Electric Wheelchair Module: Converting a Mechanical to an Electric Wheelchair

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Abstract—There is a growing need for transportation, either inside a house or office, as well as in the streets and other public spaces. This constant need is a disadvantage for anyone with some kind of disability, specially those that suffer motor disabilities. Electric wheelchairs are part of the technological solutions to this demand. However, their cost are very high in constrast to mechanical wheelchairs. In that sense, this paper aims to present a new module device that can be used for converting a mechanical wheelchair to an electrical one. The proposed device was designed for simplicity in installation, high benefit-cost ratio and easiness in control movement. Preliminary results showed the implementation of the proposal in a functional prototype.

Keywords-mechatronics; mobility; wheelchair; intelligent control; electronics

I. INTRODUCTION

Globally, there is a growing need for transportation, either inside a house or office, as well as in the streets and other public spaces. This constant need is a disadvantage for anyone with some kind of disability, which forces them to stay in a wheelchair and depend on people for mobility. Only in Mexico, the 5.13% of the population suffers of motor disabilities [1]. This is equivalent to more than 573, 000 people that use a device that allows them to accomplish their daily activities. As a consequence, they need to use any kind of wheelchairs.

For instance, the average price of an electric wheelchair in Latin America starts at 1, 200 USD and can go all the way up to 11, 600 USD depending on models and characteristics. On the other hand, a mechanical wheelchair costs vary from 60 to 220 USD. In Mexico, poverty only intensifies this problem since more than 70% of people earn in average 720 USD monthly, as evaluated by the National Institute of Statistics and Geography (INEGI) [5]. Because of this, acquiring an electrical wheelchair is inconceivable for most people in the region. Moreover, the amount of people suffering a disability attached to the high prices of autonomous mobility devices, prevents many people from living their lives much more naturally. This becomes much more apparent in different social studies that show how people with disabilities think their daily social activities cannot be fully developed [9]. Additionally, wheelchairs have always been a matter of interest in these studies that ranges from the usage to the interaction with them on a daily basis [8]. Particularly to electric wheelchairs, a study revealed a very large satisfaction rate among the users [8]. But the most criticized criteria was the weight of the chair [6]. Thus, there is the need for a wheelchair that not just provides mobility, like conventional wheelchairs, but one that empowers people to move freely on an autonomous way.

In that sense, this paper aims to present a new modular device that can be used for converting a mechanical wheelchair to an electrical one, in a third of the average cost of an actual electric wheelchair. The proposed device is a modular system that can be placed easily on most commercial mechanical wheelchairs. By adapting this module, users acquire electrical wheelchair characteristics on their standard chairs. Also, it is proposed to be controlled by the user with a joystick or a similar tracking-control system, allowing to move the chair in any direction. To this end, the module is also provided with rechargeable batteries. Experimental results present preliminary tests about the performance of the proposal implementation in a functional prototype, for ongoing research.

The key contribution of this electric wheelchair module can be summarized as: (i) the modular device for converting standard mechanical wheelchairs to electric wheelchairs, (ii) simple installation process of the device, (iii) high benefit-cost ratio, and (iv) the ease of movement. To this end, the proposal improves independent mobility and increases satisfaction of users that require wheelchairs.

The rest of the paper is organized as follows. Section II describes the related work about wheelchair devices. In Section III, we describe our proposal in detail. Section IV is dedicated to experimental results on the functional prototype implementation. Finally, we provide conclusions and future work about our proposal in Section V.

II. RELATED WORK

Different electric wheelchairs and devices have been proposed. For example, designed by ten students from the Swiss Federal Institute of Technology [3], Scalevo (now called Scewo) is an electrical wheelchair able to climb stairs. Moving on the ground is accomplished with a Segway-like system by balancing on the two main wheels. The stairs are climbed using two rubber tracks mounted on the bottom of the chair. This design not only allows the user to move

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around on the ground but also climbing up and down the stairs, which gives the user a better sense of autonomy by not depending on someone else to use the stairs. This chair also gives great stability on both kinds of movements without eliminating agility. As a limitation, this wheelchair cannot be adapted to the users' needs.

Another proposed wheelchair was designed by S. Sugi [4]. Whill is a revolutionary design of new electrical chairs with new specifications and better innovations, such as the inclusion of a mouse controller, instead of a joystick. Also, the front wheels are multi-directional, giving advantage of a 4-wheel driving chair that can go through grass, snow and rough surfaces.

Designed by J. H. Lee from Yanko Design [2], News is a table-like model device that locks on the wheels of a chair and goes over the lap of the user. This module is supposed to stay static on a charging base. The device works with two motors and it is driven with a joystick. This module provides two major advantages. First, it has lights and light indicators so the user can drive safely at night. The second one considers the height of the module height to be adaptable for every user, placing the control panel higher or lower. Since the module is rigid and very large –although it can be used in a wide range of chairs–, it is not at all flexible for transportation. It is big and heavy, making the transportation of the module with the chair fairly complicated.

In contrast, our proposal emphasizes to be modular and low-cost for attaching to conventional wheelchairs. Simple installation is a key feature, as well as the automation. In the next section, a detailed description of our proposal is presented.

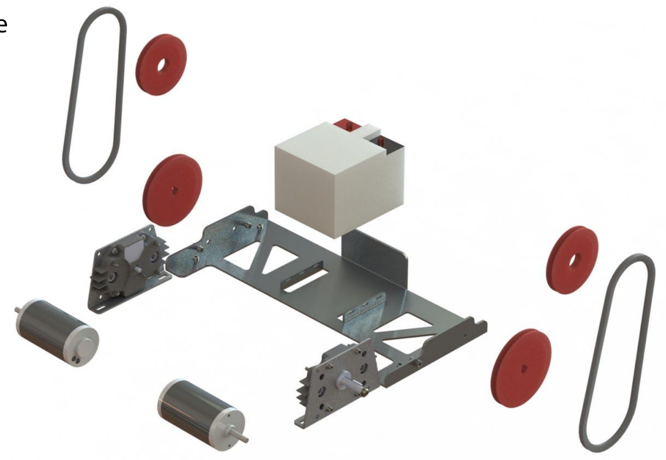

Figure 1. Explosive view of the proposed electric module. Joystick is not included in the image.

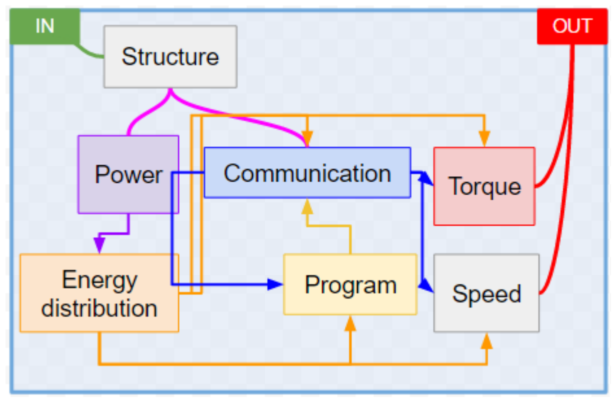

Figure 2. Block diagram of the functionality of the proposed module. Inputs and outputs are also considered.

III. Description of the Proposal

In this section, we describe our proposed adaptable module device for a conventional wheelchair that converts it to an electric wheelchair.

In order to control the movement of the wheelchair, the module has a joystick as a human interface. It has to be mounted on the armrest of the wheelchair. To power the module, a 12V battery is fixed into the device. This battery has 18Ah to ensure autonomy for a day. In addition, the unit processing system is fixed to the module inside a box. This box simplifies mobility and provides protection to the controller and other electronic components. The proposed module runs on two direct current (DC) motors, 12V each, that operate at a standard maximum efficiency at 32A. These motors are isolated and have no vents to guarantee full functionality even when facing environmental conditions. A series of mechanisms and bands are attached to the axle of the motors to ensure movility to the wheels. Figure 1 shows an explosive view of the proposed module. Functional relations among the proposed module are shown in Figure 2 as block diagram.

For installation purposes, the wheelchair needs adjusting the pulleys to the wheels. In fact, this is the only mechanical modification required, keeping the installation process simple and adequated for almost every standard geometry of mechanical wheelchairs.

A. Mechanics Components

The key components of the module are the following: joystick, battery, transmission belts and motors, and chassis. The joystick has to be placed on the armrest of the chair to which the system engages. The chassis is made up of a lightweight material. This frame serves as a support for all the components, as well as serving as a mechanical attachment to the frame of the wheelchair. This module-frame was designed considering the general dimensions of a standard wheelchair. The battery is at the center of the chassis without modifying the center of gravity. Transmission belts and motors are coupled for transmit movement to the wheels.

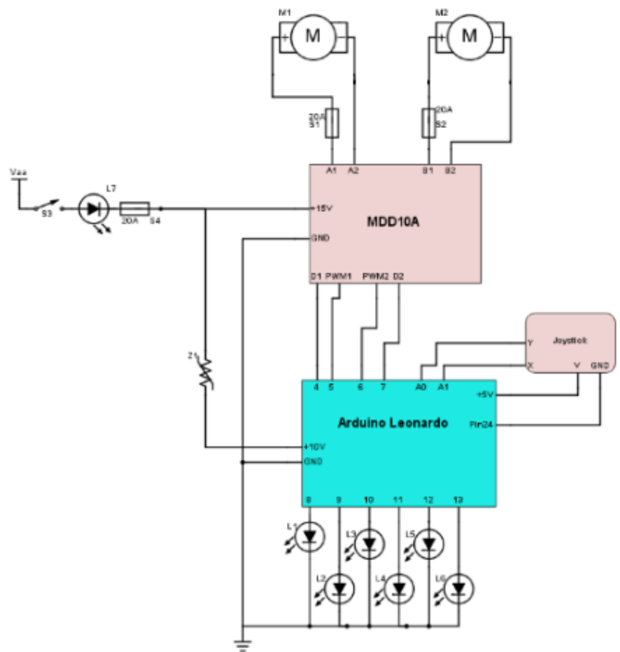

Figure 3. Schematic of the proposed module.

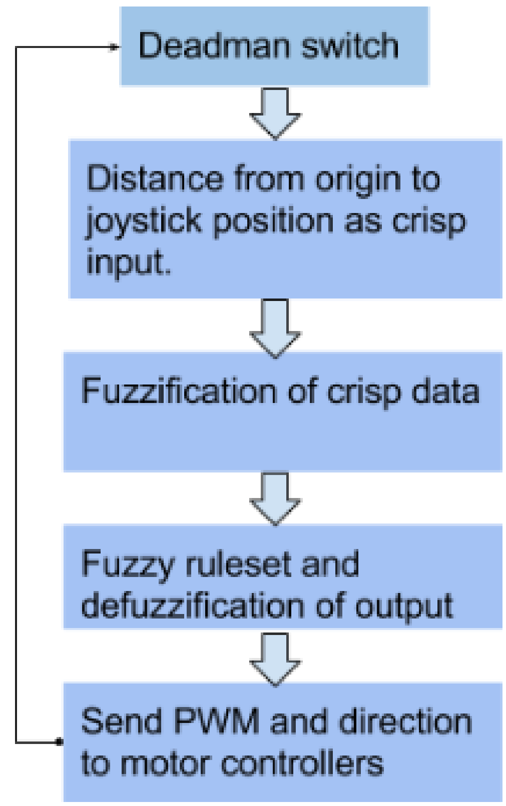

Figure 4. Flow diagram of the intelligent control system for speed regulation of the wheelchair.

B. Electrical Subsystem

For the electric circuit design, we used an Arduino-compatible motor controller (MDD10A) that supports two 12V DC motors and operates at 10A with maximum peaks of 80A. A pulse-width modulation (PWM) technique is used to control velocity in motors. This motor controller allows the system to regulate the current allowed to the motors, thus enabling a smooth control of the wheelchair movement.

C. Intelligent Control System

For the control system, input and output regulation and processing is computed by a Leonardo Arduino microcontroller. The input of the system is the joystick which delivers voltage values corresponding to the X and Y axes. These inputs are processed by the Arduino with an intelligent fuzzy controller [7] which returns a vector data that determines the duty cycle of the PWM signal. For human related movement, which it tends to be analog and diverse, fuzzy-logic based controllers are widely used. For example, literature reports an intelligent stabilizer for a seat in the wheelchair [7], [10]. Figure 3 shows the electric diagram of the proposed module. In particular, we implemented a fuzzy controller for speed regulation. This controller takes into account the relative distance of the joystick position to the origin. Then, it decides the PWM value that have to be sent to the motors, according to a set of rules. In terms ofimplementation issues, this control method is easy to program, precise and robust. Figure 4 shows the flow diagram of the intelligent controller implemented in the module.

IV. Preliminary Results

In this section, we describe preliminary results of the proposed module in terms of the implementability of the design in a functional prototype and a qualitative analysis of the performance.

The functional prototype of the module considered to built a rapid model for observing the main functionality of the proposal. For instance, the frame was made of medium density fibreboard (MDF) material. Two 12V DC motors were mounted in the frame, as well as a MDF-based box for the electronics components. A 12V / 18Ah rechargable battery was fixed on the frame too. Transmission belts were coupled to the wheelchair by disassembling the wheels. To this end, the proposed module was placed in a standard wheelchair as shown in Figure 5.

An Arduino Leonardo was used as the central processing unit system. Two MDD10A motor controllers were employed for controlling angular speed in motors. Additionally, a joystick was connected to the system and located in the right armrest of the wheelchair.

To this end, the fuzzy controller described above was implemented in Arduino using the embedded Fuzzy Logic Library (eFLL) [11]. Figure 6 and Figure 7 show the input

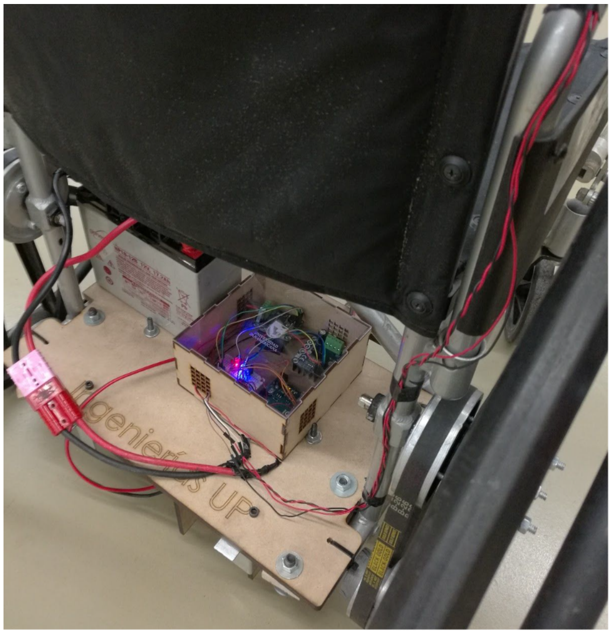

Figure 5. Implementation of the proposed module in a functional prototype on a standard wheelchair.

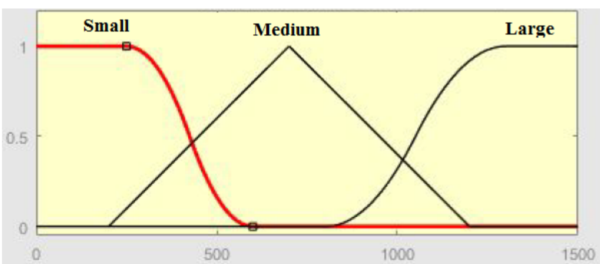

Figure 6. Input membership functions representing the displacement distance of the joystick from the origin.

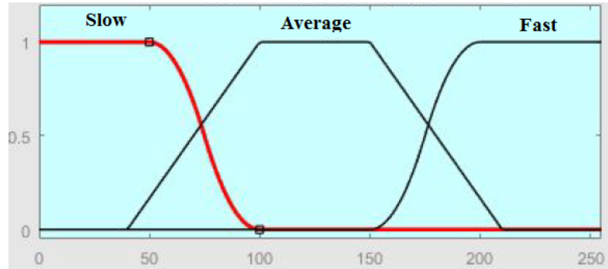

Figure 7. Output membership functions representing the angular speed based on the duty cycle of the PWM supplied to the motor.

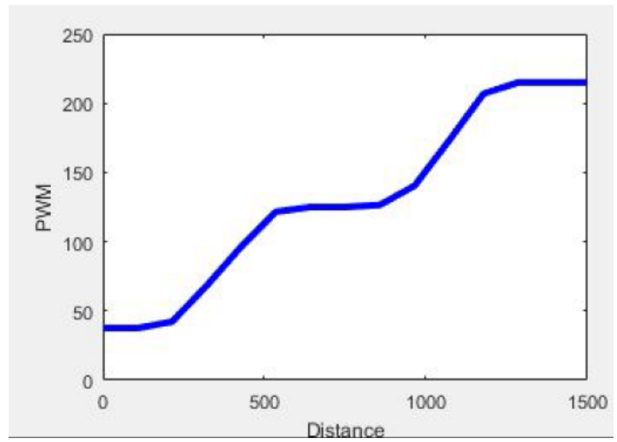

Figure 8. Surface response of the controller.

and output membership functions of the proposed controller, respectively. Currently, the input considers the displacement distance of the joystick from the origin partitioned insmall, mediumand large. The output represents the duty cycle of the PWM supplied to a motor to control the angular speed: slow, average and fast. Angular direction was computed crisp corresponding to the actual direction of the joystick. Table I summarizes the fuzzy rules. To this end, Figure 8 shows the surface response of the controller.

Until now, qualitative analysis has been done aiming to determine if the main functionality of the module has been reached. For instance, we tested that all the components in the module ensure functionality, that the intelligent controller responses and that the wheelchair moves freely with a user seated.

Table I
FUZZY RULES OF THE PROPOSED CONTROLLER .

distance	angular speed
small	slow
medium	average
large	fast

Particularly to the first test, the experiment was focused on the movement and direction of each motor, and the energy distribution. Every preliminary test performed in this stage was a success, the inputs by the joystick were read properly, the speed of the wheelchair was according to the user's inputs (i.e. the user was not seated on the wheelchair) and the chair was simple to operate. It is important to note that during the test there was no significant temperature increase in neither the motors or motor controllers. In terms of the overall controller responsiveness, it presented negligible input lag or latency and the speed control was accurate.

However, when the user was seated on the chair, the performance was poor. The pulley train was not capable of delivering enough torque to move correctly, and each movement became increasingly slower. The proposed module was subjected to meticulous inspection, revealing that the bands strained on the opposite side when the motors started running. It causes an increasing load on the motor thus making the operation much more difficult as even if the motor demands more current, it is unable of delivering that amount of torque. Also, we perceived a dramatic increase in temperature in the motors and their respective controllers. Thus, an integration of gearboxes in both motors will be implemented on future redesign.

To this end, the total cost of the functional prototype was 330 USD, representing 27.5% of the cheapest electric wheelchair price in Latin America [1], concluding that this module would improve the accessibility of electric wheelchairs in the region.

V. Conclusions and Future Work

This paper presented a new modular device that can be used for converting a mechanical wheelchair to an electrical one, in a third of the average cost of an actual electric wheelchair. As shown, the proposed module was successfully implemented in a functional prototype. However, improvements in the design should be taken into account.

It is important to point out the impact involving the necessity of projects and innovations for people with some kind of disability such as motor disabilities.

Future work includes the ability to bend the module together with the wheelchair and a more accurate and finer steering control and implementation of gearboxes for improving torque in motors. In fact, these improvements will help portability, handling and practicality of the proposed module device.

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