sen}}(i) \). \( U_{\text{len}} \) is the distance between the person and the robot. It is expressed by (3).

\[ R_{\text{ran}} = \begin{cases} U_{\text{len}} & \text{if } U_{\text{len}} \leq R_{\text{max}}, \\ R_{\text{max}} & \text{else}. \end{cases} \]

(3)

\[ 0 \leq R_{\text{sen}}(i) \leq R_{\text{ran}}. \]

IV. EXPERIMENTS

The purpose of this experiment is to verify the effectiveness of this method. A simulation environment in which this method is actually applied was created. Gazebo was used to generate the simulation environment, which is supported by ROS. A virtual person was created for the robot to follow. In the simulation, the robot measured the position and direction of the person. A ultra wide band (UWB) sensor was used to measure the position of the person. The direction of the person was calculated using this position and the simultaneous localization and mapping (SLAM) algorithm.

The robot is a Pioneer measuring 0.6 * 0.6 m. A person moves at the speed of 0.5 m/s. The maximum linear velocity of the robot is 0.85 m/s, and its angular velocity is 0.25 rad/s. Performance metrics were devised, and quantitative assessments of the proposed method were conducted. The values set in the experiment were as follows: \( p^x = 2.2 \text{ m}, p^y = 1.2 \text{ m}, k = 1.5, R_{\text{max}} = 5 \text{ m}, \) and \( n = 180 \).

A. Robot System

Our robot has perception and control system.

1) Perception System: The perception system is composed of two parts: a) a system in which the robot recognizes the posture of person and b) the risk of obstacles.

a) The robot recognizes the person’s position (x, y) and heading. To calculate the position of the person, the triangulation method is applied by using an UWB sensor [18]. Four UWB transmitters are installed in the upper edge of the robot, and the person holds a receiver. The robot reads a person’s position at the speed of 20 hz. In the simulation, a noise with a Gaussian distribution was created. The mean was 0, and the standard deviation was 0.05 m.

To obtain the heading of the person, a SLAM algorithm was used. ROS Navigation package was used to execute the SLAM algorithm. A global coordinate is created by the SLAM algorithm. The position of the person calculated using the UWB sensor is considered in the global coordinates. A vector is created using the most recently updated position and the position before this position in terms of the global coordinates. The direction of the person can be obtained using the direction of this vector.
b) The robot computes the risk of obstacles by using the front laser scanner, which is a Sick’s LMS5 product. Obstacles within the range of 180° forward can be recognized at distances of up to 80 m. The method of calculating the risk (η) based on sensor data is described in Section III-C.

2) Control System: The robot tracks a goal position by using the ROS Navigation package. A* algorithm is used to create a path between the robot and the goal position. The goal position is determined as described in Section III. The robot follows this path by using the pure-pursuit method. The pure-pursuit method considers a look-ahead point on the path that is at a certain distance (0.325 m) from the robot. Depending on the position difference between the robot and the look-ahead point, linear velocity and angular velocity are calculated. Left and right wheel speeds are obtained using these velocities.

B. Performance Metrics

The effectiveness of our method was analyzed based on two performance metrics:

$$\begin{align*}
E_{RTD} &= \frac{1}{R_{max}} \|r^{xy} - g^{xy}\| \\
E_{RTO} &= \frac{1}{\pi} |\theta_p - \theta_s|.
\end{align*}$$

(4)

$r^{xy}$ is the position of the robot, and $g^{xy}$ is the goal position. $\theta_p$ is the heading of the person, and $\theta_s$ is the robot heading.

$E_{RTD}$ evaluates whether the robot maintains good formation between itself and the person. It can be found by normalizing the distance between the robot and the formation. $E_{RTO}$ evaluates whether the robot follows the direction in which the person is moving by measuring the difference in heading alignment between the person and the robot. $E_{RTD}$ and $E_{RTO}$ can be used to evaluate whether the robot responds well to change of a goal position depending on changes in the person’s motion. If $E_{RTD}$ converges well without oscillation at 0, it indicates that the control is stable.

C. Scenario

Experiments were performed in the simulation environment shown in Fig. 5. This environment contains obstacles, such as people and funnels. A moving person walks in square formation in the simulation space (Fig. 5, (left)). At the start of the simulation, the robot is in the middle of this space. At this time, the robot starts to follow the safe location. When the robot arrives at the safe location well, the robot tracks the goal position according to $\eta$. The results of this scenario are presented in the next section.

D. Results

Figure 6 shows the simulation results. The robot avoided obstacles (t = [3 s, 44 s]) by changing the goal position along the formation. At t = 3 s, the robot was positioned at approximately $x = 8.5$ m and $y = 2.5$ m (Fig. 6. (a)), and at t = 44 s, the robot was located at $x = 3.0$ m and $y = 7.5$ m (Fig. 6. (a)). The value of $\eta$ increased upon the appearance of the obstacle. The goal position was set behind the person. By changing the goal position, the distance between the goal position and the robot becomes increased, and the value of $E_{RTD}$ increased. As the robot reached the goal position, $E_{RTD}$ decreased.

As shown at $t = 3$ s in Fig. 6. (b), the value of $E_{RTD}$ oscillates. The robot goes over the goal position, stops, and then moves again. This is because the speed of the robot is too high. It is necessary to adjust the maximum acceleration of the robot or to control it using PD or PI controller. At t = 33 s, the person turned to the left by 90°. The direction of the person changed, and the formation suddenly moved considerably. The goal position was set far away from the robot. $E_{RTD}$ and $E_{RTO}$ increased, and soon the robot reached its goal position, and then, these values decreased.

The results indicate a high correlation between $\eta$ and formed shape error ($E_{RTD}$). The reason is that if the obstacle interferes with the robot’s movement for a while, the control error will increase automatically owing to changes in the goal position. Overall, the value of $E_{RTO}$ tends to be similar to that of $E_{RTD}$.

V. CONCLUSIONS

We presented a novel method for a robot to follow a person. The purpose of this method is to enable a robot to follow a person while being in a position that makes it easy for the person to see and operate the robot. This method creates a formation for connecting the preferred location.
and the safe location. The goal position is selected in the formation according to the environment. This method allows the robot to follow the upper right position of the person (preferred location). In addition, the robot can avoid obstacles by following the person’s back (safe location) according to the density of obstacles. We presented a simulation scenario by modifying the goal position of the robot in environments with various complexities. We concluded that robots can follow the person by using the proposed method. Moreover, robots can avoid obstacles naturally.

The method presented in this paper has limitations, and further research is needed. Only minimal verification was conducted in the simulation. Experimentation in a real environment is needed. We are preparing for a robot experiment in an actual environment. There will be a need to increase the accuracy of tracking the position and orientation of a person. A test with the real robot can verify the utility and limitations of the proposed method in a variety of environments. It will also be considered that the shape of the formation is designed as a full arc, not a half arc. This will give the robot more operating space in case of obstacles appearing to the right of the person.

Video material accompanying this paper can be found at: [https://youtu.be/dfTBx8ZjXhI](https://youtu.be/dfTBx8ZjXhI).

REFERENCES


