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Real-time model based electrical powered wheelchair control☆

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ABSTRACT

The purpose of this study was to evaluate the effects of three different control methods on driving speed variation and wheel slip of an electric-powered wheelchair (EPW). A kinematic model as well as 3D dynamic model was developed to control the velocity and traction of the wheelchair. A smart wheelchair platform was designed and built with a computerized controller and encoders to record wheel speeds and to detect the slip. A model based, a proportional-integral-derivative (PID) and an open-loop controller were applied with the EPW driving on four different surfaces at three specified speeds. The speed errors, variation, rise time, settling time and slip coefficient were calculated and compared for a speed step-response input. Experimental results showed that model based control performed best on all surfaces across the speeds.

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1. Introduction

Over 200,000 people in the United States use electric-powered wheelchairs (EPWs) as their primary means of mobility [1,2]. EPWs provide functional mobility for people with both lower and upper extremity impairments. Great advances have been made in the design of electric-powered wheelchairs over the past 20 years, yet the control algorithms for these wheelchairs have improved comparatively little since the early 1980s. Electric-powered wheelchair driving could become safer, more effective in a broader array of environments, and functional for more people with the application of advanced control systems [3,4].

Control systems research has achieved broad application in other areas, such as telecommunications, robotics, automation, and medicine. The simple proportional-integral (PI) controller used on most EPWs today for velocity control does not perform well when subjected to disturbances, sensor uncertainties and load variation [5,6]. In addition, wheelchair users may encounter different environments and road conditions when driving indoors or outdoors. Incidence of loss of control and injury are far too frequent among EPW users [3,5]. A substantial fraction of EPW accidents can be directly attributed to the control system and design features of EPWs [3–6]. Persons with severe and complex disabilities might find it difficult to steer an EPW in a confined environment or under adverse conditions such as slippery or uneven terrain or obstacles. Sometimes, even experienced users may lose control of their chairs under such driving conditions. Especially problematic are the actions of negotiating a slope-transition and crossing the threshold of a doorway. These complex actions require hand–eye coordination and fine motor control that for some individuals with high-level spinal cord injury, multiple sclerosis or brain injury that may be exceedingly challenging. For some of these people, learning how to safely and effectively use an EPW can take hours or weeks. Fehr et al. reported that 18–26% of their patients who used a manual wheelchair could not safely operate an EPW. Their study concluded that no independent mobility options for these patients existed at the time of assessment [7]. Furthermore, a report using data from the United States emergency departments stated that in 2003 over 100,000 wheelchairs related accidents were treated with 65–80% of the accidents being tips and falls [8].

Some research has been conducted on simulation and control of EPWs. Brown et al. [9] applied optimal control theory to the design and development of a control system for an EPW. They developed a PID controller with self-adaptive gains. The controller did not consider robustness in terms of external disturbance rejection. Shung et al. [10] described a computer model of an EPW and its motor control circuitry. In their later work [11], they presented an EPW velocity feedback controller based on the rear wheel drive EPW model and motor control circuitry developed in Ref. [10]. A computer simulation study showed that the velocity controller made the EPW easier to drive under varying surface conditions. No driving experiments were reported to verify the practical use

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of the proposed controller. Another issue identified by EPW user's is wheel slip, which frequently occurs when driving over low-traction terrain, deformable terrain, steep hills, or during collisions with obstacles, and can frequently result in wheelchair loss of control or immobilization. The wheelchair should quickly detect the stalled state in order to let the user or control system take appropriate action, such as planning an alternate route away from the low-traction terrain region or implementing a traction control algorithm [12]. For most automobiles, wheel slip can be accurately estimated through the use of encoders by comparing the speed of driven wheels to that of the coasting wheels [13]; however, this does not apply for all-wheel drive vehicles or those without redundant encoders such as most EPWs. Ding and Cooper reviewed the past researches on EPW and stated that "control algorithms for these [EPW] wheelchairs have not improved substantially since the early 1980s." [5].

The goal of this research is to provide EPW users expanded independent mobility that is safe, to eventually provide more people independent mobility. The controller for this study is based on the Versalogic EBX-12 COBRA industrial single board computer installed with VxWorks 6.3 real-time operating system that replaces the Original Equipment Manufacturer (OEM) control electronics on an EPW as well as wheel encoders and inertia sensors to provide the researcher with control of the driving algorithms and the ability to read state data. The system is semiautonomous, which takes advantage of the intelligence of the wheelchair user by allowing the user to plan the general route while taking over lower level functions such as speed and anti-slip control. [14] This paper describes the evaluation of three different control methods on driving speed variation and wheel slip of an electric-powered wheelchair (EPW): a 3D hybrid advanced control system (3D-HACS) based on the model of EPW that includes robust velocity control (RVC) and robust traction control (RTC) to reject external disturbances and compensate for parameter and sensor variations, PID control and open-loop control.

2. Development of a 3D hybrid advanced control system

Our initial findings using a robust velocity control (RVC) algorithm based on a 2D EPW model are described in Refs. [15,16]. The simulation results showed that the RVC suppressed disturbances better than a PI controller. In this study, we further refined the previous EPW dynamic model by considering EPW motion in 3D on inclined surfaces with cross-slopes (Fig. 1). We have incorporated a tri-axial gyroscope for providing real-time feedback of the incline and cross-slope angles.

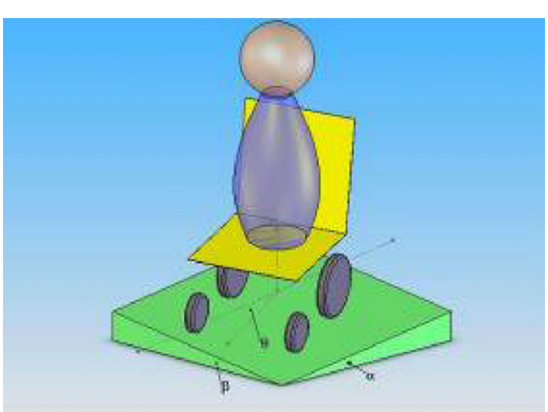

Fig. 1. Conceptual model of a wheelchair on an inclined surface with cross-slope.

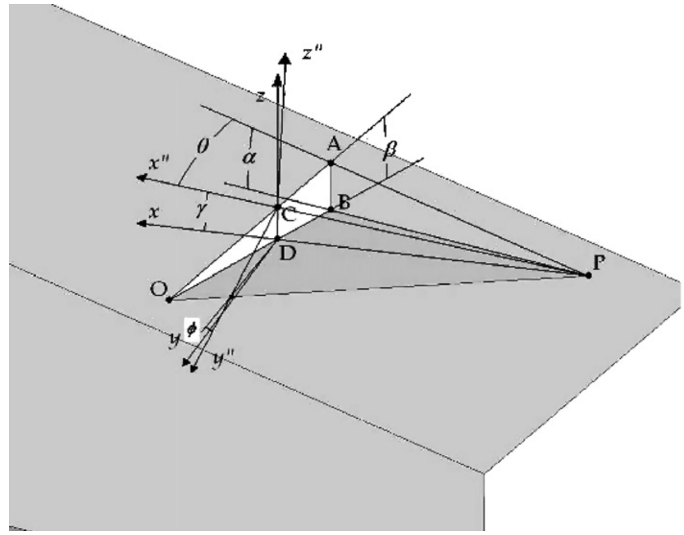

Fig. 2. Wheelchair axis systems on a slope showing OAP as the slope surface, C represents the wheelchair, α (up/downhill slope of surface) and β (side slope of surface) associated with the surface, γ (slope along line of EPW motion) and ϕ (cross-slope to EPW motion) associated with the wheelchair, and the EPW direction θ.

2.1. Robust velocity control

2.1.1. Modeling the EPW

An EPW is a coupled electro-mechanical system in which two independent electrical motors produce torque to cause rotation of the two rear drive wheels. Fig. 1 shows the coordinate systems. The wheelchair is composed of a rigid platform and non-deforming wheels, and it moves on inclines of varying slope and cross-slope. Our 3D models is based upon the coordinate system illustrated in Fig. 2, $x'y'z'$ are fixed to the earth, xyz describe the wheelchair with the z-axis perpendicular to the earth. The coordinate axes, $x''y''z''$ are affixed to the wheelchair with z-axis perpendicular to the slope surface. Referring to Fig. 2, the following relations can be obtained among angles in these three coordinate systems.

$$\sin\gamma = \sin\alpha\cdot\cos\theta - \sin\beta\cdot\sin\theta \tag{1}$$

$$\sin\phi = \sin\alpha\cdot\sin\theta + \sin\beta\cdot\cos\theta \tag{2}$$

We define the traction force provided by the drive wheels as F_L, F_R which are dependent upon the torque the motors provide to each wheel.

From Fig. 3, we can derive the force balance equations:

$$F_L + F_R - \mu(F3 + F4 + F5 + F6) - F_X = M\cdot\dot{v}_x \tag{3}$$

$$F1 + F2 - \mu(F3 + F4 + F5 + F6) + F_Y = M\cdot\dot{v}_y \tag{4}$$

$$F3 + F4 + F5 + F6 - F_Z = M\cdot\dot{v}_z = 0 \tag{5}$$

where

$$\dot{v}_x = \frac{\dot{v}_R + \dot{v}_L}{2} - \frac{l\cdot(v_R - v_L)^2}{W^2} \tag{6}$$

$$\dot{v}_y = \frac{(\dot{v}_R - \dot{v}_L)\cdot l}{W} + \frac{(v_R^2 - v_L^2)}{2\cdot W} \tag{7}$$

$$F_X = \frac{M\cdot g\cdot\tan\gamma}{1 + \tan^2\gamma + \tan^2\beta} \tag{8}$$

$$F_Y = \frac{M\cdot g\cdot\tan\beta}{1 + \tan^2\gamma + \tan^2\beta} \tag{9}$$

$$F_Z = \frac{1}{1 + \tan^2\gamma + \tan^2\beta} \tag{10}$$