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Enhancing Wheelchair Mobility Through Dynamics Mimicking

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Abstract- This paper describes a research project that aims to develop a mobility enhancing device for wheelchair users. Wheelchairs limit the freedom of movement of users over obstacles such as staircases, inclined planes and low-friction terrain such as sand or snow-covered pavement. The basic idea is to mount the wheelchair on top of a vehicle that is capable of the required maneuvers, such that the wheelchair is carried on top of another vehicle. The advantage is that the wheelchair remains unchanged and can be used where high maneuverability is required. A major problem is how the wheelchair user controls the mounting vehicle. Thus, a major goal for the project was to allow the wheelchair user to control the carrying vehicle utilizing the same user interface being used to control the wheelchair. For that purpose a "dynamics mimicking" device was developed that interfaces between the wheelchair and the carrying vehicle. The device obtains the kinematics of the wheelchair as well as the desired motion, and translates it to commands to the carrying vehicle such that the carrying vehicle performs the desired action instead of the wheelchair. In this paper, the idea and a dynamics mimicking device are presented, as well as basic results confirming the validity of the concept, and serve as a starting point for research on more complex scenarios.

Keywords: Wheelchair, Robotics, Kinematics, Maneuverability, Mobility.

1. Introduction

Traditional wheelchairs have high mobility on even terrain with reasonably high friction coefficients. However, when it comes to overcoming obstacles such as a step, low-friction surfaces such as a snowy pavement, an unpaved lane, a staircase or even a steeply inclined surface, they become hard to maneuver or even completely useless. Some solutions exist, most of them concentrate on devising alternative wheelchair designs. (Quaglia, Franco and Oderio, 2009) present a mechanical concept for a stair climbing wheelchair where each shaft has a triad of smaller wheels attached to it, which gives the chair bigger dimensions, especially its length, compared to traditional wheelchairs. Another approach is taken by (Yu, Li, Wang and Yao, 2010) who are using a chain and flippers mechanism to climb stairs, which is not much larger than a tradition wheelchair. However, chains usually have practical problems indoors with small objects laying on the floors and rugs that do not work well with chains. Smaller climbing wheelchairs such as presented by (Wada, 2008) can only climb a single stair, and (Chen and Pham, 2012) once again present a climbing robotic wheelchair that is far wider than the traditional wheelchair.

The idea presented here does not offer a new wheelchair. Instead, a robotic platform with ability to overcome obstacles can be selected. The existing wheelchair is mounted on top of the robotic platform through an interface unit that would help drive the robotic platform. This way, the wheelchair user does not need to change a wheelchair, and does not need to compromise on the high maneuverability of the traditional wheelchair indoors to obtain better performance when there are obstacles to overcome. One of the greater challenges introducing this approach is the human machine interface (HMI). Since people who use wheelchairs are used to drive and navigate themselves in a custom tailored fashion, that is, each wheelchair user has different physical limitations, and therefore different methods to drive their wheelchair, it is important to maintain the same HMI between them and the new robotic platform so that they would not be required to learn a new way to operate the robotic platform, which, in some cases due to physical limitation, may be impossible. This paper suggests a method to maintain the HMI of the wheelchair when controlling the carrier robot through dynamics mimicking. In essence, instead of reading the user input to the wheelchair, the suggested platform reads the output of the user's actions and translates them into an appropriate command to the carrier robot. To accomplish that, the dynamics mimicking system is required to collect two types of information. A pictorial representation of such a concept is portrayed in Fig. 1.

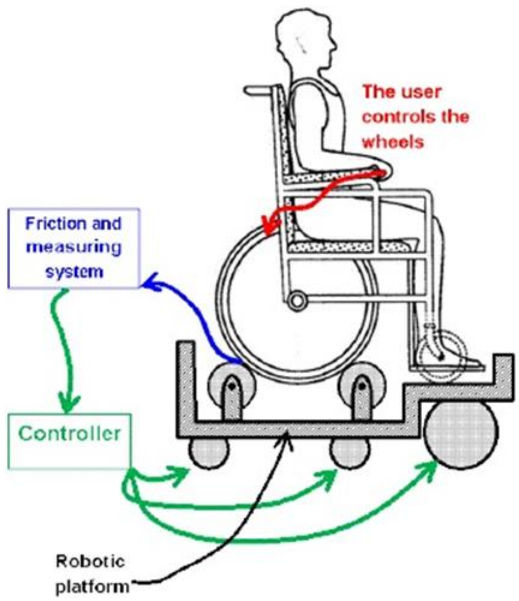

Fig. 1. Basic concept of the dynamics mimicking platform

First, the dynamics mimicking system needs to obtain information about the kinematics of the particular wheelchair and create the Jacobian for the wheelchair. Once the system has the Jacobian of the wheelchair, it needs to obtain the specific real-time desired motion of the wheelchair. Thus, the dynamics mimicking platform performs some initial measurements that are performed once the wheelchair is mounted on the system, and then continuously reads the actions of the chair, namely, the velocities of the two driving wheels of the wheelchair. A proof-of concept demonstrator was constructed and experiments were performed to verify the concept. Experimental results and simulations are presented in this paper for a realistic ideal case.

2. Required Measurements

The first step was selecting the parameters that are required to obtain the information regarding the kinematics of the wheelchair. The basic assumption, supported by surveying the market state for traditional wheelchairs suggests that wheelchairs are controlled through the manipulation of two wheels controlled separately but with the same axis of rotation. Controlling the speed of each wheel separately allows for controlling the speed and direction of motion of the wheelchair. A typical wheelchair Jacobian looks like:

$$\begin{bmatrix} u \\ \omega \end{bmatrix} = \begin{bmatrix} \frac{1}{2} & \frac{1}{2} \\ \frac{1}{d} & -\frac{1}{d} \end{bmatrix} \begin{bmatrix} u_r \\ u_l \end{bmatrix} \tag{1}$$

where u is the forward speed of the wheelchair's centre of mass, ω is the forward wheelchair's angular velocity, u_r is the forward velocity of the right hand side wheel, u_l is the forward velocity of the left hand side wheel, and d is the distance between the driving wheels. It is clear then that the parameters that need to be measured for the construction of the Jacobian of the wheelchair are the constant d, the distance between the left and right wheel of the wheelchair,which may be measured once when the chair is initially mounted on the system. In addition, to obtain the motion of the wheelchair, the two forward velocities of the driving wheels, u_r and u_l are needed, and they need to be measured continuously.

2.1. Distance Between Driving Wheels

Measuring the distance between the driving wheels is done by placing a linear array of touch resistive sensors. These sensors are affected by pressure. Each component is a small circuit and pressing upon one closes an electric circuit, which results in a logical ’0’ or ’1’ output. Knowing the location of each of the components allows us to measure the distance between the two driving wheels. In case where the system is dedicated to a specific user, this information may be entered manually and save the measuring system.

2.2. Driving Wheels’ Forward Velocities

The forward velocities u_r and u_l are measured using encoders located at the free-rolling cylinders for each driving wheel. Since the radii of the rollers is known, these velocities are simply calculated using the basic relation:

$$u_r = r\dot{\theta}_r \tag{2}$$

$$u_l = r\dot{\theta}_l \tag{3}$$

where r is the radius of the rollers, $\dot{\theta}_r$ is the measured angular velocity of the right hand side roller, and $\dot{\theta}_l$ is the measured angular velocity of the left hand side roller.

Fig. 2 shows the dynamics mimicking system design.

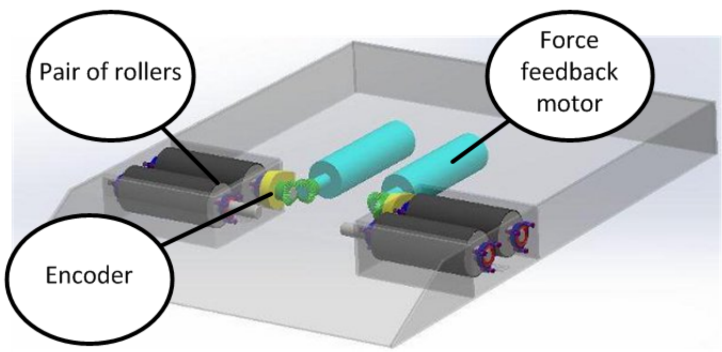

Fig. 2. Dynamics mimicking system

The first two measurements allow us to obtain the Jacobian of the wheelchair, whereas the encoders give us the real-time input from the user, using the output of the wheelchair, thus allowing us to pass the user input to the carrier robot without changing the HMI and the user experience, or learning to use a new input device.

3. Experimental Validation

The system described in previous sections was designed and constructed, and experimental validation performed. The experimental setup was constructed with dynamics mimicking in mind rather than overcoming obstacles, since the idea of controlling the robotic platform through the wheelchair output is the challenge under question. Thus, instead of mounting the wheelchair and dynamics mimicking platform on top of a robotic platform, we have separated the two, and constructed a stationary dynamics mimicking platform where the wheelchair is mounted, which communicates wirelessly with a small mobile robot that is performing the desired motion. The desired motion of the wheelchair is measured using encoders on the driving wheels of the wheelchair, and the motion of the robotic platform is measured using a high-speed camera mounted on the ceiling of the room. The basic setup of the system is shown in Fig. 3.

Kinematically speaking, the dynamics mimicking platform is converting the kinematics of the wheelchair to the kinematics of the robotic platform. This is done mathematically through a transformation matrix that combines the measured velocities of the wheelchair’s wheels and the Jacobian of the robotic platform.

If the wheelchair kinematics is described using a Jacobian $[J_c]$

$$\vec{V_C} = [J_C]\vec{u_C} \tag{4}$$

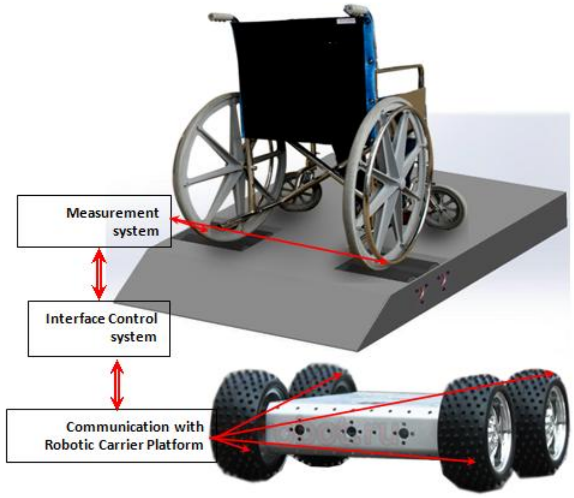

Fig. 3. Basic system setup

where

$$\vec{V_C} = \begin{bmatrix} u \\ \omega \end{bmatrix} \tag{5}$$

and

$$\vec{u_C} = \begin{bmatrix} u_r \\ u_l \end{bmatrix} \tag{6}$$

for the wheelchair, and similarly, for the robotic platform

$$\vec{V_R} = [J_R]\vec{\omega_R} \tag{7}$$

with corresponding definitions for the components of $\vec{V_R}$ and $\vec{\omega_R}$, we have

$$\vec{\omega_R} = [J_R]^{-1}[J_C]\vec{u_C} \tag{8}$$

or:

$$\vec{\omega_R} = [J_{RC}]\vec{u_C} \tag{9}$$

where

$$[J_{RC}] = [J_R]^{-1}[J_C] \tag{10}$$

. This is, of course, true only if the Jacobian of the robotic system $[J_R]$ is invertible. For the purpose of verifying the concept a suitable robotic system was selected to accommodate the mathematical convenience presented above.

4. Initial Results, Conclusion, and Future Work

The initial results showed that for a simple system where there is a good correspondence between the workspaces of the wheelchair and the robotic platform, a good tracking is achieved, provided that the position of the centre of rotation of the wheelchair and the centre of rotation of the robotic platform align. Fig. 4 shows simulation predictions for an example of trajectory tracking. On the left hand side, the centre of rotation of the wheelchair is not aligned with the centre of rotation of the robotic platform, which results in the two separate trajectories presented in the graph

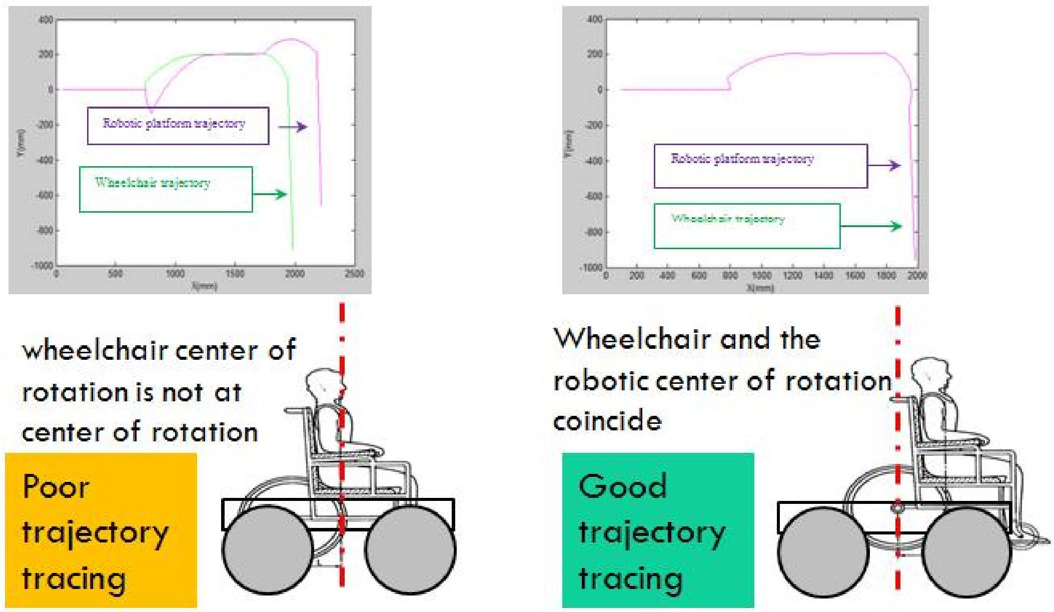

Fig. 4. Simulation: Trajectory tracking with coinciding (right) and non-coinciding (left) rotation centres

on top. On the right hand side of Fig. 4, one can observe that when there is perfect alignment between the centre of rotation of the wheelchair and the centre of rotation of the robotic platform, there is an excellent match between the expected trajectory of the wheelchair alone and the expected trajectory of the carrier robotic platform.

Fig. 5 shows the experimental setup for the validation process. On the right hand side is the schematic representation of the experiment, and on the right hand side one can see the actual platform. Notice that the particular robotic platform shown was one of a few platforms that were used for validation purposes.

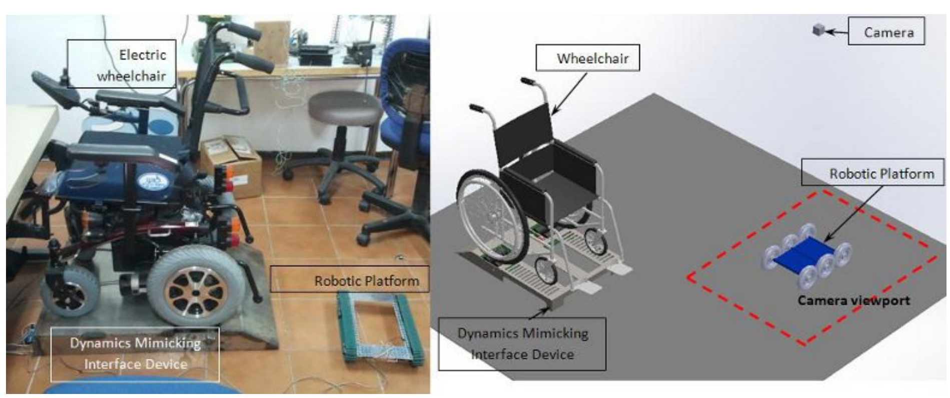

Fig. 5. Experimental setup

Fig. 6 shows experimental results for a similar case where the rotation centres of the wheelchair and robot coincide. It is clear that the experimental results validate the concept, as the trajectories are very close together.

Future work on the project goes in two main directions. The first is obtaining the effects of deviation from the ideal case on the performance of the platform and its ability to track on the one hand, and its inverse, i.e., what maneuver should be performed to obtain good tracking for a given deviation from the ideal case presented here. The

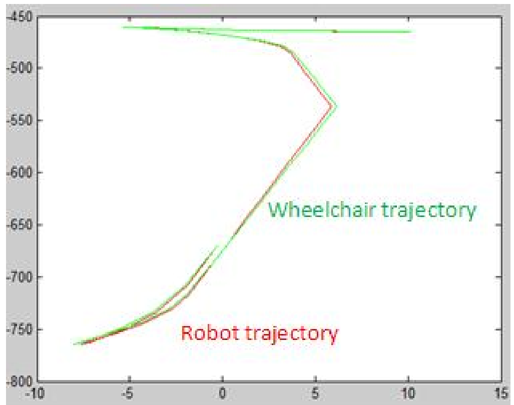

Fig. 6. Experiment: Trajectory tracking with coinciding rotation centres

second direction, is working with wheelchair users to help define what will be considered ”good” tracking from their standpoint, i.e., what are the limits of the tracking errors before the users can ”tell” that there was an error.

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