# Optimal Reciprocal Collision Avoidance for Human Guidance

Tommaso Lisini Baldi[1,2], Stefano Scheggi[1], Marco Aggravi[1], and Domenico Prattichizzo[1,2]

***Abstract*— Human guidance in situation with poor/no visibility, such as assistive or search-and-rescue scenarios, is a challenging task. We address the problem of guiding users along collision-free paths in dynamic environments, assuming that they cannot rely on hearing and vision. The proposed approach relies on haptic stimuli to provide effective directional cues to the subjects. The navigation policy presented in this study exploits the nonholonomic nature of human locomotion in goal directed paths, which leads to an intuitive guidance mechanism. In order to dynamically generate motion controls which guide the subjects along collision-free paths, we adapt the Optimal Reciprocal Collision Avoidance for non-holonomic agents to our specific problem. The collision avoidance algorithm takes into account the haptic stimuli which can be displayed to the users and the motion uncertainty of the users when reacting to the provided stimuli. Experimental results reveal that blindfolded subjects are successfully able to avoid collisions and safely reach the target in all the performed trials.**

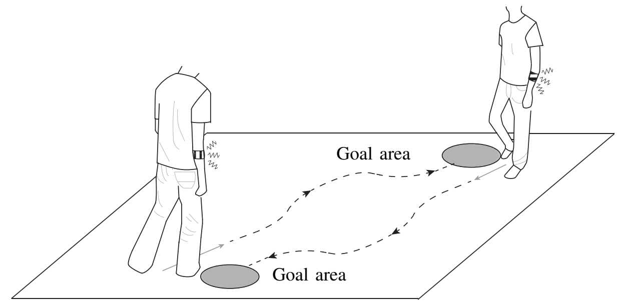


Fig. 1. We address the problem of guiding human subjects in situations with poor/no visibility. The subjects have to reach the respective goal areas while avoiding collisions with static obstacles and moving users. Each user wears two vibrotactile armbands which provide appropriate directional cues.

## I. Introduction

Let us consider the problem of guiding a subject toward a goal location in a dynamic environment while avoiding obstacle collisions (Fig. 1). Possible scenarios are assistive and search-and-rescue scenarios. In such cases, environmental noise, dust, or fog from debris severely reduce the human operator sensing. Other examples of applicability of human guidance are human-robot cooperative tasks, where the robot can guide the user along collision-free paths without violating the mechanical constraints of the robot itself.

We present a human navigation policy in order to guide multiple users along collision-free paths in dynamic environments. For each subject, the proposed navigation policy generates online suitable directional cues in order to minimize the possibility of collisions among the users. Directional cues are provided to the users via haptic stimuli displayed by two vibrotactile armbands. Finally, the users adjust their heading according to the perceived vibrations. The proposed method relies on the Optimal Reciprocal Collision Avoidance for non-holonomic agents proposed in [1], that we adapt to our specific problem. It is worth pointing out that while it is simple to steer a robot, it is not trivial to impose a desired velocity to a human. In fact, by providing directional cues via haptic feedback, only a discrete set of different stimuli (i.e., instructions) can be displayed to the users. Such set of stimuli is far smaller than the set of all the possible velocities that a user can perform. Moreover, the larger is the set of stimuli provided to the users, the harder could be for a subject to recognize a particular stimulus and react accordingly. Finally, when a user perceives a guiding stimulus, she/he will never react in the same exact way. The proposed human guidance policy takes into account the motion uncertainty of the users when reacting to a particular stimulus in order to minimize possible collisions among them and the environment.

In this study, we employ an effective haptic policy which allows users to easily recognize the provided stimuli. In this regard, we assume that the human locomotion can be approximated by the motion of a unicycle system, i.e., nonholonomic constraints similar to those of mobile robots seem to be at work when a human is walking [2]. This assumption allowed us to define an intuitive haptic policy which was successfully used to guide users also in mixed human-robot scenarios [3], [4], [5]. In what follows, we assume that the human is free to select her/his desired walking speed. Control signals (i.e., haptic stimuli) are sent to the users in order to steer their locomotion. Requirements of our approach are that a person should always remains in charge of the final decision to take, the type of correction provided to the user should be perceived as very soft, and unnatural stimulations must be avoided as much as possible.

The proposed method is evaluated in three different scenarios consisting of: $(i)$ Two users; $(ii)$ two users and a static obstacle; and $(iii)$ three users. A total of 18 users participate in the evaluation. In all scenarios, the users have to move toward their respective goal areas, while avoiding reciprocal collisions and collisions with the environment.

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[1]Tommaso Lisini Baldi, Stefano Scheggi, Marco Aggravi, and Domenico Prattichizzo are with the Department of Information Engineering and Mathematics, University of Siena, Via Roma 56, I-53100 Siena, Italy. {lisini, scheggi, aggravi, prattichizzo}@diism.unisi.it

[2]Tommaso Lisini Baldi and Domenico Prattichizzo are with the Department of Advanced Robotics, Istituto Italiano di Tecnologia, Genova, 16163, Italy. {tommaso.lisini, domenico.prattichizzo}@iit.it

Fig. 2. Experimental validation for all three scenarios. The blindfolded and audio-occluded users have to move towards their goal areas by following directional cues provided by haptic armbands. (Left) Scenario with only two users; (Center) Scenario with two users plus an obstacle; (Right) Scenario with three users.

## II. Obstacle avoidance via haptic feedback

The proposed human guidance policy is based on the assumption that the human locomotion can be approximated by the motion of a unicycle system, i.e., the human's walking direction is tangential to her/his trajectory [2]. Moreover, we assume that the human is free to select her/his desired walking speed. Thus, haptic stimuli are sent to the user in order to steer her/his heading. In order to provide easily-recognizable cues, the device could elicit only three basic behaviors (*turn left*, *turn right*, and *go straight*). We displayed vibrotactile stimuli via two haptic armbands placed on the forearms: vibration of the left armband alerted the participant to *turn left*, while vibration of the right armband alerted the participant to *turn right*. If the armbands do not vibrate, it means that the user can *go straight*. We used an additional stimulus to *stop* the user by activating both the haptic devices. When an armband was engaged, its motors alternatively vibrated for $0.2$ s at a frequency of $250$ Hz.

The algorithm we used to safely navigate the users in dynamic environments is based on the extension of the Optimal Reciprocal Collision Avoidance (ORCA) for non-holonomic robots (NH-ORCA) presented in [1].ORCA is a velocity-based collision avoidance approach for multiple holonomic agents [6]. The algorithm provides a sufficient condition for each agent to be collision-free for at least a fixed amount of time into the future. Each agent takes into account the observed velocity and pose of the other agents in order to avoid collisions with them. Then, the optimal velocity is selected by using linear programming. Then, a set of holonomic allowed velocities is computed. Finally, the algorithm calculates the optimal holonomic velocity, which is mapped to the corresponding non-holonomic control inputs for the agent. The proposed algorithm differs from [1], since NH-ORCA starts by considering a holonomic behavior for the agent. Positions are estimated using an Extended Kalman Filter which provides an estimate of the variance, and hence the standard deviation, of the measured quantities. These values are taken into account by the obstacle avoidance algorithm by expanding the edges of the velocity obstacle. For the uncertainty related to the angular velocity $\omega$, we use a numerical approach to estimate the half planes which represents the sets of permitted velocities for the corresponding holonomic velocities.

## III. Experimental Validation

An experimental evaluation was performed to assess the feasibility and functionality of our approach. We considered three different scenarios. In the first scenario, two users were asked to reach two different goal areas, wearing two vibrotactile armbands (one per arm), which displayed the directional cues. In the second scenario, the trial was augmented by introducing a static obstacle. Both users still had to reach two different goal areas, while avoiding the object. The third scenario was built from the first one and by introducing a third human operator. A visual resume of the scenarios can be found in Fig. 2. Three metrics were used for evaluating the functionality of our approach: Time to reach the goal, length of the trajectories, and minimal distance from agents. In all trials and for all the modalities, no collision with other agents—either another user or the obstacle—has happened. While for the visual conditions this was expected, regarding the haptic guidance condition the obtained results show that our approach works, i.e., our system is able to successfully guide two or three users along collision-free paths, towards a goal area.

## IV. Conclusions and future work

The proposed navigation policy exploits the nonholonomic nature of human locomotion in goal directed paths, which leads to a very intuitive guidance mechanism. The proposed method is evaluated in three scenarios. Experimental results reveal that all the blindfolded subjects could safely reach the goal area. Although this result is promising, a comparison between the results obtained using this approach and experiments performed with sighted people reveals that additional studies need to be done in order to have comparable walking speed.

In future work, we plan to extend the proposed idea with the predictive approach on the human angular velocity.

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