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Design and evaluation of a seat orientation controller during uneven terrain driving

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ABSTRACT

Electric powered wheelchairs (EPWs) are essential devices for people with disabilities as aids for mobility and quality of life improvement. However, the design of currently available common EPWs is still limited and makes it challenging for the users to drive in both indoor and outdoor environments such as uneven surfaces, steep hills, or cross slopes, making EPWs susceptible to loss of stability and at risk for falls. An alternative wheel-legged robotic wheelchair, "MEBot", was designed to improve the safety and mobility of EPW users in both indoor and outdoor environments. MEBot is able to elevate its six wheels using pneumatic actuators, as well to detect changes in the seat angle using a gyroscope and accelerometer. This capability enables MEBot to provide sensing for a dynamic self-leveling seat application that can maintain the center of mass within the boundaries of the wheelchair, thereby, improving EPW safety. To verify the effectiveness of the application, MEBot was tested on a motion platform with six degrees of freedom to simulate different slopes that could be experienced by the EPW in outdoor environments. The results demonstrate the robustness of the application to maintain the wheelchair seat in a horizontal reference against changes in the ground angle.

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Abbreviations

CAREN	Computer Assisted Rehabilitation ENvironment
CoP	Center of Pressure
EPW	Electric powered wheelchair
MEBot	Mobility Enhancement RoBotic Wheelchair
IMU	Inertial Measurement Unit
P-D	Proportional-derivative controller
PWM	Pulse Width Modulation

1. Introduction

An electric powered wheelchair (EPW) is a key mobility device for people with disabilities, providing independence, mobility, and a higher quality of life [1]. Currently, over 400,000 Americans benefit from using an EPW [2], and this number continues to increase over the years [3]. However, there have been limited improvements in EPW design to meet the increasing needs of users for both indoor and outdoor mobility over the past 20 years [4]. Few notable improvements have been the inclusion of passive suspension [5] to decrease vibration, power seat functions, and expanded intuitive user interfaces [4]. Despite these improvements, current designs limit most users to drive in indoor environments with firm and reasonably flat surfaces. Furthermore, may have difficulties, and thus must avoid, driving their EPW over uneven terrain (noncompliant terrains with ADA standards in cross slopes (2° max) and ramps(5° max) [6]). Driving in these uneven environments has been shown to cause shift in the center of mass that leads to lack of stability control of the EPW [4], thereby increasing the risk of tips and falls [7–9]. These significant challenges have increased the need to design an EPW that is not only suitable for indoor environments, but will allow the user to be safe and highly functional in structured and unstructured outdoor environments (e.g., parks, trails, lawns).

Recent work in assistive mobility devices using wheeled-legged robots has led to the research and development of EPWs that can maintain seat orientation when traversing over uneven terrains. An advanced prototype EPW design was the iBot [10] which incorporated indoor and outdoor mobility applications, including two wheel self-balancing in the fore-aft directions. The PMR wheelchair, a two wheeled-legged EPW uses a balance platform and a linkage system within the wheelchair to self-balance in the face of small ground angle changes [11]. The RT-Mover robot [12]

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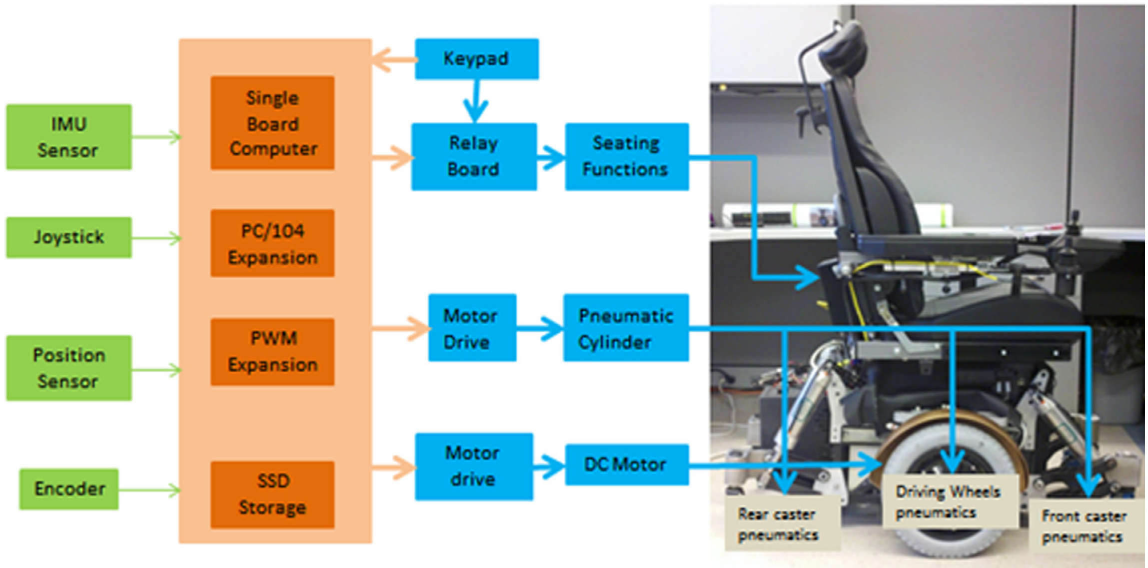

Fig. 1. Electronics diagram of the MEBot wheelchair.

is another EPW that uses two arm actuators to control the elevation of the rear/front caster wheels. The large dimension of the RT-Mover allows the robot to overcome obstacles as well as to pivot the wheel linkage to preserve seat orientation up to 30°. These recent improvements in mobility applications among robotic wheelchairs have provided possible solutions for better maneuverability in uneven terrains. However, these EPWs have limited capability in accommodating the physical impairments and mobility goals of EPW users for everyday use, such as powered seating functions and alternative controls.

The Mobility Enhancement RoBot (MEBot) was designed to address the limitations in wheelchair design and provide better maneuverability in outdoor terrains. MEBot is a novel EPW that utilizes a dual system of electric and pneumatic actuators to maintain the seat orientation, aimed to reduce the risk of tips and falls. A simulation based testing of the seat orientation controller showed MEBot maintained its orientation when driving up-down hills (pitch angle) or cross-slopes (roll angle) independently without a payload [13]. In this paper we describe the implementation and experimental assessment of the controller that addresses simple as well as compound angles and compensate for user's center of mass. A general account of the components and kinematics of the MEBot wheelchair is provided in Section 2.1, followed by the description of the orientation stabilization divided into lower and higher level control in Section 2.2. Section 2.3 presents the test methods and Section 3 presents the results of the controller at different ground angles.

2. Methods

2.1. Description of the MEBot wheelchair

MEBot is a novel robotic EPW comprised of a six-wheel design and an EPW seating system with powered seat functions. The characteristics of MEBot are shown in Table 1. The front and rear wheel casters are controlled via four independent pneumatic actuators, mounted to the main frame using a four-bar linkage to follow vertical movement. Hub-motor powered wheels are mounted to the frame via a vertical-horizontal sliding platform, which allows the drive wheels to be moved fore/aft the frame and up/down independently with air spring actuators [13]. Pneumatic actuators are supplied by an air source through an air manifold. The electronic

Table 1
Characteristics of MEBot.

Parameters	Values
MEBot length	125.7 cm
Wheel-to-wheel width	66.0 cm
MEBot mass (without payload)	165.5 kg
Wheels vertical movement	7.1 cm
Driving wheel horizontal movement	20.3 cm
Maximum velocity	7.2 km/h (2.0 m/s)
Maximum payload	113.0 kg

design of the MEBot wheelchair includes an EBX-COBRA embedded computer (Versalogic Co, USA); two 50A20DD motor drivers (Advanced Motion Controls, USA); a PC/104 PWM board to control the speed and direction of the pneumatic actuators; and position sensors in each pneumatic actuator, including a gyroscope and accelerometer combined to detect the pitch, roll, and yaw angle change in the seat (Fig. 1).

2.2. Seat orientation controller design

The active seat orientation control is divided into two components. The higher level control uses an Inertial Measurement Unit (IMU) to determine the pitch/roll angles of the MEBot's seat. These data are used with an internal mathematical model to determine the desired instantaneous position of each pneumatic actuator to maintain seat orientation. The model reference position is used in a closed-loop low level proportional-derivative (P-D) control for position regulation of each pneumatic actuator. The model then updates based upon the IMU data. Both levels of the seat orientation controller are sampled every 1.0 ms.

2.2.1. Higher level control

The IMU detects the angle change in the seat while position sensors detect the actual position of each pneumatic actuator. This section describes the use of the IMU sensor to obtain the desired position of the frame height to compare it with the actual position of the frame height calculated by the position sensors.

Frame height calculation using IMU (desired position): The IMU sensor ONI-23503 is composed of an accelerometer and gyroscope with a range of +/− 2.0 g and +/− 150°/s respectively. In order