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Conceptual Project of a Servo-Controlled Power-Assisted Wheelchair*

Fausto O. Medola, Benedito M. Purquerio, Valeria M.C. Elui, Carlos A. Fortulan

Abstract— **Manual and powered wheelchairs have been widely used as assistive technologies to improve users' mobility. However, both types of wheelchairs have problems that limit the users' ability in moving independently, thus impacting social participation, health and quality of life. This paper report on the conceptual development of a manual wheelchair equipped with a servo-controlled power-assisted system. The development process comprised the design of a wheelchair frame properly designed to receive the components of the power-assistance system; the measurement and integrated processing (with an onboard computer) of the user's forces applied to the handrim and rear wheels angular velocity. The integrated processing of these data generates an order to the motor driver, according to an algorithm of conditions that specifies the state (activation or deactivation) and magnitude of operation of the servo-motor. The output torque of the servo-motor (located below the seat and between the rear wheels) is distributed to both rear wheels via mechanical differential, thus allowing similar drivability to a standard manual wheelchair. The implementation of the innovative and ergonomic characteristics of the servo-controlled power-assisted wheelchair may improve users' ability to move longer and with comfort and safety, thus benefiting social participation and quality of life.**

I. INTRODUCTION

Wheelchairs are widely used as assistive technologies aimed to promote independent mobility and improve users' social participation. However, propelling manual wheelchairs is a very extenuating and inefficient mode of ambulation [1], which may be related to a very curious and controversial finding: many users referred that the wheelchair is the main factor limiting their community participation [2]. Improving wheelchair mobility may benefit users' independence and quality of life and, to do so, both scientific and technological advances must be targeted by an interdisciplinary point of view between health sciences and engineering.

From the users' perspective, the two most common types of wheelchair – manual and powered – do not provide full independence in locomotion. Quantifying daily mobility evidences the gap between normal gait and wheeled mobility: while walkers move a mean of 6 to 7.5 km a day [3], wheelchair users move only 1.5 to 2.5 km [4, 5]. These findings suggest that the wheelchair, even being an assistive device, plays an important role on users' mobility limitation.

Manual propulsion, the most common mode of operating a wheelchair, is characterized by the combination of loads and repetition [6]. As a result, long term use of manual wheelchairs has been related to the high incidence of upper limb injuries [7, 8]. Due to the high demand on upper limbs, many mobility situations become difficult or even impossible for the users to perform, such as moving on uneven terrains, ramps, uphill and long distance displacements. On the other hand, motorized wheelchairs, the immediate solution for most of the problems associated to manual propelled chairs, have limitations that, ultimately, do not fully benefit users' mobility. Indeed, the daily distance traveled of power-wheelchair users is similar to those who move with manual wheelchairs [9]. Furthermore, motorized chairs expose the user to a passive condition in his/her locomotion, which is important to consider since inactivity may contribute to obesity and cardiovascular problems. Other aspects such as total mass, cost, battery autonomy and maintenance contribute to the limited acceptance of power-wheelchairs among users.

In an attempt to improve users' mobility, alternative devices were developed based on hybrid systems, whose concept is based on the association of motorized assistance complementary to manual propulsion, with the objective of minimizing the users' workload during locomotion and keeping the manual propulsion as the mode of operation. The assisted propulsion systems currently available are based on a sensing and motorizing system for each of the two rear wheels [10-12]. In commercially available power-assisted wheelchairs, the two motors are coupled to the respective wheels hub and supplied by a single battery attached to the frame of the chair. In general, these systems increase from 15 to 24 kg in the mass of manual chairs, a significant increase considering the weight of most manual wheelchairs ranging from 12 to 17 kg.

Previous studies have shown the benefits of motorized assistance for manual wheelchairs. From the perspective of functionality, the use of assisted propulsion systems improved the mobility of tetraplegic subjects on ramps, uneven terrain and carpeted surfaces [13]. The benefits for

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Fausto Orsi Medola is with the Department of Design and the Programme of Post-graduation in Design, Faculty of Architecture, Arts and Communication, UNESP – Univ. Estadual Paulista, Bauru, SP, Brazil. (phone: 55-14-3103-6062; e-mail: fausto.medola@faac.unesp.br).

Benedito M Purquerio and Carlos A. Fortulan is with the Department of Mechanical Engineering, University of Sao Paulo, Sao Carlos, SP, Brazil (e-mail: purqerio@sc.usp.br).

Valeria Meirelles Carril Elui is with the Department of Neuroscience and Behavioural Sciences, Faculty of Medicine of Ribeirao Preto, University of Sao Paulo, Brazil. (e-mail: velui@fmrp.usp.br) and Programme of Post-graduation Interunits in Bioengineering, University of Sao Paulo, Sao Carlos, Brazil.

tetraplegic subjects also comprise the reduction on energy expenditure, propulsion frequency and upper limbs range of motion [14]. For users with upper limbs symptoms, the use of power-assisted systems proved to be beneficial, with decreased energy expenditure and perceived exertion, as well as significant increase in distance travelled [15]. In addition, Arva et al. [16] demonstrated that power-assisted wheelchairs provide greater mechanical efficiency and lower energy consumption compared to manual equipment.

Despite the above mentioned benefits, power-assisted systems are still not widely used among wheelchair users. Possibly, the main limitation of these devices is related to the difficulty in performing maneuvers in areas locals of reduced space [12]. Once each rear wheel is independently motorized, applying asymmetric forces on the handrims – commonly used to move on curves, turn the chair and perform short displacement maneuvers - result in asymmetric amplification of the torques on the wheels, thus altering the turn radius from the primarily intended by the user. From this perspective, power-assisted systems work satisfactorily only when moving straight or the trajectory is not constantly changed, which does not represent how people move with wheelchairs in their daily routines.

This way, although the biomechanical benefits have been demonstrated, up to date, the use of power-assisted wheelchairs does not find definitive support for unequivocal prescription. Furthermore, the independent motorization for each rear wheel represents an increase in system's cost, weight and complexity. This study aims to present a proposal for a conceptual project of an intelligent power-assisted system for manual wheelchairs. Scientific and technological challenges inherent to this project involve the development of mechanical and electronic solutions for sensoring the handrim forces, motorizing and transmission of torque to the rear wheels, in order to provide optimal propulsion assistance and similar drivability to manual wheelchairs.

II. Experimental Procedure

The current study was carried out in the Laboratory of Tribology and Composites (LTC) at School of Engineering of Sao Carlos, University of Sao Paulo. Firstly, it was designed a wheelchair with an original project in order to enable a power-assisted system to be properly installed to the wheelchair. The wheelchair was design with ergonomic characteristics, in order to provide the most appropriate conditions for a safe, comfortable and efficient use.

After designing the wheelchair, the components of the power-assisted system were defined in terms of sensoring, acquiring and processing the data from user's actions on the wheels. The most appropriate sensors for each data were then selected, and an algorithm for data processing was developed to determine the specific conditions for activating, working and deactivating the power-assisted system. Finally, it is presented the implementation of the system, that is, the prototype of the servo-controlled power-assisted wheelchair.

III. Results

The current results are consequence of a multidisciplinary approach and include issues of: ergonomic design; propulsion and assistance; algorithm for data processing and power-assistance; and a build of a prototype to qualitative evaluation.

A. Equipment Design

An original project of wheelchair frame and wheels was designed, in order to receive the components of the power-assistance system. Ergonomic features were applied on the design of the handrim interface: an improved hand-to-rim coupling was provided by a handrim with greater surface and anatomical shape for hand's contact. The handrim was connected asymmetrically to the wheel hub, resulting in more space between the wheel (with camber) and the vertical (orthogonal) handrim, as shown in Figure 1. Besides protecting the hands against traumas with the wheels, this increased space allows the user to push the handrim in variable grip positions, thus benefiting propulsion comfort and safety. Because the handrim and the wheel are connected asymmetrically, the handrim forces are transmitted to the wheels by drag pins connecting the inner face of the handrim to the outer face of the wheel.

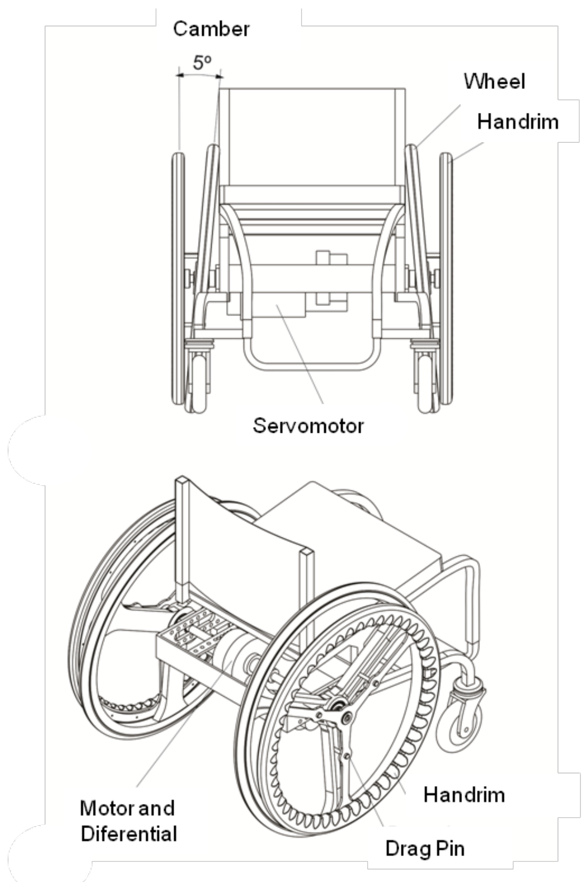


Figure 1. Schematic drawing of assistive wheelchair: front view (above) and isometric rear view (below).

The power-assisted system comprised a servo-motor (EC45 Maxon Motor, brushless, 250 Watt, planetary

Gearhead GP62A and Driver 4-Q-EC Amplifier DEC 70/10). The output torque of the servo motor was distributed to the rear wheels through a mechanical differential system. The components of the motor system were positioned inside a box – here called motor box – positioned in the center of the wheelchair, under the seat. This is an important feature that distinguishes this prototype from the current commercially available power-assisted chairs, because most of the added mass is located in a centered position of the system (between the rear wheels) and, therefore, close to the wheelchair center of mass. Theoretically, it minimizes the effect of the added mass on the wheelchair rotational inertia [17], thus ensuring similar drivability to conventional manual wheelchairs.

B. *Propulsion and assistance*

During manual propulsion, the system recognizes the user's intention to move and provides complementary power proportional to the handrim forces. To combine the manual force with the torque provided by the motor under a certain condition of locomotion, three types of information were used: (i) user's forces on the handrim, measured with strain gauges; (ii) rear wheels rotation, measured with optical encoders; and (iii) slope of the terrain, measured with a triaxial accelerometer. A scheme of the position of the force sensors is presented in Figure 2. To process and use these data during real time propulsion, a data acquisition system collect (DAQ NI USB 6009®, National Instruments) and processes it (with a program develop in Labview®, National Instruments) onboard (with a portable computer with Windows Operational System). Figure 3 shows a scheme of the electric power supply and system's operation.

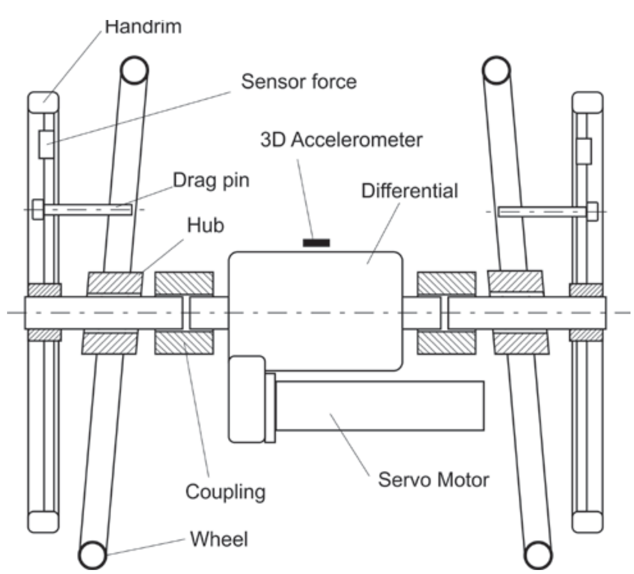


Figure 2. Acquisition of force and motor system scheme.

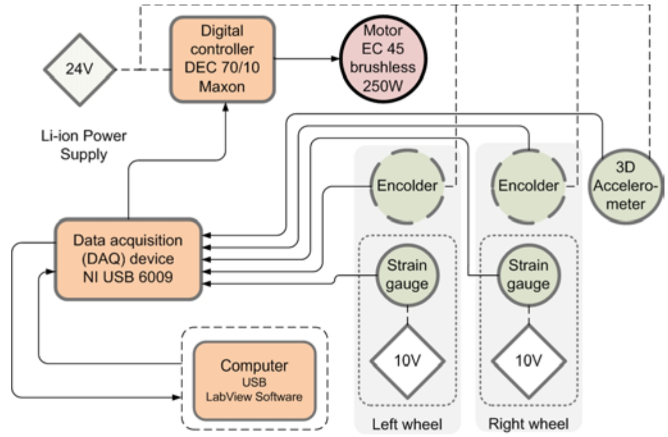


Figure 3. Electric power supply and system's operation.

C. *Algorithm for the Power-Assistance System*

In order to properly match the power-assistance to user's needs and intention to move, an algorithm of conditions and actions was developed (Figure 4). To activate the assistance system, the most important answer to respond is:"Does the user want to move?" Two conditions need to be satisfied in order to activate the system: (i) a second push; and (ii) a minimal wheel angular rotation of 180°. If these two conditions happen simultaneously, then the motor is activated with a certain torque (T1) and velocity (V1, wheel rotation), both dependent on and proportional to the measured handrim force and rear wheels angular rotation. To maintain the motor assistance, another force must be applied on the handrim before the wheels stop moving. If this force (F2) is of similar strength to F1, then both torque and velocity are kept the same as T1 and V1. On the other hand, forces of greater or lesser strength activate mode of acceleration or deceleration, respectively. The deactivation of the power-assistance is triggered if two applied forces of lesser strength are measured consecutively or no push is detected after a decrease in the measured force.

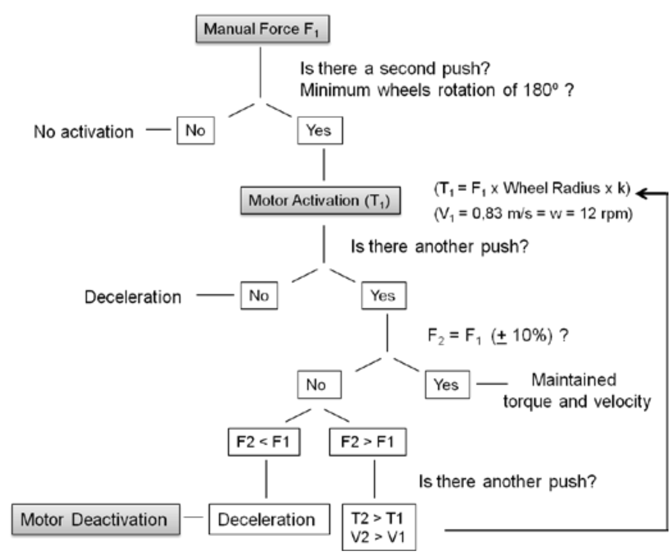
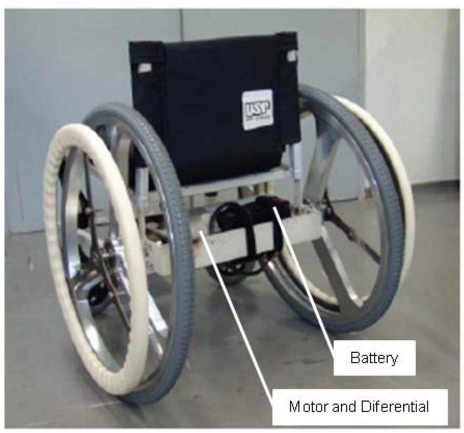


Figure 4. Algorithm for the activation and deactivation of the power-assistance.

D. Prototype of the Servo-Controlled Power-Assisted Wheelchair

The development of the wheelchair prototype comprised: the design and production of an original wheelchair frame; design and production of a pair of rear wheels with original designed wheel hub; a pair of two ergonomic handrims; a pair of two commercially available casters. All these components were mounted as a wheelchair prototype, and then instrumented with the power-assistance system, as shown in Figure 5.

(a)



(b)

(c)

Figure 5. Prototype of the servo-controlled power-assisted wheelchair: (a) isometric front view; (b) isometric rear view; (c) user and chair interaction.

IV. CONCLUSION

This paper reported on the conceptual project of a servo-controlled power-assisted wheelchair. The system comprised a number of technologies applied for: sensoring and processing real-time measurements of handrim forces, wheel rotation velocity and slope terrain; controlling of a single motor and transmission of torque and velocity to the rear wheels through a mechanical differential system. Furthermore, the wheelchair prototype was designed with ergonomic features in the handrim interface, in order to provide a stable, safe and comfortable grip when pushing the handrims. The preliminary tests showed promising results in terms of power-assisted system and mechanical operation. The system configuration is currently being adjusted to improve its operation. Future tests will investigate propulsion biomechanics, wheelchair drivability and users' perception on the servo-controlled power-assisted wheelchair.

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