Design and implementation of an automatic control system applying PID in the positioning of an electric wheelchair

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Abstract

According to the World Health Organization (2018), a large part of the population requires a wheelchair to be able to mobilize and perform their daily activities. Conventional wheelchairs have been used for years to assist users in their mobility. However, it is believed that people's needs have evolved over the years and they are currently looking for something more in assistive devices. So, what this project wants is to give the user more control over the angle, positions and height of the wheelchair seat to improve the quality of life of this person.
The control will incorporate both manual and automatic control. the manual drive system to control the movement and height of the chair. The automatic control applying a PID control with data obtained from an IMU as an input and its output is the voltage to drive the motor, which activates an electric piston that regulates the inclination of the wheelchair seat by 3 degrees, all this improves the quality of life of the person and makes the development of their activities more practical.

Keywords
Wheelchair, PID, IMU, Mechanical Design and Automatic Control.

1. Introduction
According to research conducted by INEI in 2012, it is estimated that there is a disabled population of approximately 1.6 million individuals in Peru, of which 59% suffer from some form of motor disability that limits or prevents their mobility and the performance of daily activities. Globally, in 2018, the World Health Organization reported that around 70 million people require the use of a wheelchair.

Electric wheelchairs provide greater utility than conventional wheelchairs, but in addition to mobility, people also need to perform other actions such as reaching the window of a bank, picking up objects from a shelf, maintaining a conversation with a person at a comfortable height, and keeping the seat position stable during inclination disturbances.

This paper presents the design and implementation of a mechatronic system that allows for the control of wheelchair movement, direction, and height, as well as the stability of the seat at an angle of 3 degrees.

1.1 Objectives
- Develop a PID control system for the automatic regulation of the wheelchair seat tilt to 3 degrees.
- Design and build a manual control system for the displacement, direction, and height regulation of a wheelchair.
- Design and construct a mechanical system for a wheelchair that enables height and tilt regulation.

2. Literature Review
Reviewing the literature, various contributions to the technology used in electric wheelchairs were found. Aulia et al. (2021) implemented the development of a Fuzzy PID control, which allows regulating the speed and remaining stable at an angle not greater than 10°. Results were obtained with 80% effectiveness in users with different weights. Mikhail (2021) developed a control system using methods on control theory that makes it possible to stabilize the object when moving on horizontal and inclined surfaces. The proposed algorithms register and analyze the distance and movement to guarantee the possibility of vertical movement with greater precision and to be controlled in different modes. Wafa

and Yusra (2020) aim to improve the mobility of wheelchair users by using an application to control the movement of their wheelchairs, especially in narrow places, turns, and U-turns. Consensus algorithms are used for wheel movement, which contains three separate components to control rotation and vertical and horizontal displacement independently from the other wheels and thus generate a small margin of error. PDI controllers are used for wheelchair maneuverability. It is simulated in the MATLAB software, and the PD-Fuzzy P controllers have faster convergence in tracking the trajectory than the GA-PID controller.

Derasari and Sasikumar (2022) present a motorized wheelchair model that is controlled by a glove that provides basic wheelchair control. The microcontroller processes all the data received from the glove and sensors to determine the direction in which the wheelchair will move. The purpose of this work is to offer greater ease, comfort, and control to the wheelchair-dependent public. Seki and Tanohana (2012) propose a fuzzy algorithm based on a torque control scheme to assist in wheelchair mobilization. It contains a simple structure that allows maintaining speed even on long roads. Tests were carried out, and the results were detailed to verify the effectiveness of the proposed system. Luo et al. (2022) point out that traditional wheelchairs have a fixed seat and are not optimal for user comfort because the inclination angle cannot be regulated. Therefore, an electric wheelchair with a more comfortable control interface is proposed. The model is carried out using multi-body dynamics and vibration mechanics to evaluate comfort, acceleration, and vibration during movement. Using elevation mapping, the wheelchair can recognize the terrain from any viewpoint as a camera is connected to the system, and through the RTAB-MAP algorithm, 3D terrain data can be collected. The results show that stability and comfort can be obtained in the wheelchair and that the simulations verified the accuracy when verifying the terrain.

Castillo et al. (2015) developed an innovative and cost-effective prototype of a wheelchair that can climb stairs, thanks to its four X-type wheel rims. Moreover, the seat can be adjusted to correct the center of gravity, thanks to IMU sensors that detect the angle of the seat in relation to the surface on which the wheelchair is moving and a PID controller that horizontally balances the seat. To ensure continuous climbing, a PID controller is implemented to synchronize the wheels and allow the wheelchair to perform the task. Gabrie et al. (2020) presented an economical electromobile system that integrates power control circuits based on MOSFETs to control a wheelchair with lower energy consumption. This project is functional to optimize and modify the wheelchair for the desired location and without presenting motor failures, resulting in better use and efficiency for the user. García et al. (2023) designed an intelligent wheelchair prototype using low-budget hardware and software in robots combined in a certain model, which can be adapted to different profiles. This wheelchair contains two electric motors, a low-level electronic control system, and a joystick. Loiseau et al. (2022) designed a wheelchair to increase the performance of athletes with disabilities. For this purpose, two models were created. The first model defined the optimal position of the athlete's body to achieve maximum speed in long-distance races, while the second model specifically targeted 100-meter races. For this second model, the position of the athlete's pelvis was taken into account to reduce the arrival time on the trajectory of 100 meters.

Fariña et al. (2023) compared two sensor fusion algorithms based on their characteristics and performance when applied to a localization system for an autonomous wheelchair in dynamic environments. The mobile robot localization module is composed of three sensors: wheel encoders, LIDAR, and IMU. The information provided by each sensor is combined according to its covariance to obtain the most reliable pose estimation possible. The study focuses on two fusion algorithms, the Kalman filters (Extended and Unscented), detailing their properties and operation. Both methods are implemented in the wheelchair for comparison. Cui et al. (2022) proposed and developed an IoT intelligent wheelchair with various functions. The first is for multimodal detection of the occupant's wheelchair environment. For this purpose, a PAJ7620 sensor was used to recognize gestures as information, and an IMU sensor was used to detect positioning, speed, and posture information. Secondly, a mobile control scheme based on rocker and gesture recognition. Lastly, human-machine interaction: the wheelchair is connected to Tencent IoT Explorer via the ESP8266 WiFi module, using the MQTT protocol to upload sensory data, while the state of the wheelchair can be viewed and controlled in the application. This wheelchair can detail the real-time status of the occupant, the environment, and the wheelchair itself, and everything can be visualized through an app.

Gonzales et al. (2022) detail a prototype of a wheelchair built with electronic parts and implement software to operate using head movements. It was simulated in MATLAB and Python software with 10 participants. The mean response time with manual control was 37.8 seconds, while with constant speed it was 36.5 seconds. Finally, the mean orientation control with variable speed was 44.2 seconds on a specific route. Zhang et al. (2015) proposes the use of brain signals to control an electric wheelchair, which is promising and interesting, but it is found to be unstable and uncomfortable for the user. As a solution, the Brain-Computer Interface (BCI) is proposed to define an automated displacement of a wheelchair. An MI or P3000 motor is used to allow mobility and both are compared to determine their effectiveness in driving the wheelchair with brain signals.

De La Iglesia et al. (2018) proposes to design a low-cost universal control panel to control the trajectory of the wheelchair, in order to increase the quality of life of the public affected by a disability. Ngo and Nguyen (2022) propose a wheelchair control system using electroencephalography based on a map to help people with disabilities move. For the movement of the wheelchair in a real indoor environment corresponding to the virtual 2D grid map, the initial position of the wheelchair will be determined based on natural reference points and a graphical user interface designed for on-screen visualization can help people with disabilities select the desired destination from a list of predefined locations using electroencephalogram (EEG) signals through blinking eyes. Nghia et al. (2008) proposes an optimal route tracking control approach for a smart electric wheelchair. The second Lyapunov method is used to find an equilibrium position. Takagi et al. (2023) proposes a system that works with omnidirectional screens. The system is evaluated and wheelchair users are interviewed about their experience.

These studies show the development and implementation of various technologies, control models, and sensors in wheelchairs to offer more functionality, thus improving the quality of life for people with disabilities.

3. Methods

3.1 Prototyping and 3D printing

A physical prototype of the wheelchair was designed and fabricated using FDM 3D printing technology, which enabled the implementation of electronics and the development of the control system for further analysis of its behavior before implementation in the final prototype.

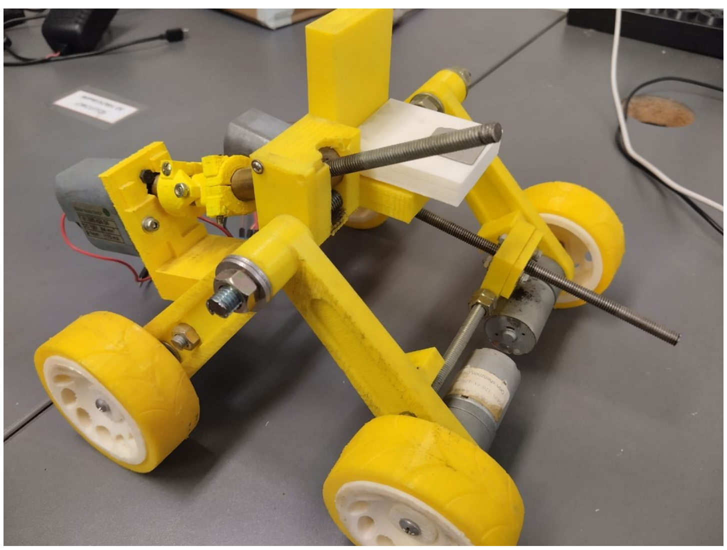

Figure 1. 3D printed scale prototype

3.2 Mechanical Design and construction

The mechanical system was designed using the Computer-Aided Design (CAD) tool Autodesk Inventor Professional. Figure 2 shows the final design of the wheelchair.

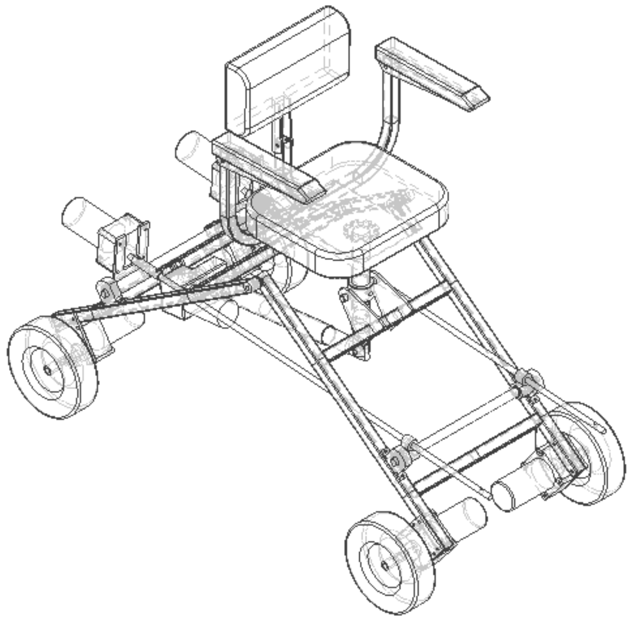

Figure 2. Wheelchair CAD

In the manufacturing of the wheelchair, square carbon steel pipes were used for the metal structure. They were cut to the measurements of the design and welded using TIG welding. The remaining pieces, motors, and the seat were assembled.

The mechanism works as follows: The height adjustment is achieved through two worm screws coupled to 2 motors that, when functioning, close the metal structure, which allows for increasing or decreasing the height. In the case of the inclination regulation, an electric piston is used, which is coupled between the chassis and the steel tube concentric to the seat, as shown in Figure 3.

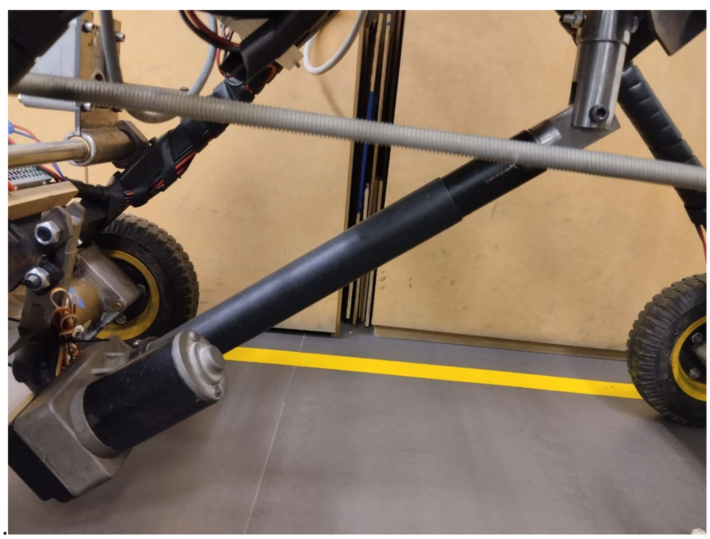

Figure 3. Attached Electric Piston

3.3 Electric system

To achieve the displacement and height adjustment, direct current motors will be used, each with a power of 120 watts, 5 amperes, and 24 volts. There are 4 motors in total, one for each wheel and 2 for the worm screws that will regulate the height. In Figure 4, the configuration of one of the motors equipped with its respective wheel can be appreciated.

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Figure 4. DC motor used for displacement

For the regulation of inclination, an electric piston or linear actuator of 24V and 5 amperes was implemented. To power the system, 2 batteries of 12 volts and 70 amperes configured in series are required. The power drivers have a capacity of 15 amperes, taking into account cases where the current may increase, such as on slopes, rough terrain, and overloading. Figure 5 shows the electrical system mounted on the back of the wheelchair.

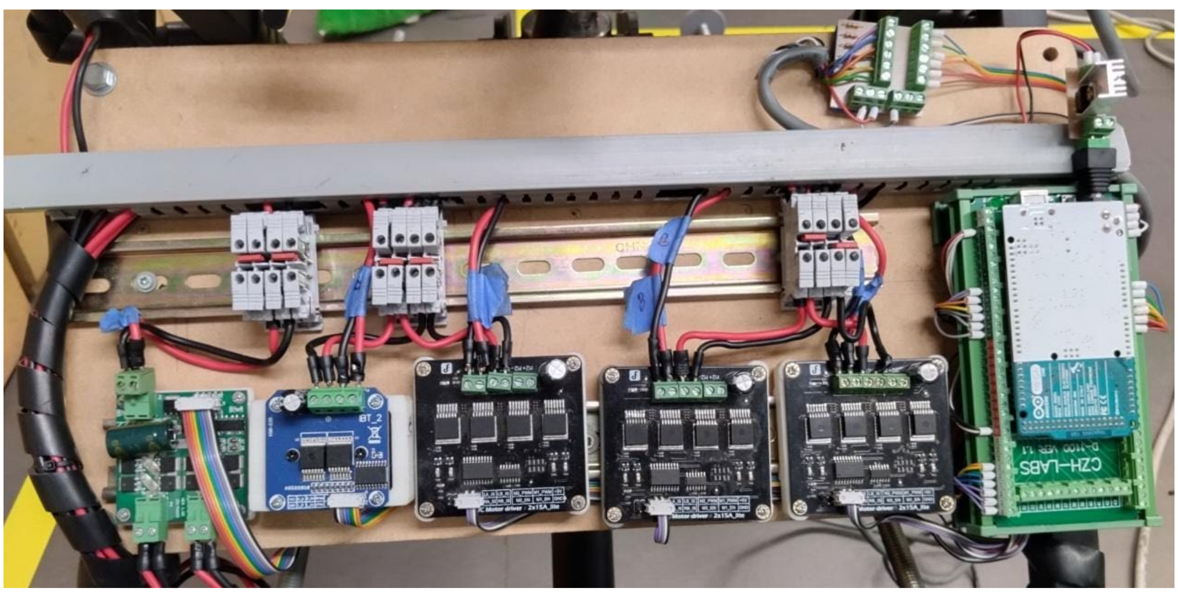

Figure 5. Electrical system installed

3.4 Electronic and control system

The programming that will enable control over the wheelchair will act independently, while the functionality of movement and height regulation will be activated by the buttons on the control panel shown in figure 6, and the electric piston control that will allow for the regulation of the chair's tilt will be automatic using a PID control model.

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Figure 6. Wheelchair control joystick

The control system for the wheelchair will use two Arduino Mega 2560 as controllers. One will be responsible for reading signals from the control panel (forward, backward, left, right, up, down) and sending PWM signals to the respective motors to perform the required actions. The other will read and process signals from the MPU6050 inertial measurement unit, which will be positioned on the seat base, and use them in the PID control to regulate the PWM output of the piston, allowing for automatic and controlled tilt regulation. Figure 7 shows a diagram of the hardware used in the wheelchair control system.

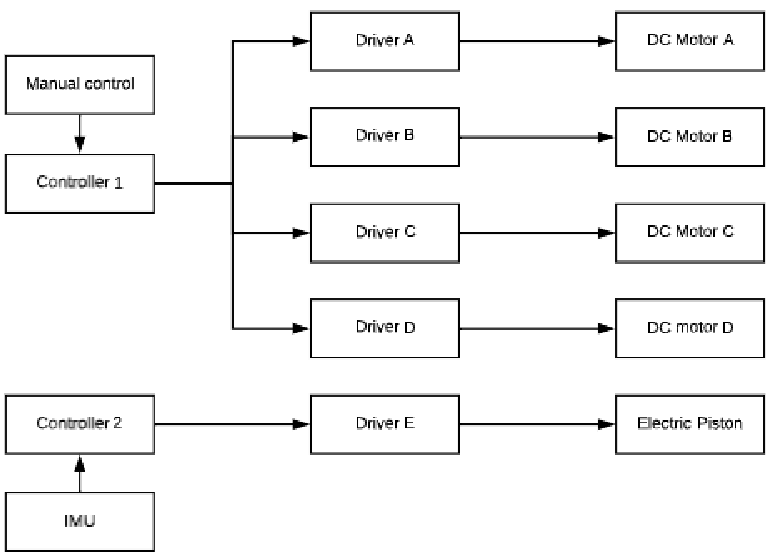

Figure 7. Hardware diagram

3.5 Programming

As mentioned earlier, two separate controllers were programmed using the Arduino IDE interface. The programming for movement and height read digital signals from the control panel switches and entered the logical control statement generating an output that would activate the motor direction and PWM.

A PID control system was chosen because we have one variable to control. It was implemented in the scaled prototype, where the IMU reading was conditioned. This sensor allows us to measure linear acceleration, angular velocity, and the orientation of an object in the x, y, and z axes as shown in figure 8. What we need is to extract the pitch and transform it into sexagesimal degrees to work with in our control logic.

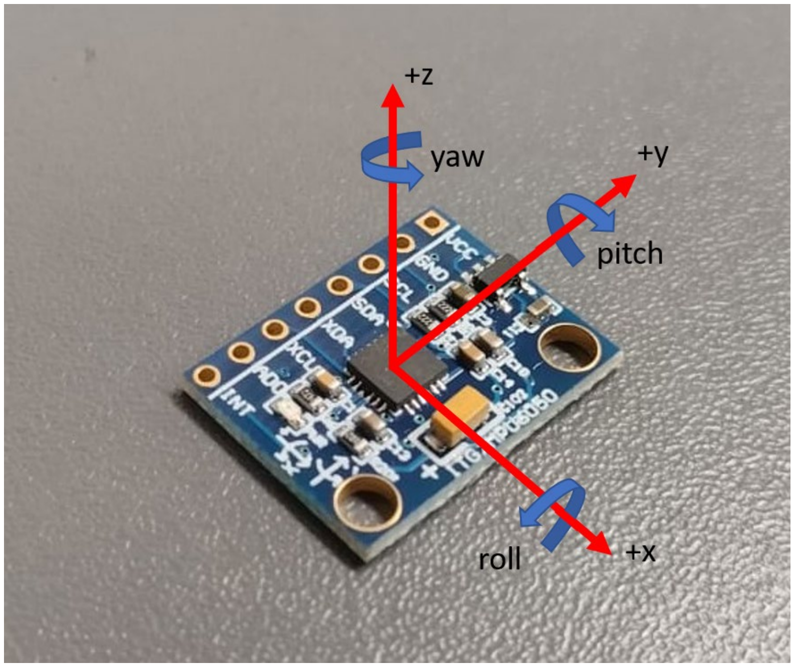

Figure 8. Orientation of MPU6050.

The PID control target is defined as 3 degrees, which is the position we want the user to maintain, as shown in figure 9. The PID control works with the error, which is the result of the sensor reading compared to our target. Based on this error, our PID control will send a higher PWM signal when the difference is greater and a lower signal when the error decreases, indicating that we are getting closer to the target.

Figure 9. PID target at 3º

The proportional, integral, and derivative parameters were obtained experimentally in the scaled prototype and finally tuned in the final prototype.

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5. Results and Discussion

The system was successfully implemented in the final prototype, and the mechanisms responded well to the controller commands. To evaluate the system, its use was simulated in a working environment, and the PID control system responded satisfactorily to changes in tilt, stabilizing the user's seat at 3 positive degrees. As the angle moves away from its target, the piston acts more quickly, while if the difference decreases, the piston slowly reaches the desired point.

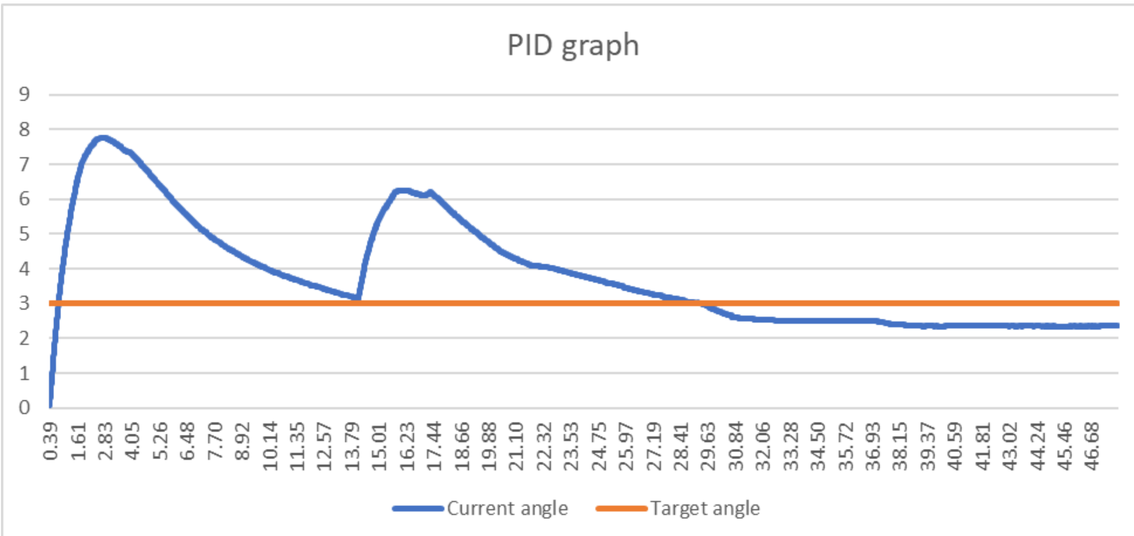

Figure 10. Behavior of the PID control during the use of the wheelchair

Figure 10 shows an angle versus time graph of the behavior and reaction time during the test when the user tested the height regulation. It can be observed that the system tries to keep the person stable despite sudden movements and changes in tilt that occur when using the wheelchair. The height regulation increases to a maximum of 15 cm, allowing the user to reach places that previously required external assistance, such as shelves and bookcases. Figure 11 shows the maximum height of the chair, while Figure 12 shows the minimum height.

Figure 11. Wheelchair at its maximum height

Figure 12. Wheelchair at its lowest height

5.1 Proposed Improvements

Although the results are satisfactory, there are many possible improvements to the prototype, both in the mechanical and control parts.

Adding encoders and their own PID control as part of the control for wheelchair movement could allow for more precise movements. The mechanical system could be improved by adding a suspension system that reduces vibrations, as shown in Figure 15, and reducing the weight of the wheelchair by using aluminum instead of steel.

Figure 13. Suspension system as improvement proposal

6. Conclusions

The development of this project allowed for the programming and design of a mechanical and electronic wheelchair system that fulfills the set objectives. A PID control system was successfully programmed for automatic regulation of the wheelchair seat inclination at 3 degrees, as well as a manual control system for movement, direction, and height

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regulation of the chair. In addition, a mechanical system was designed that allows for safe and efficient regulation of height and inclination.

The implementation of the control system was successful, enabling effective use by individuals with reduced mobility. The PID automatic control system allowed for precise regulation of the seat inclination, providing greater comfort for the user. Furthermore, the manual control system provided greater autonomy for the user, allowing for easy movement, direction, and height regulation of the seat.

In summary, the project successfully integrated the programming and design of a mechanical and electronic wheelchair system that allows for safe and efficient regulation of height and inclination, providing greater comfort and autonomy for individuals with reduced mobility.

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