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A navigation model for side-by-side robotic wheelchairs for optimizing social comfort in crossing situations

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ABSTRACT

One challenge in designing side-by-side robotic wheelchairs is to improve the comfort of the users, caregivers and surrounding people in crowded environments. Among different scenarios that a side-by-side robotic wheelchair has to deal with, crossing pedestrians is a common situation. Yet techniques developed for tackling the problem of passing pedestrians have still failed to take into account enough factors related to human walking behavior, therefore the navigation plan is not natural. To tackle this problem, this paper proposes a novel navigation model for side-by-side robotic wheelchairs that considers the Friendly Link factor and Preferred Walking Velocity related to the comfort of wheelchair users, caregivers and pedestrians. The model is carried out based on an experimental observation and data collection. The developed model is then validated by comparing the distance errors between the moving solutions of the new model and previous methods with the real solutions of humans based on a natural walking scenario. The experimental results show that the performance of the proposed technique is significantly better than that of previous techniques.

1. Introduction

The world population is aging and the demand for in-house care for the elderly is increasing [1]. The number of disabled people has also increased [2]. Meanwhile, the proportion of people of working age has been decreasing, thus increasing the cost of labor-intensive services, including care services for the elderly and disabled. This has drawn the attention of robotic researchers for developing autonomous devices, including autonomous wheelchairs, to support them. As a result, many kinds of assistant wheelchair robots have been developed to support people [3–7].

Under this research direction, developing wheelchairs that can autonomously move with a caregiver in a peer-like manner is a relatively new initiative. In many situations, people using wheelchairs have difficulties in controlling them. As a result, in some environments, e.g. hospitals or nursing homes, a caregiver has to take control of the moving function of the wheelchair, thus putting an extra burden on the caregiver. Therefore, the idea of developing robotic wheelchairs that can move alongside a caregiver, thereby easing their workload, has drawn much attention recently.

However, to be truly acceptable to humans, robotic assistants in general, and robotic wheelchairs in particular, need to not only satisfy the technical requirements, but also meet the psychological needs of the users [8–10], i.e. they should give comfort to users and surrounding people while working. In the case of robotic wheelchairs, when walking in pairs, maintaining a side-by-side formation is a natural habit of humans (Fig. 1). It is a more comfortable motion pattern for a friendly pair rather than, for example, walking one after the other. This is explained referring to the psychological benefits it brings to both members of the pair [11–13]. Therefore, the robotic wheelchairs should be able to move alongside their caregivers in a suitable human-like manner; this is called a side-by-side robotic wheelchair.

Developing a side-by-side robotic wheelchair is not a trivial problem [3]. Many factors need to be considered, such as keeping a stable relative distance to the caregiver, moving at a preferred velocity, reducing the acceleration changes, avoiding static and moving obstacles, etc. [14–23].

During a navigation session, among various different scenarios that a side-by-side robotic wheelchair has to deal with, passing pedestrians is a common problem. Fig. 2 depicts five main modes in which a walking pair can pass another pedestrian walking in the opposite direction on a pathway (a to e).

In modes (a) and (b), the pair tries to maintain their side-by-side formation during the passing period. In modes (c) and (d), the pair switches from side-by-side formation to leader–follower formation, where one person follows the other person while passing. In mode (e), the pedestrian's trajectory disturbs the side-by-side formation of the pair. As can be seen from our observations, which are described in detail in Section 3, the majority of people

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Fig. 1. Maintaining side-by-side formation is a natural habit of humans in walking.

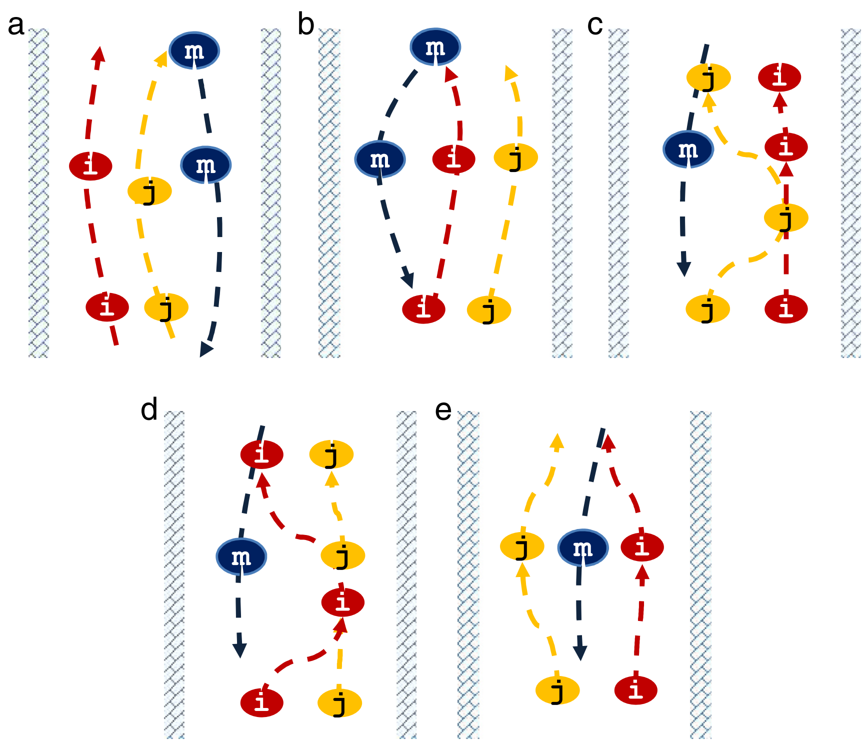

Fig. 2. Passing behavior between a pair and a pedestrian (*i* and *j* are a walking pair and *m* is a pedestrian walking in the opposite direction).

prefers the passing modes (a) or (b) if the pathway is not too narrow.

Based on our investigation, although a large number of studies have been conducted for passing pedestrians, most of those solutions are developed for robots moving alone; not with a human moving alongside. Among the few studies which were conducted for a side-by-side robot and human pair avoiding obstacles, there are three main approaches [3–5].

In the navigation solution developed by Sato et al. [5,24] the wheelchair goes to a side of the caregiver by default. While following the caregiver, assuming that agent i is the caregiver and agent j is the wheelchair, the wheelchair j changes its relative position with the caregiver i from side-by-side formation to leader–follower formation (wheelchair follows the caregiver) if an obstacle or a pedestrian is found, i.e. the robot always chooses passing mode (c). This allows both the caregiver and the wheelchair to avoid collisions with the obstacle or pedestrian. However, this model does not reflect the reality that people prefer passing modes (a) and (b) to other modes, i.e. this model is not capable of producing natural human-like motions; or it lacks the methods to maximize the comfort of people when passing pedestrians.

Ferrer et al. [4] developed a mobile robot to accompany a person based on social-force and proxemics concepts in which their model mainly focuses on maintaining a comfortable distance between the robot, its companion, and surrounding people. Yet, some important factors are ignored, e.g. in real-world scenarios, the robot not only has to take into account the navigation plan to move alongside a caregiver, but the caregiver himself and the surrounding people also have their own predictions and reactions based on the past and future actions of the robot. One of the main disadvantages of