DEVELOPMENT OF A FOUR *MECANUM* WHEELS OMNIDIRECTIONAL MOBILE PLATFORM ENABLING REMOTE MOTION CONTROL THROUGH A *.NET* GRAPHICAL APPLICATION OR AN INERTIAL MEASUREMENT UNIT

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Abstract - Omnidirectional mobile platforms allow simultaneous translation and rotation, which leads to the optimization of their trajectories, a possible reduction of the distance traveled and, consequently, a reduction of the energetic consumption. This paper presents an omnidirectional mobile robot platform based on four *Mecanum* wheels, a graphical application running on *.NET* virtual machine which allows remote motion control and monitoring of several parameters of the platform, and an inertial remote control that uses an IMU (Inertial Measurement Unit) and an AHRS (Attitude and Heading Reference System) to set the movements of the platform.

Keywords: *Mecanum* wheels, omnidirectional mobile platform, motion control, AHRS, IMU.

1. Introduction

In many applications, the use of non-omnidirectional platforms constitutes an important limitation. An example is a classic electric wheelchair such as the one presented in [1]. Its main purpose is to facilitate the transportation of disabled people but it cannot perform some movements in an *xOy* plane because it uses the Ackermann steering system, which has 2 DOF (degrees of freedom). Usually, non-omnidirectional steering systems require complex algorithms for the dynamic management of trajectories and they may imply high response times.

Figure 1 shows the trajectory described by a generic vehicle with the Ackermann steering system that needs to move from a point A to a point B, considering the orientation defined [2]. It is clear that the distance traveled is more than twice the minimum distance between the points. Considering this fact, it is also possible to conclude that there will be a waste of energy.

Figure 2 presents the trajectory that could be described by an omnidirectional platform in order to move from point A to point B. In this case, translation and rotation can occur simultaneously, which leads to the following benefits:

1) **Optimization of the trajectories of the mobile platform** – The distance traveled is minimized due to the combination of simultaneous rotation and translation;
2) **Possible reduction of the energetic consumption** – Since the distance traveled is minimized, the required energy may also be decreased.

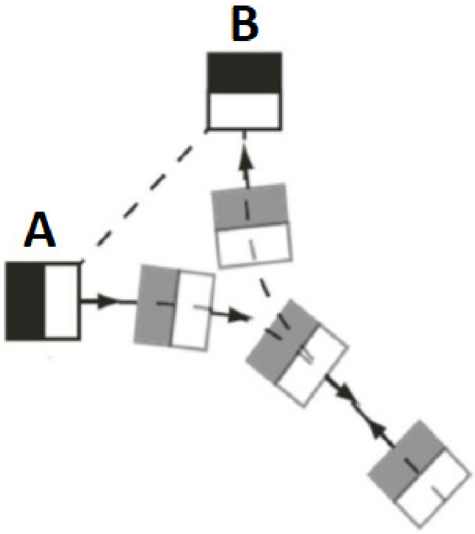

Figure 1: Trajectory described by a mobile platform with the Ackermann steering system in order to move from a point A to a point B [2].

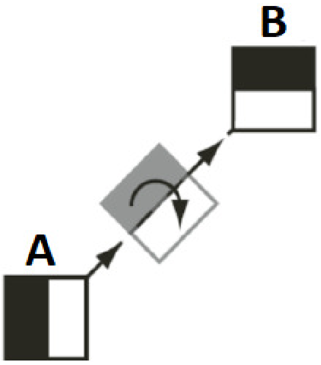

Figure 2: Trajectory described by an omnidirectional mobile platform in order to move from point A to point B [2].

Mobile platforms with four *Mecanum* wheels [3] are omnidirectional. Each wheel has its own motor and platform motion control requires controlling each motor individually. The great variety of movements achievable through simultaneous translation and rotation cannot be properly controlled by traditional steering wheels used in non-omnidirectional platforms. More adequate solutions have been developed, usually based in joysticks [4]. A motion control system based in hand gestures recognition is presented in [5].

This paper presents an omnidirectional mobile robot platform based on four *Mecanum* wheels, a graphical application which allows remote motion control and monitoring of several parameters of the platform, and an inertial remote control that uses an IMU (Inertial Measurement Unit) and an AHRS (Attitude and Heading Reference System) to set the movements of the platform. The complete system is suitable, for example, for educational purposes.

2. System Architecture Overview

The developed system (Figure 3) has three main components, which will be detailed in this section: 1) Omnidirectional mobile robot platform, 2) Graphical application, and 3) Remote control.

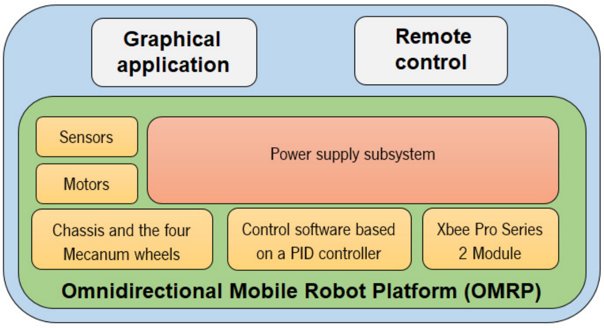

Figure 3: Block diagram of the developed system.

2.1. The Omnidirectional Mobile Robot Platform (OMRP)

The omnidirectional mobile robot platform (OMRP) exchanges data either with the graphical application or the remote control. As shown in Figure 3, it has several subsystems. The power supply subsystem, which has both ultracapacitors (they allow ultra-fast charging) and a conventional lead-acid battery (for increased autonomy) as energy-storing devices, provides the required electrical power for each part of the OMRP. It is detailed on [6].

The OMRP has four *Mecanum* wheels placed as suggested in Figure 4. This omnidirectional steering system is inherently more stable than those with only three wheels. For a two-dimensional *xOy* plane, its steering system provides three independent possible movements: a translation along the x-axis, a translation along the y-axis and a rotation about the z-axis.

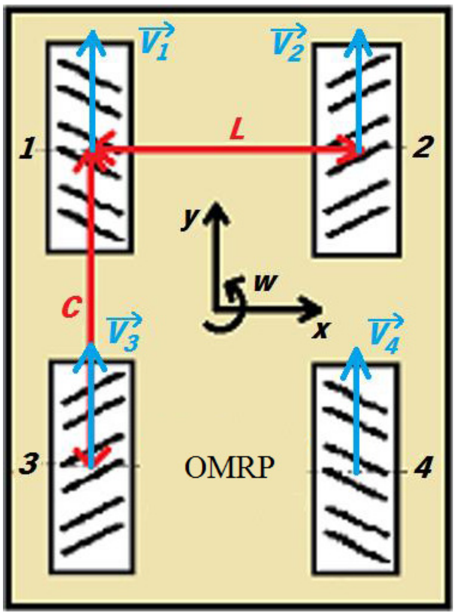

Figure 4: Schematic top view of the OMRP, clarifying the positions of the four Mecanum wheels and the referential used.

Controlling the movements of the OMRP requires defining its instantaneous velocity, which may be given as a three-dimensional vector: the linear velocity in the x-axis v_x, the linear velocity in the y-axis v_y and the angular velocity about the z-axis w_z. Taking this into consideration, it is necessary to compute the instantaneous velocity of each *Mecanum* wheel. Such computation requires the following conversion model that specifies the relationship between the velocities v_x, v_y and w_z, and the velocity of each *Mecanum* wheel, v_1, v_2, v_3 *and* v_4 (*C* and *L* are the distances highlighted in Figure 4;

International System units are considered) [7] [8] [9]:

$$\begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \end{bmatrix} = \begin{bmatrix} 1 & 1 & -\frac{C+L}{2} \\ -1 & 1 & \frac{C+L}{2} \\ -1 & 1 & -\frac{C+L}{2} \\ 1 & 1 & \frac{C+L}{2} \end{bmatrix} \cdot \begin{bmatrix} v_x \\ v_y \\ w_z \end{bmatrix} \tag{1}$$

A PID controller system was used in order to ensure that the measured velocity is as close as possible to the computed reference velocity. The PID controller has four instances, each one matching one *Mecanum* wheel. An anti-reset windup block was also implemented into the PID controller in order to minimize the risk of high overshooting on its output.

Finally, a wireless module was integrated on the OMRP, enabling it to communicate with either the graphical application or the remote control. It was set a peer-to-peer network based on *XBee Pro Series 2* modules [10]. After setting up the physical layer of the network, the logical layer was developed – it was defined that each frame always begins with the character *"$"*, which informs the receiver that a new frame is coming. The end of each frame is detected by the character *"\r"*, which is the carriage return character. Therefore, in each frame, the useful information is contained after the character *"$"* and before the character *"\r"*. For example, when the whole system is turned on, in order to establish the wireless communication, the OMRP sends the frame *"$OMRP\r"* and waits for receiving either *"$GA\r"* from the graphical application or *"$RC\r"* from the remote control. Otherwise, it means that there are communication issues.

2.2. The graphical Application

The graphical application is a program, written in C# programming language (running on a *.NET* virtual machine), used to wirelessly control the movements of the OMRP using a personal computer. It also provides remote monitoring of some parameters of the OMRP. It was designed in order to have two main windows. The main goal of the first one is to establish the wireless communication between the OMRP and the computer that runs the graphical application. When the graphical application is used, an *XBee Pro Series 2* module must be connected to the computer so as to establish the communication. Another module is installed on the OMRP. The two modules establish the wireless network by themselves. On the computer side, a user simply has to select the serial port that matches the modules connected to the computer. When the right serial port is selected, some frames are exchanged in order to verify the state of the wireless connection. If no error occurs, the second window opens. Otherwise, an error message is shown and the second window is not opened.

The second window aims to provide a way for both OMRP movements definition and monitoring of the OMRP. It was designed to have four separators in order to keep the data and settings organized. The first separator provides real-time information about the status of the wireless connection, some electrical parameters of the power supply subsystem of the OMRP, the environment temperature and humidity. The second separator provides feedback about the performance of the PID controller that manages each of the four *Mecanum* wheels. The separator shows in real-time the reference velocity, the measured velocity and the error (given by the difference between the reference velocity and the measured velocity). This feedback is provided using real-time graphs. The third separator offers the possibility of controlling the movements of the OMRP. The design of the separator was done having into account that it should have an intuitive interface and, at the same time, it should allow the execution of any trajectory. To achieve that, a set of buttons was created, each one to set a standard movement of the OMRP. Furthermore, a set of three numerical input boxes was designed to ensure the possibility of defining the velocities v_x, v_y and w_z independently. The fourth separator provides some independence to the OMRP movements. In other words, the graphical application should be able to command the OMRP in order to ensure that it performs some autonomous and useful movements. Two operation modes were considered in the implementation. The first one consists in following an object autonomously – using its infrared sensors, the OMRP must follow an object trying to keep the distance to it as constant as possible. This is a useful mode of operation to, for example, ensure that an omnidirectional AGV (Autonomous Guided Vehicle) is able to follow a specific object in an industrial assembly line. In the second operation mode, the OMRP autonomously tries to maintain a constant distance to the wall while moving forward or backward at a certain speed. For example, this mode of operation may be applied to an omnidirectional electric wheelchair – a user may be seated on the wheelchair paying attention to a showcase as its wheelchair moves laterally by itself along the entire showcase.

2.3. The Remote Control

The remote control provides an intuitive way of wirelessly controlling the movements of the OMRP, using an IMU.

An IMU has, at least, an accelerometer and a gyroscope. The remote control uses a 9-DOF IMU *Pololu MinIMU-9 V2.* It contains a 3 DOF accelerometer, a 3 DOF gyroscope and a 3 DOF compass. Using the data given by the three sensors and the DCM (Direction Cosine Matrix) algorithm [11], it is possible to set up an AHRS, a system that collects the data from an IMU and converts it to a new referential whose origin is the centre of mass of the remote control. Its rotation axes are *roll*, *pitch* and *yaw*. Figure 5 is a representation of the three-rotation axes of an AHRS on a generic homogeneous object.

The computed values of *roll*, *pitch* and *yaw* must be converted into the three velocity components of the OMRP (v_x, v_y and w_z), which is accomplished through the model

$$\begin{bmatrix} v_x \\ v_y \\ w_z \end{bmatrix} = \begin{bmatrix} 0,8 & 0,8 & 1 \end{bmatrix} \cdot \begin{bmatrix} roll \\ pitch \\ yaw = yaw_1 - yaw_0 \end{bmatrix} \qquad (2)$$

where the angles of the AHRS (*roll*, *pitch* and *yaw*) are given in degrees, linear velocities are given in cm/s and angular velocity is given in rad/s. Angle *yaw0* is a reference heading and *yaw1* is the actual heading. This model was designed empirically.

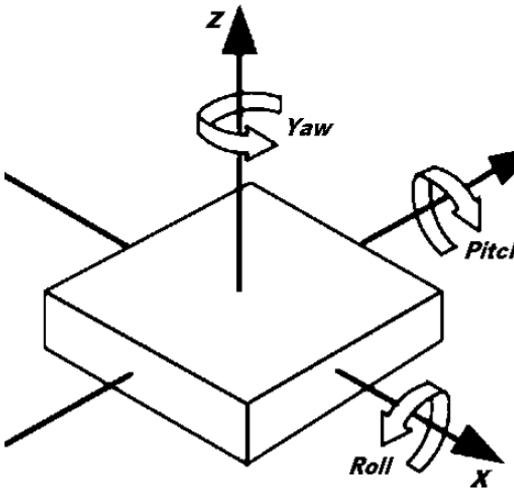

Figure 5: Representation of the three-rotation axes of an AHRS – roll, pitch and yaw.

Besides the IMU, the remote control incorporates an *XBee Pro Series 2* module and an *Atmel Atmega 328P* microcontroller for handling the collected data through the DCM algorithm. The system is powered by a 9V rechargeable Ni-MH battery and some linear regulators provide the right voltage levels. A block diagram of the developed remote control is shown in Figure 6.

3. Results

This section presents some results obtained with the previously described system.

3.1. The Omnidirectional Mobile Robot Platform (OMRP)

Figure 7 shows the final aspect of the developed OMRP. Coupled to each wheel there is a gearbox, an optical encoder and a brushed DC motor. In order to measure the distance to objects and obstacles, the OMRP also has four analog infrared sensors *Sharp GP2Y0A21YK0F* [12] (one at each side of the platform).

In order to control the movements of the platform based on the kinematics model presented in (1), it was necessary to set a referential on the OMRP, as explained in section 2.1 (Figure 8).

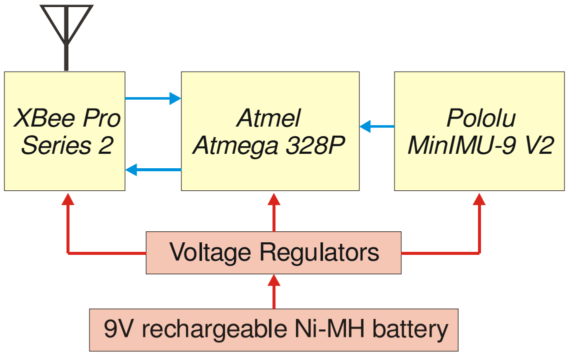

Figure 6: Block diagram of the developed remote control.

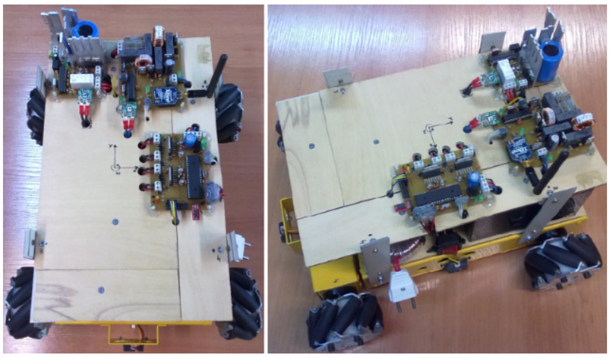

Figure 7: Final aspect of the OMRP.

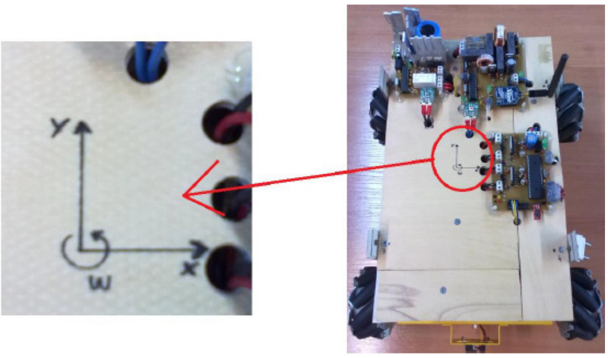

Figure 8: Referential considered for the kinematics model previously presented.

The OMRP was tested. It is capable of exchanging data with either the graphical application or the remote control. Each *Mecanum* wheel can be controlled independently, enabling the platform to perform any movement on an *xOy* plane. A video demonstrating the OMRP operating may be found at: *https://www.youtube.com/watch?v=Nm4K14rrIr8&feature=youtu.be*.

It was validated that the OMRP is capable of following a moving body, keeping a predefined constant distance to it. It was also tested that it is able to maintain a predefined constant distance to a wall while moving forward or backward at a specific speed.

3.2. The Graphical Application

As mentioned before, the graphical application is divided into two windows. The main purpose of the first one is to enable a connection to the OMRP. The interface shown in Figure 9 enables a user to select the right serial port of the computer in order to start the connection with the OMRP.

After the first window, the second comes up evidencing its four separators. The first separator is focused on showing the values of several parameters of the OMRP, such as electric output power, ultracapacitors voltage and environment temperature (Figure 10). The second separator presents graphs related to the speed of each *Mecanum* wheel (Figure 11) – the green line is the reference speed, the blue line is the real speed and the red line is the error (difference between reference speed and real speed). The third separator enables a user to command the OMRP through a set of intuitive buttons (Figure 12). Finally, the fourth separator is focused on enabling the OMRP to follow an object autonomously (keeping a specific distance to it) or to maintain a constant distance to the wall while moving forward or backward at a certain speed (Figure 13).

3.3. The Remote Control

The prototype of the remote control (Figure 14) was developed and tested. It is capable of computing its values of *roll*, *pitch* and *yaw*. Figure 15 shows the output data when the remote control has an inclination of 15 degrees with respect to a horizontal plane about the *roll* axis – it may be seen that the error is less than 2 degrees. Furthermore, two buttons were added to ensure safety – data is only sent to the OMRP while both buttons are pressed simultaneously.

It was found that the computed values of the velocities v_x, v_y and w_z, sent to the OMRP, may be updated at a frequency of 50 Hz, considering a system clock of 16 MHz.

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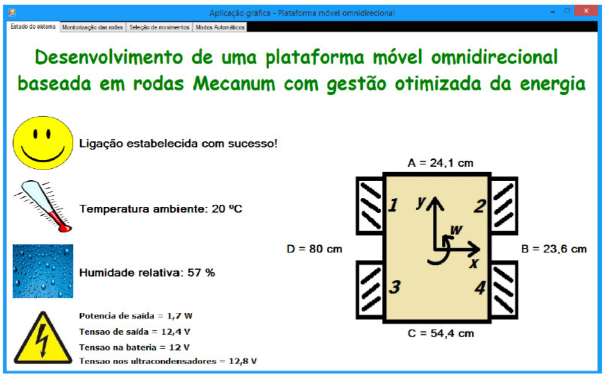
Escolha a porta série associada ao sistema:
COM3
COM4

Figure 9: First window of the graphical application.



Desenvolvimento de uma plataforma móvel omnidirecional baseada em rodas Mecanum com gestão otimizada da energia

Ligação estabelecida com sucesso!

Temperatura ambiente: 20 ºC

Humidade relativa: 57 %

Potencia de saida = 1,7 W
Tensao de saída = 12,4 V
Tensao na bateria = 12 V
Tensao nos ultracondensadores = 12,8 V

Figure 10: First separator of the second window of the graphical application.

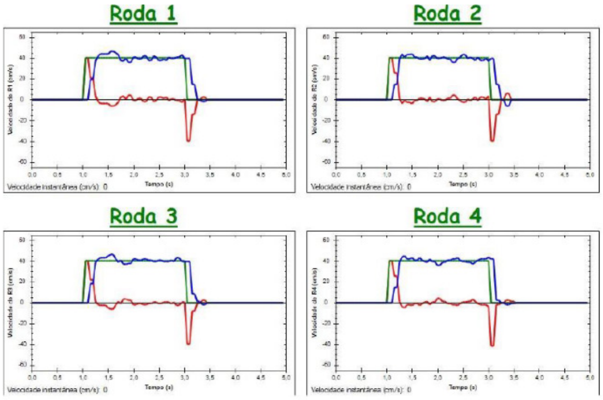
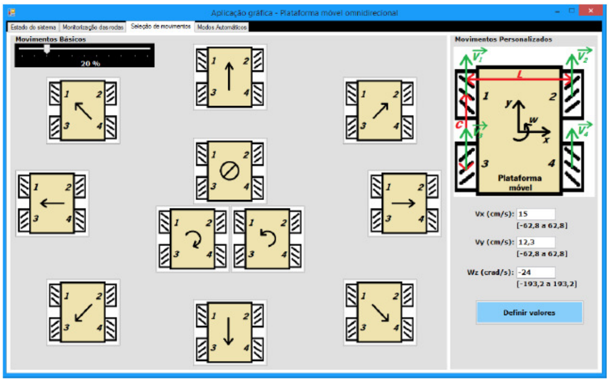
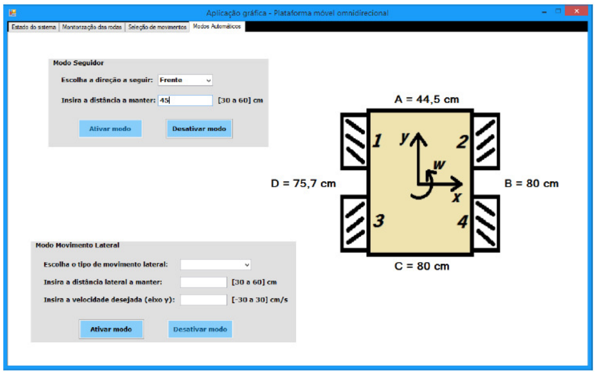


Figure 11: Second separator of the second window of the graphical application.



Vx (cm/s): 15
[-62,8 a 62,8]
Vy (cm/s): 12,3
[-62,8 a 62,8]
Wz (crad/s): -24
[-193,2 a 193,2]

Figure 12: Third separator of the second window of the graphical application.



Modo Seguidor
Escolha a direção a seguir: Frente
Insira a distância a manter: 45 [30 a 60] cm

Modo Movimento Lateral
Escolha o tipo de movimento lateral:
Insira a distância lateral a manter: [30 a 60] cm
Insira a velocidade desejada (eixo y): [-30 a 30] cm/s

Figure 13: Fourth separator of the second window of the graphical application.

The energy consumption of the remote control was measured. It needs 585mW of electric power and its 9V battery lasts for, approximately, 1 hour and 13 minutes.

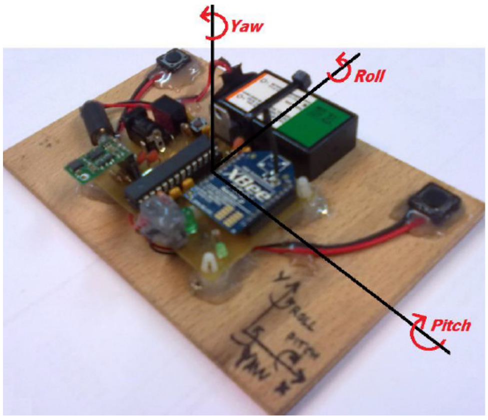
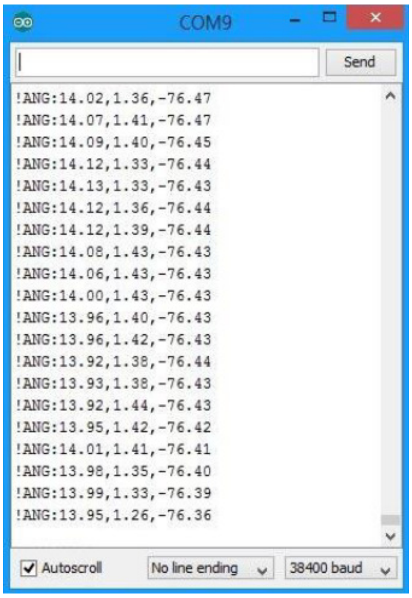


Figure 14: Prototype of the remote control, evidencing the hardware and the referential considered.



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!ANG:14.02,1.36,-76.47
!ANG:14.07,1.41,-76.47
!ANG:14.09,1.40,-76.45
!ANG:14.12,1.33,-76.44
!ANG:14.13,1.33,-76.43
!ANG:14.12,1.36,-76.44
!ANG:14.12,1.39,-76.44
!ANG:14.08,1.43,-76.43
!ANG:14.06,1.43,-76.43
!ANG:14.00,1.43,-76.43
!ANG:13.96,1.40,-76.43
!ANG:13.96,1.42,-76.43
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!ANG:13.92,1.44,-76.43
!ANG:13.95,1.42,-76.42
!ANG:14.01,1.41,-76.41
!ANG:13.98,1.35,-76.40
!ANG:13.99,1.33,-76.39
!ANG:13.95,1.26,-76.36
```

Figure 15: Output data when the remote control had an inclination of 15 degrees with respect to a horizontal plane about the roll *axis.*

4. Conclusions and Future Developments

This paper presented an omnidirectional mobile robot platform (OMRP) with four *Mecanum* wheels. It is capable of 1) following a moving body, keeping a constant distance to it, and 2) maintaining a constant distance to a wall while moving forward or backward at a specific speed. The motion control of the platform is also possible through the use of either a graphical application or a remote control.

Besides controlling the movements of the OMRP, the graphical application monitors some parameters of both the environment and the platform, including showing the performance of the PID controller that tries to keep the measured velocity of the *Mecanum* wheels as close as possible to a reference velocity. This application is useful in order to study how the error (difference between the reference velocity and measured velocity) affects the trajectory described by the mobile platform.

The developed system may be used for educational purposes in the scope of omnidirectional platforms based on *Mecanum* wheels and AHRS. Furthermore, since the OMRP has the advantages inherent to omnidirectional platforms in terms of freedom of movements, it may be used in places in which the space is reduced.

As future developments, it is suggested to add a LIDAR sensor in order to enable the OMRP to have a very precise mapping of the space around it. Adding sensors for detecting harmful gases such as carbon monoxide would also be useful in some applications.

Acknowledgements

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