Adaptive Robotic Arm System for Wheelchair Assistance in Autonomous Vehicles

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***Abstract*—As we move towards the era of autonomous vehicles, it is critical to consider the impact of automation on individuals with mobility impairment who are dependent on human assistance to make effective use of transportation. We consider the problem of designing accessible autonomous transportation for people on wheelchair. We present the design of a robotic arm that can be installed on a vehicle to assist such people. We discuss the use cases, design challenges, and a prototype modeling framework for this design. We show simulation results demonstrating its viability and effectiveness.**

***Index Terms*—Mobility impairment, Accessible transportation**

I. Introduction

We are at the cusp of the era of autonomous transportation. Modern vehicles are being increasingly infused with sensors, software, perception, and communication capabilities designed to replace human driving functionality. Autonomous vehicles hold the promise of better road safety, better comfort, and better utilization of the transportation infrastructure by reducing response time of the vehicle to environmental stimuli and eliminating human errors. However, one upshot of autonomy is the increasing challenge of people with disabilities (PwD) to avail of these transportation. Note that in today's (human-driven) vehicle, the operator of the vehicle has more functions than simply driving the vehicle: they facilitate accommodation of PwDs by helping them embark and disembark and providing assistance during the transit. As we move towards autonomous vehicles, it is imperative that we re-think their design providing alternatives to human assistance that enable PwDs access the benefits of autonomous transformation.

In this paper, we develop an initial approach to address this crucial problem. We design a robotic arm that enables passengers on wheelchairs to smoothly embark and disembark autonomous transportation. We present some of our design choices and architecture for the infrastructure, some research challenges, and our approaches to address those challenges.

II. Related Work

Assistive robotics has improved the independence and quality of life of people with impairments, with applications such as smart-powered wheelchairs, autonomous mobility robots, and socially assistive robots [1]. Nevertheless, we are not aware of any previous research on robotic arms for accommodating PwDs in autonomous vehicles where human assistance may not be available. Brose *et al.* presented a compensatory assistive robotic to boost the independence of people with upper-extremity impairments performing physical tasks [2]. Catalan *et al.* classified the existing AR based on two approaches: (1) approaches based on portable robot helpers like Care-O-bot, PR2, and Tiago, (2) use of an external robotic arm or a robotic exoskeleton that is fixed or installed on a wheelchair [3]. Asadi *et al.* developed an autonomous ground vehicle equipped with a robotic arm for detecting and removing obstacles [4], which could be used by PwDs. Yang *et al.* developed robotic arms fitted to electric wheelchairs to assist people with disabilities in carrying out their daily tasks [5]. They conceptualized a self-operated wheelchair in terms of providing free mobility to disabled people. However, a self-driven wheelchair would only provide in-house and short-distance transportation. Kavya *et al.* proposed a robotic arm which serves to aid physically challenged persons to do their work themselves [6]. Song *et al.* designed intelligent rehabilitation system to assist the PwDs and the elderly for independent activities [7]. To test the system, few basic tasks were defined and these tasks were performed autonomously in a semi-structured environment.

There has been significant work on smart wheelchairs to enable movement of PwDs. Tsui *et al.* designed and conducted an experiment to investigate the hypotheses that users would prefer a simple visual for wheelchair-mounted robotic arms rather than the manufacturer's default interface, which delivers increased autonomy, with lesser user input needed for control [8]. While this approach has shown promise, a challenge with it is sophistication and cost. In particular, smart wheelchairs have significant sophisticated electronics, and their interactions with the human PwDs generally involves an expectation that the PwD is comfortable with complex electronic gadgets. They concluded that users would prefer a simple visual interface for wheelchair-mounted robotic arms, rather than greater levels of autonomy. Furthermore, the increasing sophistication of electronics and software drives up the cost of such a wheelchair. This precludes their use by lower-income communities.

III. Design Choices, Approach, and Challenges

Our goal is to enable PwDs using wheelchairs to smoothly embark and disembark an autonomous vehicle, accounting for the challenges with autonomy and cost. Our design constitutes a robotic arm connected to the *vehicle* to facilitate control and

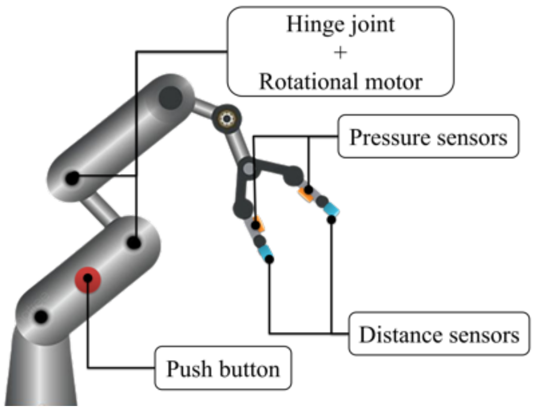

Fig. 1. Components of the robotic arm system

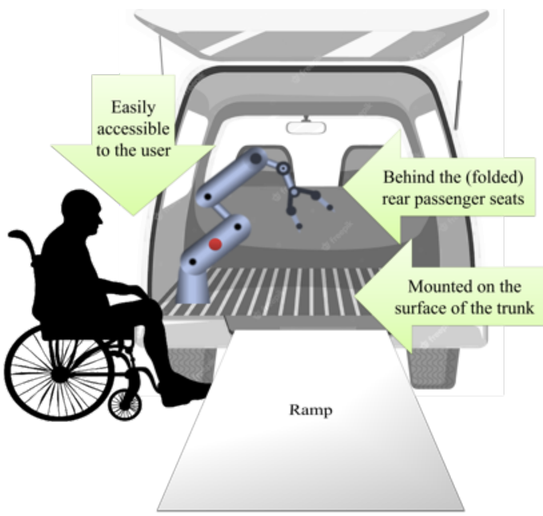

Fig. 2. Placement of the robotic arm in the car

guidance of the wheelchair. No assumption is made on the wheelchair itself (and the PwD). Fig. 1 shows the components of the robotic arm. Note that no sophisticated interface is required with our setup. The user activates the arm with a simple push-button setup, during boarding of the vehicle and during disembarking.

Features and Functionality: The robot arm is designed to settle the user into the car through the back (see Fig. 2). The user activates the arm by opening the trunk lid (not part of our implementation) and pressing the push button. On detecting a user on the wheelchair, the robotic arm would (1) pull the levers of the rear passenger seats and fold them; (2) move the stored ramp and lay it out; (3). When the user is detected inside the car, the robotic arm would stow the ramp inside the car again and transform into resting position beside the car seat. During disembarking, the user would open the trunk lid from inside and press the push button. The robotic arm would (1) lay out the ramp again; (2) when the user is detected on the ground, the robotic arm would store the ramp and unfold the rear passenger seats.

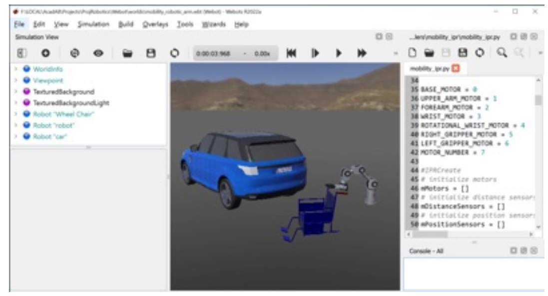

Fig. 3. Simulation in Webots software

Note that the implementation of the arm requires precision computation and sensing of multiple parameters. For instance, the hinges and the motors of the arm must enable movement of the arm freely to grab the levers of car seat at a specific location, lay out the ramp, and guide movement of the wheelchair.

IV. Implementation

We developed our initial implementation system using Webots. The robotic arm used was Neuronics IPR HD6M90. A simulation system was developed to enable visualization of the actions of the robotic arm. This enabled multiple trials for selecting the appropriate robotic arm model and validating the proposed functionality. Fig. 3 gives an overview of the simulation system. For this purpose, the robotic arm and its components, *e.g.*, motors, hinges, etc. were initialized so that the components could be coded independently. Each component was assigned a unique variable for identification. The wheelchair simulation was built using basic shapes like rectangular pyramids and cylinders. The positions of all the robotic arm components and the others objects were recorded to facilitate analysis of computation accuracy.

V. Conclusion and Future work

As transportation becomes increasingly autonomous, it will become challenging for PwDs to use emergent vehicles. In this paper, we explored how to design a robotic arm to assist PwDs in wheelchairs to smoothly use autonomous vehicles. We discussed some of the challenges in the design, and our approaches to address them. We also discussed a simulation setup to enable exploration and tuning of parameters involved.

Obviously, accessibility in autonomous transportation is a broad and complex topic and we have only scratched the surface. Note that our solution is simply a prototype. In future work we will integrate the robotic arm system with physical components and apply it for wheelchair assistance in real-life autonomous vehicles. Furthermore, in the context of disabilities in transportation, wheelchairs constitute one of the "simpler" disability issues requiring relatively little support; we will consider more complex disabilities, including visual, auditory, and mental disabilities and exploring ways to handle such disabilities in the context of autonomous transportation.

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