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Electronic system teleoperated by mobile application for the control of an omnidirectional wheelchair[1]

Sistema electrónico teleoperado por aplicación móvil para el control de una silla de ruedas omnidireccional

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***Abstract*—People who use wheelchairs as a displacement device due to their mobility limitations are repeatedly restricted by architectural and social factors. It is necessary to grant users greater autonomy and independence and the news developments in technological devices as an alternative to improve their lives. The project was executed in three phases. In the first phase, a study was made of the state of the art of omnidirectional platforms and their mathematical modeling by means of the kinematic equations of an omnidirectional mobile platform; in the second phase, the electronic system was designed and developed, finally in the third phase it covers programming, development and remote interaction between a mobile application with the wheelchair. An electronic system is developed for the remote control of an omnidirectional platform adaptable to a wheelchair to grant it holonomic movements.**

Keywords—Mathematical model, mobile application, omnidirectional mobile platform, remote control, wheelchairs.

***Resumen*—Las personas que utilizan sillas de ruedas como medio de desplazamiento debido a sus limitaciones de movilidad, en varias ocasiones están restringidos por factores arquitectónicos y sociales. Es necesario otorgar a estos usuarios una mayor autonomía e independencia, siendo los nuevos desarrollos de dispositivos tecnológicos una alternativa para mejorar sus vidas. El proyecto se abordó en tres fases, en la primera fase se realizó un estudio del estado del arte de las plataformas omnidireccionales y de su modelado matemático por medio de las ecuaciones cinemáticas de una plataforma móvil omnidireccional, en la segunda fase se diseña y construye el sistema electrónico, finalmente en la tercera fase se abarca la programación, desarrollo e interacción remota entre un aplicativo móvil con la silla de ruedas. Se desarrollo un sistema electrónico para el control remoto de una plataforma omnidireccional el cual es adaptable a una silla de ruedas con el fin de otorgarle desplazamientos holónomos.**

***Palabras clave*—Aplicación móvil, control remoto, modelo matemático, plataforma móvil omnidireccional, silla de ruedas.**

I. INTRODUCTION

THE wheelchair as a means of displacement must allow the user clean, comfortable, and innovative mobility, needs that are not covered by most conventional vehicles on the market; therefore, in recent years, electromechanical devices have been developed that provide better mobility, allowing greater autonomy for users when moving, helping them to overcome the different limitations of certain activities due to architectural or urban factors that hinder and impede mobility, such as the type of floor, presence of unevenness, accessibility and movement through reduced spaces, transportation of objects, among others [1]. Another factor to consider is the type of mobility possibilities in users according to their physical limitations; while some users can use their upper limbs, others will not.

Currently, there are electronic and mechanical developments that have allowed the inclusion of people who must use a wheelchair; in [2] the development of a prototype of a voice-controlled wheelchair is described; in [3] the voice control system and identification of obstacles by means of ultrasound sensors are included, in [4] a control system is used to allow autonomous movements through voice commands and with the incorporation of a system that is responsible for

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[1] Producto derivado del proyecto de investigación “Diseño y construcción de un sistema de control manejado de forma remota, adaptable a una silla de ruedas con movimiento omnidireccional, dirigida a niños con capacidad de movilidad en sus extremidades superiores”, apoyado por la Universidad Industrial de Santander (UIS) a través del programa de ingeniería electrónica y cómo parte de la extensión del proyecto de investigación 5598 del programa UIS Ingenium.

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reconstructing a model of the environment to avoid obstacles. In [5] the possibility of controlling a wheelchair by voice commands and by means of a system joystick is integrated. In [6] and in [7] systems that allow control through cerebral orders are exposed. Another type of movement enabler is the eyes and eyelids, as shown in [8], whereby blinking a defined number of times the chair can move, and in [9], through eye movement the chair can scroll in multiple directions. The previously included developments of voice control, eye movement, blinking, and brain waves are especially directed at a population that lacks mobility in their upper and lower extremities.

Another way of giving users well-being is to modernize wheelchair control systems with the integration of a teleoperated system, as shown in [10] and in [11], where developed a mobile application that allows communication between the user and the chair by Bluetooth technology, or in [12] where a mobile application with WIFI communication between the user and the wheelchair is developed, allowing users to operate their chairs remotely. In [13], a project is shown that covers the mechanical, electronic, and software development system to obtain an omnidirectional configuration with Mecanum wheels that performs frontal, lateral, and diagonal displacements and turns on its own axis. In [14] and [15], the control by means of a joystick system of an omnidirectional base and of a wheelchair, respectively. In [16], a wheelchair controlled by a joystick system with omnidirectional movement and the possibility of climbing steps was developed.

There are various electronic and mechanical configuration possibilities that allow for notable improvements in wheelchair applications and design. This project is based on the electronic design exposed in [17] and it covers the design and implementation of an electronic system that allows the remote control of an omnidirectional platform adaptable to a wheelchair by Bluetooth and WIFI technologies through a mobile application. This development is aimed at people who use wheelchairs and have mobility in their upper extremities because the control of displacements is done by touch through a mobile application.

II. METHODOLOGY

The methodology used in this project consists of three states, as seen in Fig. 1. In the first phase (Omnidirectional Systems) a study was carried out on the operation of omnidirectional platforms and mathematical modeling using kinematic equations; in the second phase (design of the electronic system) covers the structure and arrangement of the electronic system and its interaction with the electronics devices and with actuators and sensors; in the third phase (programming of the control system and mobile application) covers the programming, the development and the remote interaction between a mobile application with the electronic system.

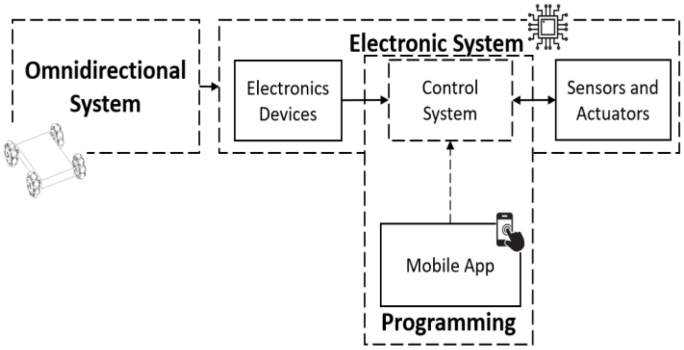

Fig. 1. Methodology implemented in the project.

The description of the phases taken is shown below:

A. *Omnidirectional Systems*

The term omnidirectional is used to describe the ability of a system to move in any direction, depending on the configuration used in the displacement system. Omnidirectional platforms are known as holonomic systems because they allow displacements to be obtained in all directions of a plane, unlike non-holonomic systems such as conventional displacement platforms. Depending on the type of wheel used, it is possible to obtain more compact designs with high load capacity and robustness [18]. Among the range of possibilities, there are the configuration with "Omni wheel" wheels; these wheels are able to roll forward, back and side due to the presence of small wheels with rotating axles parallel to the plane of the wheel disk [19]. The “omni-ball” wheels are composed of the union of two passive rotating hemispherical wheels and an active rotating axle [20]. With the wheels called “MY wheel” a mutual passive movement of two balls cut in the same active axis is generated [21]. The Mecanum omnidirectional wheels are based on the principle of a central wheel with several rollers placed at its periphery at a strategic angle [22]. Depending on the direction and speed of each wheel individually, a total force vector is obtained; therefore, the platform can move freely in any direction of the resulting force vector while maintaining the position of the wheels [23].

In this project, the omnidirectional displacement system implemented by a Mecanum wheeled platform is implemented; for this configuration, there are 4 wheels with orientation according to Fig. 2, where depending on the result of the combination of forces from the turns and speeds exerted by each wheel can be obtained a variety of displacements in any direction of the plane [24].}

Fig. 2 shows the motion vector components and the coordinate system of the mobile platform that are assimilated into a Mecanum type omnidirectional displacement system [25]. And y refers to the position of the platform, b corresponds to half the distance between the front wheels, a is half the distance between the front wheel and the rear wheel, and R indicates the radius of the wheel.

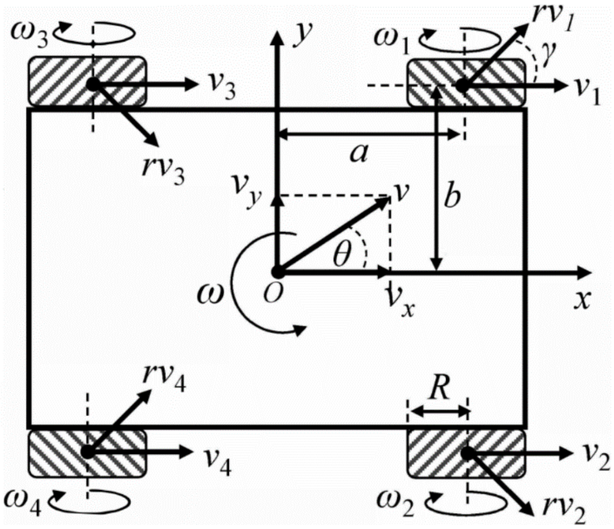

Fig. 2. Kinematics model of a mecanum wheels platform. [25].

Equations (1) to (5) describe the mathematical model of the Mecanum system; the equations are extracted from [26], where vx and vy correspond to the linear speed of the robot; ω at the angular velocity of the robot; ωi is the angular speed of the wheels with i = 1, 2, 3, 4; θ and υ is the resulting angle of displacement and the velocity of the platform with respect to the linear speed components, respectively.

$$v_x(t) = (\omega_1 + \omega_2 + \omega_3 + \omega_4) \times \frac{R}{4} \tag{1}$$

$$v_y(t) = (-\omega_1 + \omega_2 + \omega_3 - \omega_4) \times \frac{R}{4} \tag{2}$$

$$\omega_x(t) = (-\omega_1 + \omega_2 - \omega_3 + \omega_4) \times \frac{R}{4(b+a)} \tag{3}$$

$$v = \sqrt{{v_x}^2 + {v_y}^2} \tag{4}$$

$$\theta = tan^{-1}\left(\frac{v_y}{v_x}\right) \tag{5}$$

The resultant velocity and its direction in the stationery coordinate axis (x, y, z) can be achieved by (4) and (5) [26].

B. *Electronic system design*

The electronic system comprises all the hardware elements that regulate, control, act, sense, and communicate the device with the user, as shown in Fig. 3.

The electronic system has a control system that manages the input and output signals of the device to execute the correct algorithms according to the orders given by the users for interaction with the different peripherals. The control system houses the software where the programming of the control algorithm of the kinematic equations for the correct execution of the omnidirectional displacements.

For the omnidirectional platform to be able to carry out the holonomic movements, it is necessary that each wheel works independently; for this reason, four motors are available as an output system powered by two dual H-bridges. The H bridges, in addition to driving the motors, function as an isolating circuit between the low-power system, such as the control system, and the high-power system, such as the actuators.

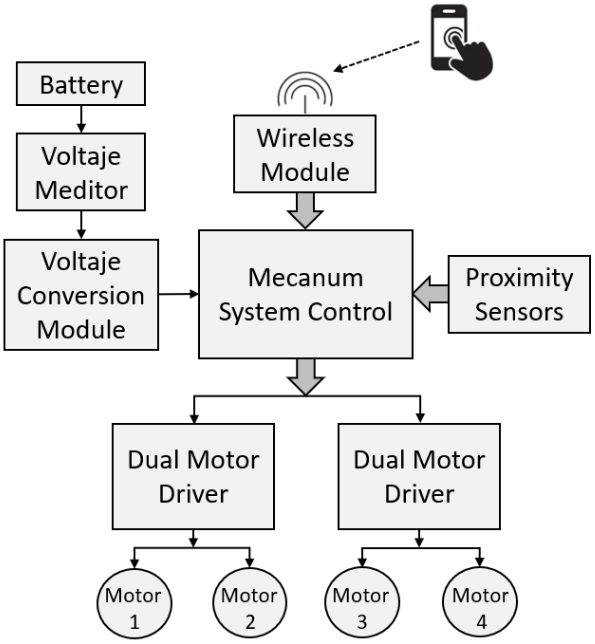

Fig. 3. Hardware structure diagram.

The hardware has a proximity sensor that allows the detection of obstacles through the emission of a sound, no audible signal. This sensor constantly feeds back to the control system and activates only when the user issues a scroll.

Two different modules are used to receive commands sent by the user through a mobile application. A Bluetooth module and a WIFI module are used; it should be noted that only one of the two must be enabled at the time of execution.

For the correct operation of the electronic system, a DC-DC voltage converter module was used which regulates and distributes the correct energy to the different elements of the circuit; this includes the sensors, actuators, control, and communication system. A 6S LIPO battery (22,2 V - 22000 mAh) is used as the power source. This supply system includes a sensor that measures the battery level to be recharged if the value decreases according to a previously defined threshold.

The design and adaptation of the omnidirectional platform was performed in a wheelchair, as shown in Fig. 4. The design of the electronic control system was located within the omnidirectional base.

C. *Programming of the control system and mobile application*

The programming algorithm is carried out in the control system, which allows the administration of all the peripherals and integration with the wireless communication systems. First, local communication tests were carried out directly and locally between the user and the wheelchair. Once the correct operation was verified of the device, a mobile application is developed to carry out the control remotely.

Fig. 4. Omnidirectional platform adapted to a wheelchair.

An Android mobile application was created to interact with the user and the wheelchair. Through this application, the displacement orders are given. The application has 10 possibilities for wheelchair movements, including clockwise and anticlockwise turns, displacement towards forward, backward, both sides and the 4 diagonals. Fig. 5 shows the mobile application developed where the 10 mentioned movements are available, a button for connection, and a slider to regulate the displacement speed up to a maximum of approximately 3,46 km/h.

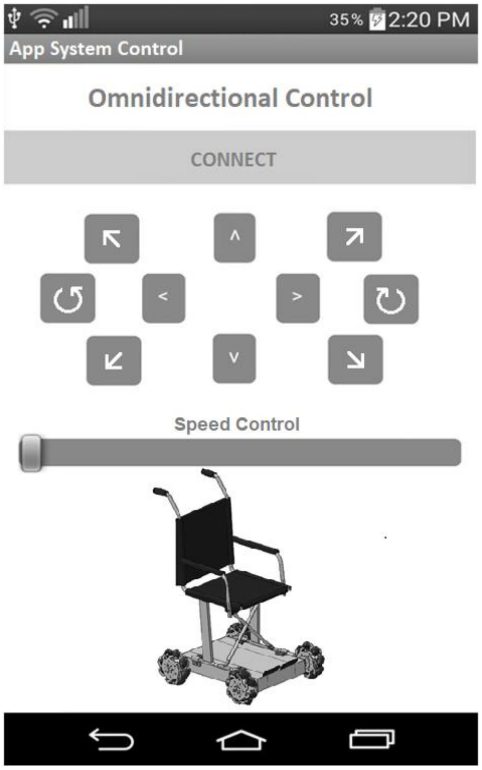

Fig. 5. Mobile application.

III. RESULTS

The multiple programmed movements in the wheelchair are validated by means of the mathematical equations of the kinetic movement of a Mecanum base of omnidirectional technology (equations 1 - 5), the value of a is 21 cm, b is 15,75 cm, and the radius of the wheel R is 7,62 cm. Table I shows the experimental results of the values of angular velocity in the wheels, the components of velocity in the x and y plane, the linear speed and angular velocity of the chair, as well as the resulting angle of displacement by the components v_x and v_y.

TABLE I
EXPERIMENTAL RESULTS.

Direction	**Wheel 1 (rad/s)**	**Wheel 2 (rad/s)**	**Wheel 3 (rad/s)**	**Wheel 4 (rad/s)**	v_x **(m/s)**	v_y **(m/s)**	v **(m/s)**	ω_x **(m/s)**	θ **(°)**
Forth	12,63	12,63	12,63	12,63	0,96	0	0,96	0	0
Back	-12,63	-12,63	-12,63	-12,63	-0,96	0	0,96	0	180
Left	-12,63	12,63	12,63	-12,63	0	0,96	0,96	0	90
Rigth	12,63	-12,63	-12,63	12,63	0	-0,96	0,96	0	-90
Left diagonal forward	0	12,63	12,63	0	0,48	0,48	0,48	0	45
Rigth diagonal forward	12,63	0	0	12,63	0,48	-0,48	0,48	0	-45
Left diagonal backward	-12,63	0	0	-12,63	-0,48	0,48	0,48	0	135
Rigth diagonal backward	0	-12,63	-12,63	0	-0,48	-0,48	0,48	0	-135
Clockwise rotation	12,63	-12,63	12,63	-12,63	0	0	0	-2,62	0
Anticlockwise rotation	-12,63	12,63	-12,63	12,63	0	0	0	2,62	0

Table I shows that according to the independent direction of rotation of each of the four wheels, the displacement desired by the user can be obtained linearly v or angularly in a direction. To make the diagonal movements, only two of the four wheels are activated; therefore, the resulting speed v is half of when the four wheels are activated. On the other hand, the component of ω_x only appears in clockwise and anticlockwise turns; however, since it is a rotation, there is no displacement v.

Table II shows the main characteristics given to a wheelchair when implementing and integrating the remotely controlled electronic system developed in this project.

TABLE II
WHEELCHAIR FEATURES.

Features	**Value**
Maximum power consumption	88,42 W
Autonomy	5,52 h
Maximum speed	3,46 km/h
Load Capacity	70 kg
Type Control	Mobile application

IV. CONCLUSIONS

An electronic system for the remote control of an omnidirectional platform adaptable to a wheelchair was developed, allowing it to obtain holonomic displacements. The control system of the device was programmed with the equations of the mathematical model of an omnidirectional

Mecanum system, and its correct operation was validated through experimental tests, as shown in Table I. The device supports a maximum weight of 70 kg, has a maximum power consumption of 88,42 W, and has an autonomy of 5,52 hours of use. This wheelchair can be remotely controlled through a mobile app.

The maximum resulting speed v of the wheelchair is 3,46 km/h; however, this value is halved in diagonal movements because only two of the four wheels are activated. The component ω_x only appears in clockwise and anticlockwise turns; however, since it is a rotation, there is no displacement v, as seen in Table I.

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