Development and Control of a Robotic Attendant Wheelchair

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ABSTRACT
Attendant Wheelchairs (AWs) provide mobility to patients who cannot control wheelchairs. They are either manual, which have excellent maneuverability but offer no power assistance, or electric powered with joystick control interface, which provide power assist but have poor maneuverability in confined spaces. Hence, with the objective of combining the merits of manual and electric powered AWs, this paper presents the development and control of a robotic AW. The AW provides power assistance by using a motorized mobile base while excellent maneuverability is achieved by employing a motion control strategy that emulates the behavior of a manual AW. The motion control employs a desired dynamics that takes user’s intention in the form of applied force/torque and generates desired velocities, which are tracked by low-level controllers. Experimental results show the efficacy of the control approach.

Keywords: Motion Control, Wheelchair

1. Introduction
Improving quality of life of people with disability requires the aid of intelligent assistive devices and one of them is an attendant wheelchair (AW). AWs aid not only patients, but also caregivers/attendants. They are used to transport patients who do not have the ability to control wheelchairs and commonly employed in airports, hospitals, and healthcare facilities. Manual AWs have excellent maneuverability, but do not provide power assist to the attendant while electric powered AWs with joystick control interface provide power assist but have poor maneuverability in confined spaces. Hence, it will be ideal to have an AW that combine the positive characteristics of manual and electric powered AWs.

Robotic wheelchairs have been studied in [1], [3], however, the focus is generally on control interfaces and assistance to patients and not toward attendants/caregivers. For example in [1], a slip mitigation approach for electric powered wheelchair has been proposed to improve safety of the user. Excellent maneuverability of motorized assistive devices specifically walking support systems has been demonstrated in [2], [3], [5], where force/torque sensors are used as control interface and basis for the assistive device motion behavior.

This paper presents the development and control of a robotic AW with the object of assisting attendants through power assist and excellent maneuverability functionalities. To achieve the aforementioned objectives, this study uses an electric powered wheelchair modified to have a custom built control system and uses a force/torque interface for excellent attendant-wheelchair physical interaction and manipulation. A desired dynamics, which emulates a passive system specifically a manual pushed wheelchair, uses the force/torque information and generates desired velocities of the AW. Figure 1. shows the general control diagram of the robotic AW. A force/torque sensor reads the attendant’s intention, which is fed to the desired dynamics and used as a basis to determine the desired linear and angular velocities of the wheelchair. The inverse kinematics transforms robot velocities to left and right wheel velocities. The desired wheel velocities are tracked by low-level controllers. The above hardware configuration and control approach should enable the robotic AW to provide power assistance and have excellent maneuverability.

The remaining sections are described as follows. Section II discusses the high-level control, which addresses the attendant-wheelchair interaction. The high level control emulates the behavior of a manual attendant wheelchair.
Section III discusses the electronic hardware used by the robotic AW. Section IV presents the evaluation and followed by the summary.

2. High Level Control

The high level control emulates the behavior of a manual wheelchair, which is described by a desired dynamics. A force/torque sensor reads the attendant’s intention, which is fed to the desired dynamics and used as basis to determine the desired linear and angular velocities of the wheelchair.

The equation of the desired dynamics is described below

$$M_d \ddot{x}_d + D_d \dot{x}_d = F_a,$$  \hspace{1cm} (1)

where $M_d$ and $D_d \in \mathbb{R}^{2 \times 2}$ are the inertia and damping and are respectively given below

$$M_d = \begin{bmatrix} M_{dx} & 0 \\ 0 & M_{dθ} \end{bmatrix}, \quad D_d = \begin{bmatrix} D_{dx} & 0 \\ 0 & D_{dθ} \end{bmatrix}.$$  \hspace{1cm}

$F_a$ is the attendant intention given as

$$F_a = \begin{bmatrix} F_x \\ F_θ \end{bmatrix}.$$  \hspace{1cm}

Note that the variables with a subscript of $x$ are for the linear motion while variables with a subscript of $θ$ are for the angular motion.

The output is $\dot{x}_d$, where the components are the desired linear and angular velocities of the robotic AW and is given below

$$\dot{x}_d = \begin{bmatrix} v_R \\ \omega_R \end{bmatrix}.$$  \hspace{1cm}

Based Fig. 2 the forward kinematics of the AW is given below

$$\begin{bmatrix} v_R \\ \omega_R \end{bmatrix} = \begin{bmatrix} 1/2 & -1/2 \\ 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}.$$  \hspace{1cm} (2)

The left and right desired wheel angular velocities can be expressed as $\dot{θ}_1 = v_1/r$ and $\dot{θ}_2 = v_2/r$, respectively. Hence, (3) can be written as

$$\begin{bmatrix} \dot{θ}_1 \\ \dot{θ}_2 \end{bmatrix} = \begin{bmatrix} 1/r & -1/2r \\ 1/r & 1/2r \end{bmatrix} \begin{bmatrix} v_R \\ \omega_R \end{bmatrix}.$$  \hspace{1cm} (4)

The result of (4) will be assigned as desired wheel velocities and represented as $\{\dot{θ}_1, \dot{θ}_2\}$. The desired wheel positions and accelerations are respectively represented as $\{θ_{d1}, θ_{d2}\}$ and $\{\ddot{θ}_{d1}, \ddot{θ}_{d2}\}$, which are numerically determined for the use of the low-level controller as shown in Fig. 3.

3. Experimental Setup

Figure 4 shows the experimental setup. It based on a commercially available electric powered wheelchair that is wheel, and $v_2$ is the linear wheel velocity of the right wheel. For control purposes, the inverse kinematics will be used that is $v_1$ and $v_2$ will be expressed in terms of $v_R$ and $\omega_R$ and is given below

$$\begin{bmatrix} v_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} 1/2 & -1/2 \\ 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} v_R \\ \omega_R \end{bmatrix}.$$  \hspace{1cm} (3)

Figure 3. Low-Level controller of the robotic attendant wheelchair
modified to handle the high level control as discussed in Sec 2. Fig. 5 shows the hardware diagram of the robotic AW. A PC104 plus computer system with pentium III 900 MHz processor runs the realtime QNX operating system. It also handles the low-level control and high level motion control algorithm and both are running at 1 kHz control rate. It is stacked with a Sensoray 526 data acquisition board as shown in Fig. 6 and JR3 receiver board as shown in Fig. 7. The Sensoray 526 reads the incremental encoders, which are directly coupled to the motor shafts. In addition, the 526 communicates to the motor drivers through its analog to digital channels. The force/torque sensor captures user’s intention and transmits the data to the receiver board.

Figure 8 shows the left wheel, motor, and encoder assembly. The motors are coupled with gearboxes with gear ratio of 32:1. To read the wheel angular positions, incremental encoders with resolutions of 1000 counts per revolution are installed at the back of the motors. This approach gives a finer angular wheel resolution and requires less hardware modification/installation in contrast to attaching the encoders to the wheels.

4. Evaluation

This section discusses the initial evaluation of the high level control of the robotic AW. A predefined path as shown in Fig. 9 is given and the user needs to track it with different desired dynamics parameters, i.e., $M_x$ and $D_x$, for generating...
translational velocities while fixing $M_\theta$ and $D_\theta$. The user moves from the starting point to A, B, C, and returns to start.

Figures 10 (a) - (c) show the resulting applied forces to generate linear velocities. For all the evaluations, $M_\theta = 3 \text{ kg.m}^2$ and $D_\theta = 6 \text{ N.m.s/rad}$. Figure 10 (a) shows the applied force for $M_x = 50 \text{ kg}$ and $D_x = 50 \text{ Ns/m}$ and the mean absolute applied force is 15.56 N. Figure 10 (b) shows the applied force for $M_x = 25 \text{ kg}$ and $D_x = 25 \text{ Ns/m}$ and the mean absolute applied force is 10.91 N. Figure 10 (c) shows the applied force for $M_x = 10 \text{ kg}$ and $D_x = 10 \text{ Ns/m}$ and the mean absolute applied force is 5.81 N. It can be noticed that as the desired dynamics parameters are reduced the applied intentional forces also reduces, which is excellent for power assist. Also, the task completion time is reduced for low mass and damping as shown in Fig. 10. However, oscillations are observed at low values of mass and damping especially when the arms are fully extended.

5. Conclusions

This paper presented the hardware components and control approach of a robotic attendant wheelchair with the objective of providing power assist while maintaining excellent maneuverability. An electric powered wheelchair was used as the mobile base and installed with electronic hardware to handle the proposed high level control that addressed attendant-wheelchair physical interaction. The control approach was based on desired dynamics, which emulates the behavior of a manual pushed wheelchair. The initial evaluation results showed that less applied forces were required to complete the given task as the dynamics parameters were reduced. However, oscillations were observed. Future works will focus on further power assist and maneuverability evaluations and addressing the instability of the system during attendant wheelchair physical interaction.

References


