Robot Trajectories When Approaching a User with a Visual Impairment

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ABSTRACT

Mobile robots have been shown to be helpful in guiding users in complex indoor spaces. While these robots can assist all types of users, current implementations often rely on users visually rendezvousing with the robot, which may be a challenge for people with visual impairments. This paper describes a proof of concept for a robotic system that addresses this kind of short-range rendezvous for users with visual impairments. We propose to use a lattice graph-based Anytime Repairing A* (ARA*) planner as a global planner to discourage the robot from turning in place at its goal position, making its path more human-like and safer. We also interviewed an Orientation & Mobility (O&M) Specialist for their thoughts on our planner. They observed that our planner produces less obtrusive trajectories to the user than the ROS default global planner and recommended that our system should allow the robot to approach the person from the side as opposed to the front as it currently does. In the future, we plan to test our system with users in-person to better validate our assumptions and find additional pain points.

CCS CONCEPTS

• **Human-centered computing → Accessibility technologies**.

KEYWORDS

rendezvous, robot navigation, people with visual impairments, approach trajectory

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1 INTRODUCTION

Navigating alone in unfamiliar, complex, indoor spaces like airports, shopping malls, and university buildings can be challenging for people with visual impairments. Since a sighted guide might not always be available in all public indoor spaces when requested, many researchers have investigated the use of mobile service robots for providing navigational assistance [1, 3, 6, 7]. One of the challenges is how the user will rendezvous with these robots. Many approaches rely on the users spontaneously adjusting their trajectories based on their visual knowledge of the robot's trajectory when rendezvousing with it [2, 9], but this method might be unsuitable for users who are blind or have low vision. In order to help a user with a visual impairment rendezvous with the robot in a seamless way without relying on the user's visual knowledge of the robot's orientation and position, the robot should perform most of the localization to pinpoint exactly where the user is in the space and drive up close to them. Furthermore, the robot needs to approach the user in a way such that the user can easily rendezvous with it without startling or creating additional difficulty for the user.

Recent participatory design research suggests that one effective way to initiate an interaction with a mobile navigation robot is to let a user with a visual impairment summon it through a smartphone application when they need escort assistance upon an arrival to a new indoor space [1]. Then, the robot should respect the user's autonomy and independence by allowing them to have ultimate control of the overall interaction [1].

Our paper investigates the interaction when a mobile robot approaches a user with a visual impairment. While prior work has explored how robots can detect target users [10], one of the most important design questions that has yet to be answered is how the robot should travel to the person when they are within a few meters of the robot.

2 APPROACH

We propose a system that allows the user to summon the robot via their mobile phone when they arrive at a public indoor space. Our approach is to ask the user to position their smartphone screen displaying a fiducial marker facing outward at their desired robot handle position when the robot is within a few meters of them. The marker is then used to detect the position and orientation of the

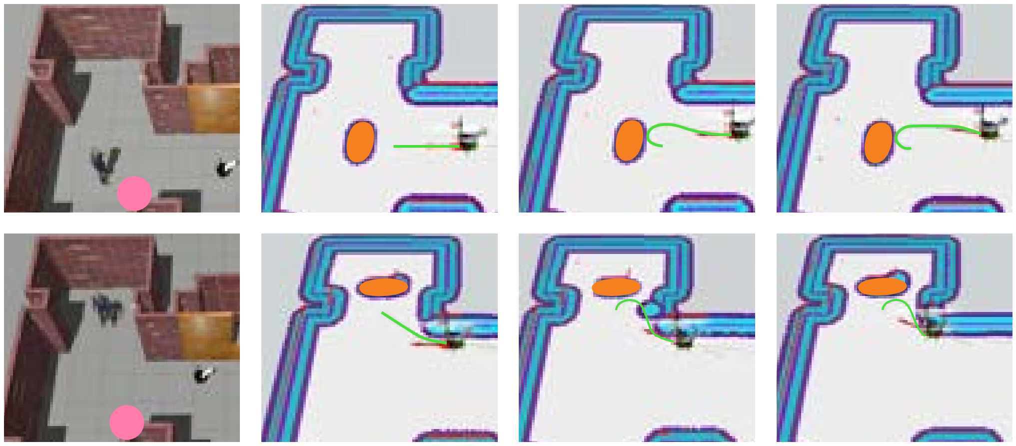

Figure 1: The left most images show the scenes from the simulator where the participant imagines themselves standing at the pink circle to witness the interaction. The other six images show the path planned by the different global planners for both scenes, from left to right: baseline, narrow, and wide. Notice that there is no visible turn on the path planned by the baseline approach since the baseline global planner does not account for the orientation at goal state, causing the robot to turn in place when it reaches the goal position when the local planner takes over.

user's preferred hand, which is used to calculate the robot's goal position and orientation.

After we establish the goal position and orientation for the robot, we use motion planning with hand-tuned parameters to help the robot approach the user seamlessly. Our navigational system is based on the ROS navigation stack [5], which plans and controls the robot in two stages. It uses a global planner that plots a path to the goal in a predefined map followed by a local planner to execute the movements on the robot while accounting for any obstacles missing from the map. The default global planner does not account for the robot's orientation and often results in the robot turning in place at the goal position (the second column from the left in Figure 1). We assume that allowing the robot to turn in place close to the user poses a serious safety risk of bumping the person's hands and/or knocking their cane over. However, making the turn radius too wide can limit the robot's ability to get to the user in smaller corridors. To control the turning radii and plan with orientation in mind, we use the lattice graph-based Anytime Repairing A* (ARA*) global planner [4] in order to explicitly hand-tune the different turn radii that our non-holonomic robot can perform. The state space of the lattice graph is constructed by applying a set of specified turn radii, called motion primitives, as a transition from each state. Then a graph search algorithm like ARA* is applied on the lattice graph to get a trajectory from a starting state to a goal state. We decided to use ARA* since it allows the planner to output a sub-optimal solution if an optimal solution cannot be found within 5 seconds.

To generate motion primitives for the lattice planner, we use the SBPL library with a discretization of 0.05m. We created two different sets of motion primitives, one that encourages the robot to make a wide turn and another that restricts the robot to a narrow turn while still preventing it from turning in place.

3 EXPERT FEEDBACK PROCEDURE

Due to the COVID-19 pandemic, we were unable to conduct in-person usability testing. Our initial design was based on our previous experience and research with people with visual impairments [8]. To obtain feedback for our prototype, we conducted a 30-minute semi-structured interview online with an Orientation & Mobility (O&M) Specialist. At the beginning of the interview, they were asked about their usual method to approach a person with a visual impairment in general and their definition of a socially acceptable way to approach a person with a visual impairment before beginning sighted escort assistance for navigation. They viewed two sets of simulated videos of the robot approaching someone in a wide hallway (the two images in the left most column of Figure 1). In one set, the user called the robot from a corner of the room, and in the other set, the user called the robot from the middle of the room. Each set had three videos showing three different trajectories generated from the baseline ROS default global planner and our ARA* planner with two different sets of motion primitives. After each video, the expert was asked to imagine that they physically witnessed the interaction and rate their agreement on a 5-point scale with the following six statements: 1) This robot behaves in a socially acceptable manner; 2) I would interrupt this robot before it reaches a person with a visual impairment; 3) This robot makes me uncomfortable; 4) I would recommend people with visual impairments call for this robot whenever it is available in a place they are unfamiliar with; 5) I would recommend the person with a visual impairment call for robot assistance only when human assistance is not available; and 6) I would discourage the person with a visual impairment from using this robot. After each set, they were asked to provide qualitative comparisons among the three different videos. At the end of the interview, they were asked about what the robot should do after arriving within the person's reach and their overall feedback for the system.

4 FINDINGS

The expert's ratings to the six statements did not differ across the videos. They agreed that the robot behaved in a socially acceptable manner and would recommend it to people with visual impairments if available. They disagreed that they would interrupt this robot from assisting people, advise people to only use the robot when no humans were around, and actively discourage people from using this robot. The O&M specialist also strongly disagreed that the robot makes them feel uncomfortable. They explained that their expectations for robot guide assistants' behavior are different from human assistants' in that their opinion depends more on whether the robot respects the person's personal space and approaches the person in a smooth trajectory than on whether the trajectory is unobtrusive or human-like. The expert felt that the difference between the two paths generated with different radii is subtle, but the differences between the baseline path and the other two paths are much more noticeable. They believed that the planner that allows the robot to start reorientation earlier when possible provides a less obtrusive path to the user than the one that forces the robot to reorient itself at the goal position. This was because the robot spends less time in the user's personal space, lowering the chance of crashing into the person.

The O&M specialist shared that they usually approaches a person with a visual impairment from the side and tap them on the shoulder before introducing themselves. They then ask which arm the person with a visual impairment prefers to hold onto and which side the person prefers them to be on. Then, they usually bump their arm into the person with a visual impairment's to allow them to determine where they should hold; typically, it is right above their elbow. In general, the expert recommended that an guide assistant should indicate that they are talking to the person with a visual impairment ("e.g., by tapping them on the shoulder") and then introduce themselves before beginning the navigation together to make the interaction socially appropriate. They further suggested that the assistant should also be courteous of the user's primary navigation guidance tool, whether it is a guide dog or a white cane.

The O&M specialist liked that the robot respects the independence of the user by letting them grab onto its handle so that they can let go of the robot whenever they want. They also appreciated that the robot allows the user to use their primary guidance method (e.g., a guide dog or a white cane) alongside the robot. This allows the person to begin their navigation with the robot and continue to navigate by themselves when they reach their destination. More importantly, this feature allows the person to let go of the robot and continue navigating on their own if the robot malfunctions. The expert expressed confusion when the robot approached the person from the front rather than the side unlike a trained sighted assistant; however, they said that people may be able to get used to this behavior when they use it on a regular basis. They also noticed that the robot did not consistently stop on one particular side of the person. They were worried it might be confusing for the user and noted that it is crucial that the robot stops at a consistent spot agreed upon with the user and then signals the user when it is ready to be gripped.

They commented that the speed shown in the video seemed slow and safe but that they would want to know more about how that speed would be perceived in a physical space, how the robot works, and how much noise it makes because those factors that cannot be fully grasped through simulation impact whether the interaction is socially appropriate. Overall, they found our prototype to be promising and believed it has the potential to allow people with visual impairments to travel in an unfamiliar indoor environment more independently.

5 CONCLUSION

This paper described a proof of concept for a robotic system that helps people with visual impairments rendezvous in an indoor space with a mobile navigation robot in a socially appropriate and seamless fashion. We used a lattice graph-based ARA* planner as a global planner to encourage the robot to approach a person with a smooth trajectory. We conducted a semi-structured interview with an O&M specialist who provided feedback about our system to better understand the design considerations for future robotic escort systems. Specifically, the O&M specialist advised that the robot should approach the user from the side rather than the front, and it should approach the person consistently from the side they indicated. While the expert provided valuable feedback on our initial design, the insights from that interview do not necessarily reflect how a person with a visual impairment would use the system in real-life. To address this, we plan to further test our system in-person with users with visual impairments. We also believe this approach can be extended to help people with visual impairments rendezvous with autonomous vehicles. For example, the vehicle could generate the planned path for the user and relay guidance back to the user's phone.

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