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Development of a robotic wheel door opener system assistive device

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Abstract: Physical disabilities significantly impact individuals' ability to perform activities of daily living (ADL), leading to reduced autonomy and difficulty to accomplish daily living tasks. One such barrier is the difficulty or inability to open doors, preventing access to different rooms in their residence (bathroom, bedroom, etc.), rooms at work, or shopping areas. Existing solutions, such as robotic arms on wheelchairs and door openers mounted at the top of doors, remain expensive, complex to install, and relatively difficult for the target population to use. Addressing this challenge, this study introduces a Robotic Wheel Door Opener System (RWDOS) designed to facilitate the opening and closing of the door. The RWDOS is installed at the bottom of a door and is controlled remotely through a smartphone application. The paper presents the mechanical design and control system along with a cost analysis. It concludes with initial results and outlines the future directions for the project.

1 Introduction

The inability to use one's arms or hands to grasp, manipulate, and move objects significantly limits an individual's ability to perform daily living tasks, work, and leisure activities. This is a common challenge for people living with physical and cognitive disabilities, which restricts their activities of daily living (ADLs) and, in turn, affects their autonomy and quality of life [1]. Moreover, a study revealed that the risk of ADL impairment increases with the number of chronic diseases in both middle-aged (45-59 years) and older adult (60-74 years) groups [2].

An example of a crucial and simple ADL task essential for daily life is opening a door. This action allows users to access different rooms in their residence (bathroom, bedroom, etc.) and enables them to go out for work, shopping, and other needs outside the home. The difficulty or inability to open a door autonomously and safely can significantly impact a person's ability to maintain their ADLs, level of autonomy, and overall quality of life.

To address this problem, home adaptations have been developed. A systematic review has shown that accessible housing has a positive physical and cognitive impact on patients' health [3]. However, in 2017, 13% of Canadians with physical disabilities indicated that they were unable to obtain the accessibility features and aids that they needed in their home [4].

2 Literature review

Existing solutions to open doors, such as assistive humanoid robots, robotic arms installed in wheelchairs [5], and automatic door openers and closers above the door [6], can be expensive, and a significant proportion of potential users are unable to afford these assistive devices. In fact, the leading reason for not obtaining the assistive device needed is cost (77% of the reasons) [7]. In addition, home installation of these assistive devices can become complicated due to several factors and, as a result, hinder the implementation of these solutions.

In the case of assistive humanoid robots, the complexity of installation and maintenance requires specialized knowledge and infrastructure, which may not be readily available in all homes. Furthermore, these robots often need significant space to operate effectively, which can be a constraint in smaller living environments. Lastly, ensuring that the robot is compatible with the unique needs and preferences of each user adds another layer of difficulty, as it often requires customization and ongoing adjustments.

As for the robotic arm on a wheelchair, the cost of these advanced assistive devices can be prohibitive, limiting their accessibility for many users. In fact, this technology is mostly used for various tasks such as pick up a drink or a phone. Moreover, the installation process can be complex, requiring modifications to both the wheelchair and the home environment, which may not always be feasible or practical. Additionally, the robotic arm needs to be finely calibrated to ensure it can operate various types of door mechanisms reliably, which can be challenging in diverse home settings. The integration of such technology with existing wheelchair systems also demands specialized maintenance and troubleshooting, which may not be readily available.

Finally, door openers installed above doors, although cheaper and less complex than the previous solutions, still require significant modifications to the existing door structure and hardware, which may not be feasible in some cases or need the intervention of a technician to install the device correctly, which will increase the costs for the user.

The originality of this article lies in its development of a robotic door opener system designed through an iterative process that closely involved occupational therapists and potential users. Specifically, the system is designed to be low-cost and easily installable on a door without requiring any modifications to the door itself. The system adapts mechanically to uneven surfaces and can be controlled via a smartphone. The system was refined through continuous feedback from actual users, ensuring that it effectively aligns with their specific needs and constraints.

3 Objective

The goal of this project is to enable people to independently move between different rooms for accessibility, autonomy, reduced need for assistance, and access to commerce and work. To achieve this goal, the objective of this study is to design a Robotic Wheel Door Opener System (RWDOS) that can be installed in users' residences and be controlled remotely. In such manner, this project will ensure accessibility for people living with upper limb disabilities. The main evaluation criteria will be manufacturing and installation cost, efficiency, along as installation simplicity.

4 Development

4.1 Mechanical design

The RWDOS design includes a motorized wheel fixed to a door, as shown in Figures 1 and 2. The 62-mm diameter wheel is attached to a two-bar mechanism that allows the wheel to move vertically, adapting to uneven floor levels during the opening or closing of the door. If the mechanism were simply a rigid bar, the wheel could lose contact with the floor at some points, or the floor could exert significant force on the assembly at other points due to its unevenness. The two-bar mechanism compensates for vertical floor height variations but cannot apply the necessary force to keep the wheel in contact with the floor. To address this, a pair of springs was added to the two-bar mechanism at the junction between the wheel support and the base. These springs, shown in Figure 1, keep the wheel in constant contact with the floor, preventing it from rolling in the air and by increasing adherence between the wheel and the floor.

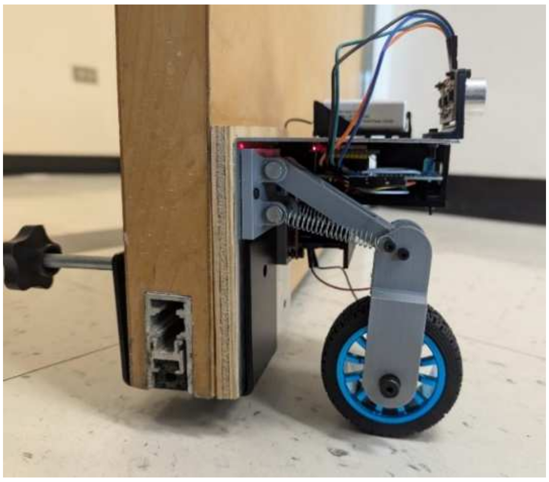

Figure 1 Side view of the WRDOS fixed on a door

The wheel is directly connected to a 25GA-370 DC motor (6V 280 rpm), responsible for its rotation movement. The DC motor, shown in Figure 2, was chosen to ensure the door can open in less than 10 seconds. The goal was to achieve an actuation time that is not too long for the user, while being slow enough for safety considerations.

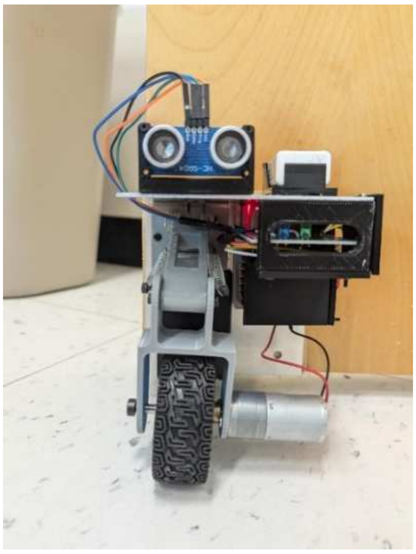

Figure 2 Front view of the wheel door opener system

4.2 Algorithm and on-board computer system

The DC motor, and consequently the door's movement, are controlled by a microcontroller (ESP32 MH-ET Minikit) through a motor driver (L298N). When the microcontroller receives the appropriate signal, it activates the DC motor to produce the desired door movement. The components are powered by a 9V battery placed at the top of the RWDOS. A functional scheme of the whole system is shown in Figure 3. The section below describes all the considerations taken to develop the RWDOS.

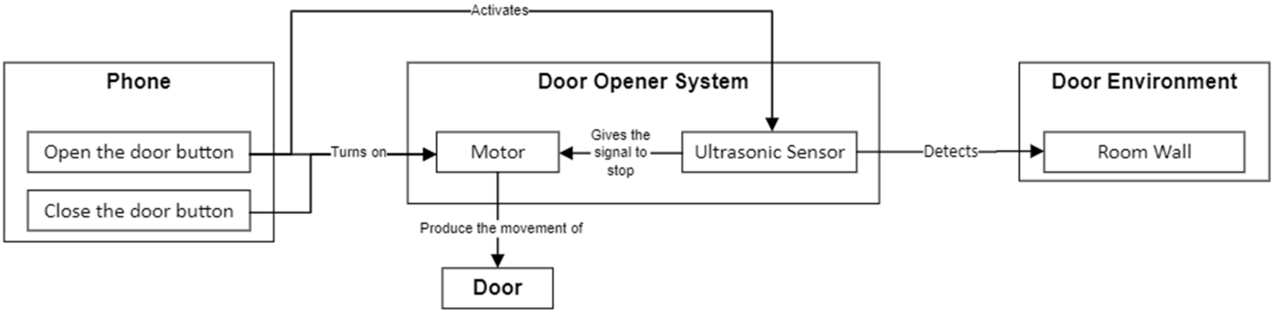

Figure 3 Functional diagram of the wheel door opener system

4.2.1 DC motor operating time

As mentioned, the DC motor must be actuated at a speed that allows efficient and safe opening/closing of the door. To this extent, a 1.5s – 7s – 1.5s speed profile (acceleration phase of 1.5s, constant speed phase of 7s and deceleration phase of 1.5s) has been chosen for the DC motor's operation. However, a challenge is that the time required to open a door can vary depending on factors such as the door's size and weight. A pre-programmed opening duration that is too short would prevent the door from opening completely, while a duration that is too long could result in a collision between the door and a wall. On the other hand, an adjustable duration might be cumbersome and less intuitive for the user.

To that end, an ultrasound sensor was installed on the front side of the RWDOS (see Figure 2). When an object, such as the wall, is detected within a predetermined range, the motor will immediately stop.

4.2.2 User interface

Many options can be used as the user interface for opening or closing the door, each with distinct advantages and drawbacks. For instance, a push button could be installed on the door, connected either via a wire or wirelessly, but this requires the patient to physically reach and press the button, which may be challenging for those with limited mobility. A classic IR remote control could be used, but this would require the user to always carry it with them and can suffer from signal loss when there is an obstruction, such as a door, between the remote and the receiver. Presence detection systems, such as cameras, although effective, are often prohibitively expensive and complex to implement. In contrast, a smartphone application, as shown in Figure 3, offers a superior solution by allowing the door to be opened from a considerable distance with ease, making it accessible for a wide range of users.

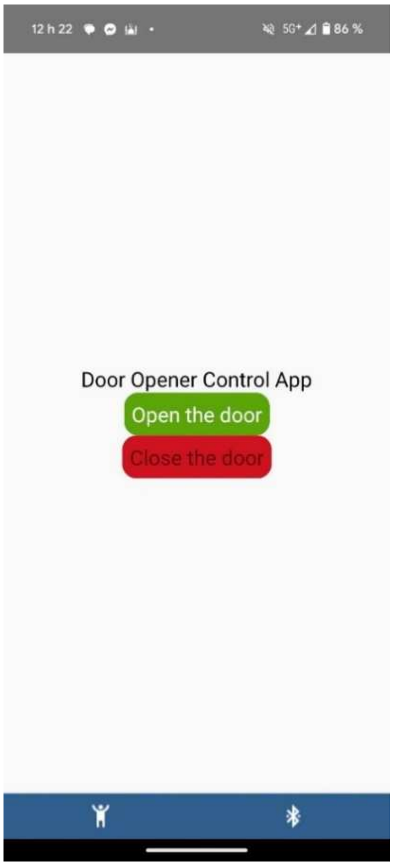

Figure 4 Wheel door opener control application

5 Discussion

In this paper, the design of a Robotic Wheel Door Opener System (RWDOS) was presented. The general objective of this project is to enable people to independently move between different rooms for accessibility, autonomy, reduced need for assistance, and access to commerce and work. At this point, the RWDOS can open and close a standard door in less than 10 seconds successfully. Additionally, the response time to the order sent by the smartphone application is almost instantaneous. The ultrasound sensor allowed a quick reaction of the system in case of room wall detection, stopping the motor before any physical contact. Finally, the cost of the first prototype has been evaluated at 300 CAD as shown in

Table 1. Nevertheless, this cost analysis was based on the production of approximately ten prototypes using prototyping components. If the project reaches the stage of manufacturing for personal use, fabrication processes and product design will be reviewed to reduce the cost and make the product more accessible.

Table 1 Cost analysis of the project.

Parts/components	75 $
Raw materials	25 $
Manufacturing Processes	110 $
Other costs (maintenance charges, training for users, etc.)	40 $
Subtotal	250 $
Unforeseen (as a percentage added to the subtotal)	20%
Total	**300 $**

6 Conclusion

The future of this project will primarily involve validating the device with rehabilitation professionals and end-users. In other words, the device will be tested in household environments with the involvement of rehabilitation professionals to evaluate its practical usability and impact on daily rehabilitation activities. Indeed, gathering feedback from real users will be essential for evaluating the system's efficiency and user satisfaction, thereby informing iterative design improvements. Based on the results and feedback received, the system will be enhanced. Additionally, technical improvements will be made to the device, focusing on sourcing parts to reduce costs and redesigning elements for cost efficiency. Through these efforts, we aim to refine the robotic assistant system to better meet the needs of therapists and patients, ultimately contributing to a higher quality of care and increased independence for users.

Acknowledgement

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