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A visual servoing approach for autonomous corridor following and doorway passing in a wheelchair

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HIGHLIGHTS

- We devise a visual servoing approach for indoor wheelchair navigation.
- The fundamental tasks of corridor following and doorway passing are tackled.
- Results in simulation and on a robotic platform show the convergence and validity of the control system.
- This work is proposed as a first step in developing the concept of semi-autonomous assistive systems.

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ABSTRACT

Navigating within an unknown indoor environment using an electric wheelchair is a challenging task, especially if the user suffers from severe disabilities. In order to reduce fatigability and increase autonomy, control architectures have to be designed that would assist users in wheelchair navigation. We present a framework for vision-based autonomous indoor navigation in an electric wheelchair capable of following corridors, and passing through open doorways using a single doorpost. Visual features extracted from cameras on board the wheelchair are used as inputs for image based controllers built-in the wheelchair. It has to be noted that no a-priori information is utilized except for the assumption that the wheelchair moves in a typical indoor environment while the system is coarsely calibrated. The designed control schemes have been implemented onto a robotized wheelchair and experimental results show the robust behaviour of the designed system.

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1. Introduction

Independent mobility for wheelchair users is a necessary part of the social and physical well being. While mobility increases social opportunity and reduces dependence, numerous studies have shown that a decrease in mobility can lead to social disorders like depression, anxiety and a fear of abandonment [1,2]. However utilizing an electric wheelchair, especially in constrained environments, can be a challenging task for disabled individuals. In the case of severe disability, it is almost impossible for a user to effectively navigate without the help of another person. The issue of security is also an important one in these cases where for example, a person with neuromuscular disabilities finds it difficult to steer a wheelchair, particularly in limited space environments, without the risk of collision [3]. In addition, it was reported that *accessibility* was the main problem encountered by wheelchair users [4] when more than four fifths of mobility device users in the United States identified themselves as living in a house with all the rooms on the same level.

Recent advances in robotics have paved way for a variety of opportunities facilitating the design of smart assistive technologies in order to help improve the lives of disabled people [5]. Keeping pace with these advances in robotics, an ordinary powered wheelchair can be enhanced into an "Intelligent wheelchair" using sensors that perceive the surroundings and control architectures that affect the motion of the wheelchair.

Extensive works have previously been reported in this area, mainly focusing on the issue of increasing the safety levels of the wheelchair (and thereby decreasing the amount of human intervention). In all these systems, the human controls the higher level intelligence whereas the wheelchair is responsible for the lower level tasks. For example one can mention the TAO Project [6],

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NavChair [7], European FP7 Radhar project [8] and the recent SYSIASS project [9] all of which are designed to provide assistance in tasks like navigating through indoor environments like corridors, basic obstacle detection/avoidance and also, in some cases, autonomous passage through narrow doorways.

We observe that such behaviour-based design approaches have been proven to lead to robust systems. However, it has to be noted that the majority of the previous works in this area use a multi-sensor system with a distributed architecture. The motivation of our work comes partly from the fact that low cost sensors such as vision sensors could be employed in designing such systems. This can ensure widespread usage taking into account the fact that reimbursement from government/healthcare companies typically only covers the wheelchair, and not its technological adaptations. But relevant control systems have to be designed around a vision-based paradigm which still remains a highly challenging task. Thus, in this work, we aim to develop a solution for autonomous wheelchair navigation in an indoor environment using a set of monocular cameras with each one being devoted to a particular task.

That being said, the aim of the work is to serve as a first step in designing assistive systems (particularly low-cost vision-based systems) that may have a human in the control loop. Such semi-autonomous wheelchair systems would be helpful in conditions where motor impairments may hinder secure and effective navigation, by providing safe assistance in performing fundamental tasks while giving high level control to the user. As such, we have tackled two important low-level tasks related to indoor navigation: autonomously keeping a stable position along corridors in a secure way and detecting and passing through doorways. We will see that this second task can also be used directly for turning from a corridor to another one. These tasks represent the fundamental capability of a wheelchair performing indoor navigation.

While specifically considering corridor following using a wheeled robot, in [10] a vision-based approach was designed using an omni-directional camera along with a visual memory framework. Whereas in [11] a stable control system was designed for corridor following and wall-following for sonar-based mobile robots (which may be extended to a wheelchair platform). Furthermore, in [12] two vision-based control algorithms for corridor navigation were presented that exploited the geometry of a typical corridor. The first one uses the optical flow measured from the corridor's lateral walls to generate an angular velocity command for the mobile robot. The second scheme finds the perspective lines of the walls meeting the floor to generate the angular velocity command for the robot. Therefore, the geometry of a corridor in an image is a viable solution to employ while designing vision-based algorithms around it for realizing the task of corridor following.

Several results have also been reported in the area of doorway passing with mobile/wheeled robots. A multi-sensor based algorithm for guiding a non-holonomic platform through a doorway was presented in [13]. The controller uses information from a camera system and a laser range finder for navigation. In the case of the previously mentioned SYSIASS project, a laser range finder with a PID controller is employed for doorway passing with a mobile robot. Another solution for secure navigation of a mobile robot in particular for doorway passing was proposed by [14]. The framework exploited a laser-based hybrid control scheme with dynamic obstacle avoidance and path planning. It has to be noted that a purely vision-based solution for doorway passing has not been proposed in the literature and is therefore one of our major contributions.

Another important constraint arises when considering that the wheelchair must be able to perform in an indoor environment without any a-priori knowledge of the environment. Consequently, a solution where the geometry of the environment and the metrical data are not known is expected. Therefore we apply an Image-based Visual Servoing (IBVS) scheme which controls the relevant degrees of freedom (dof) of the wheelchair based on visual features directly extracted from a camera on board the wheelchair [15].

The initial objective in any visual servoing scheme is to select features that represent visual data which can be effectively exploited to perform the task at hand. With respect to the task of autonomously following a corridor, features like the vanishing point and the straight lines that represent the edges of the corridors are relevant [16,17]. There are several studies which indicate the robustness of the aforementioned features [18]. Consequently to design a stable control law that achieves the objective robustly, we have developed a system that employs the measure of the vanishing point and the position of the vanishing line that corresponds to the median line of the corridor.

When dealing with the task of passing through doorways, the features available are mostly line features that represent the position of the doorposts in the image. This is a highly challenging task while employing a monocular vision sensor especially in the case where a single doorpost is visible. Thus, we have developed a novel and robust control scheme which only uses the position of the line feature corresponding to the nearest doorpost in the image to achieve the goal. This approach is utilized since global asymptotic stability [19] of the system can be demonstrated as will be shown in Section 4.3.2. Moreover, higher level constraints like the status of the door (open/closed), the decision making process of passing through the door (i.e. which door to choose from), etc., make the task non-trivial. We here focus on low level control without the help of a global planning framework. The high level attributes are left for the user/home automation system to set as they are not the objective of this work.

The developed schemes do not require any initialization step owing to the fact that a dedicated line detection framework was designed to detect and track the relevant line features in real time. Thus, bottleneck stage that still remains in most of the servoing schemes is avoided. In addition, as mentioned before, no a-priori environment data is required or utilized in the servoing process.

The paper is organized as follows. Section 2 deals with the geometric modelling of the robotized wheelchair. Section 3 details the task of corridor following with the definition of the visual features used and the control law formulation. Section 4 explains the task of doorway passing and proposes a new Lyapunov-based controller. Finally Section 5 exposes the experiments done and the results obtained while implementing the designed framework on a robotized wheelchair.

2. Modelling

The wheelchair is modelled as a six wheeled robot moving on a horizontal/inclined plane. Two differentially actuated wheels located in the middle of the wheelchair provide motion along with four passive caster wheels with two each located in the front and back. The wheelchair can then be thought of as a simple unicycle robot [20], thus matching non-holonomous constraints.

Owing to the actuated wheels, two variables can be controlled, namely the translational velocity υ and the rotational velocity ω. In this study, the control variable is restricted to the rotational velocity ω while a constant forward velocity υ^* is maintained for motion exigency. Three cameras located at different positions on the wheelchair are employed in order to realize the two different tasks. A front facing camera denoted as *camera 1* which is located on the left handle at a height h_1 from the floor is employed for the task of corridor following. The second and third cameras denoted as *camera 2* and *camera 3* are respectively located on the right and left handles at heights h_2 and h_3 from the floor. These cameras are used for realizing doorway passing: the right one to pass doors located

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