Application of PID Control System in Mecanum Wheelchair

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Abstracts: This research centers on the design and implementation of a control system for an electric wheelchair equipped with Mecanum wheels. The study details a comprehensive research methodology starting with the creation of a block diagram to guide system design, hardware selection, and overall implementation. The electric wheelchair system incorporates power resources, input devices, and energy output mechanisms, utilizing a 24 VDC battery and a joystick with a 10K ohm potentiometer connected to an Arduino Due microcontroller. The operational workflow of the system is defined, enabling the wheelchair to respond to joystick commands for forward, left turn, right turn, and other movements. A PID control system is employed to regulate motor movement, enhancing control precision. The Cohen-Coon tuning method is used to determine the PID controller's gain, ensuring efficient closed-loop control. Results from PID controller experiments under P control and PD control are presented, demonstrating the system's responses for different gain values. Optimal performance is observed with a Kp value of 80 and Kd value of 1.2, showcasing improved response speed, reduced rise time, enhanced setting time, and lower percent overshoot. In conclusion, the combined proportional and derivative control system, specifically with Kp = 80 and Kd = 1.2, proves to be effective in enhancing the Mecanum wheelchair's performance. This study provides valuable insights into precise parameter adjustments for optimal control in Mecanum wheelchair applications.

Keywords: Cohen-Coon Tuning Method, PID Control, Mecanum Wheels.

1. INTRODUCTION

The prevalence of conditions like paraplegia, myasthenia gravis, and the growing aging population highlights the increasing demand for assistive devices. Wheelchairs, a common sight in hospitals, come in various types. Hand-powered wheelchairs, though cost-effective, pose challenges, requiring significant user effort and occasional assistance. Electric wheelchairs, propelled by electric motors, offer enhanced mobility but encounter limitations in navigating tight spaces or overcoming obstacles. Research has extensively explored wheelchair user behavior, body proportions, and ergonomic workspace design [1], wheelchair use skills training, safety, fatigue, and repair frequency [2]-[5], with a focus on coaching services, public transport use, and improving wheelchair usability [6]-[10].

Despite advancements, developing a prototype electric wheelchair faces cost challenges in mechanics and electrical control system design. The Arduino training kit emerges as an alternative for prototyping. Related studies cover motor control systems [11]-[13], autonomous electric vehicles utilizing ultrasonic sensors and GPS [14], car parking distance controllers [15], and small-scale robots with servo motor systems [16]. Additional applications include a balance robot [17], line-following robot with a camera sensor [18], and a temperature monitoring system for a baby incubator [19]. Wheelchair design for individuals with disabilities has evolved, featuring autonomous stair-climbing wheelchairs [20], electric wheelchairs with balance systems [21], and mechanisms detecting sitting posture [22]. Simulation systems aid electric wheelchair practice [23]-[26], and innovative designs incorporate mechanical arms for assistance [27]. Control system development explores image processing aids [28], LIDAR for autonomous wheelchairs [29], navigation control for indoor travel [30], map applications [31], decision-making programs [32], and speed profile studies [33]. Novel approaches use facial expression, hand gesture, and eye detection for movement control [34]-[37]. Physiological signals like EOG [38],[39], EEG [41], [42], and haptic feedback [43] have been employed. Mecanum wheels offer a solution to mobility challenges, investigated in wheelchair designs [44],[45] and dynamic modeling [46]-[48]. Studies apply kinematic equations [49] and Lagrange equations [50] for design and control [53], [54]. Omnidirectional wheels [55]-[63], another option, find applications in robot locomotion testing [55] and pressure data studies [56]. Layout variations include a triangular arrangement [58]-[60] and a cross-shaped layout [61][62].

This study presents an electric wheelchair featuring mecanum wheels [64], enabling seamless omnidirectional movement. The design prioritizes the use of readily available materials, with a focus on convenient disassembly. Employing algorithms for joystick-controlled movement, the construction offers a cost-effective solution. Extensive testing has been conducted to validate the system's functionality. Additionally, a PID Controller system [65]-[80] has been meticulously designed, incorporating the Cohen-Coon tuning method for gain adjustment. The optimal configuration, determined through rigorous testing, reveals the superiority of the PD Controller system.

2. RESEARCH METHODOLOGY

2.1. Design of Electric Cart Control System with Mecanum Wheels

The research focuses on designing the control system and joystick for operating an electric cart with mecanum wheels[64], utilizing four motors corresponding to each wheel. Figure 1 illustrates the schematic diagram of the control system. The design process initiates with creating a block diagram to outline stages such as system design, hardware selection and design, and overall system implementation. The electric wheelchair system comprises three key components: power resources, input, and output. For power, a 24 VDC battery is employed, connected to a 3-way switch facilitating wheelchair enablement, disablement, and charging mode selection. Input signals controlling the wheelchair's movement come from a joystick featuring a 10K ohm potentiometer (VR) and a 2-axis controller. These input devices connect to an Arduino Due microcontroller. The speed of the DC motors is regulated by these input signals, along with four H-bridge DC motor driver boards and control boxes linked to the Arduino Due. Additionally, an emergency button, connected to the Arduino Due, triggers a horn sound (piezo buzzer) in case of an emergency. Figure 1 depicts the entire electric wheelchair system, providing a comprehensive overview of its components and their connections.

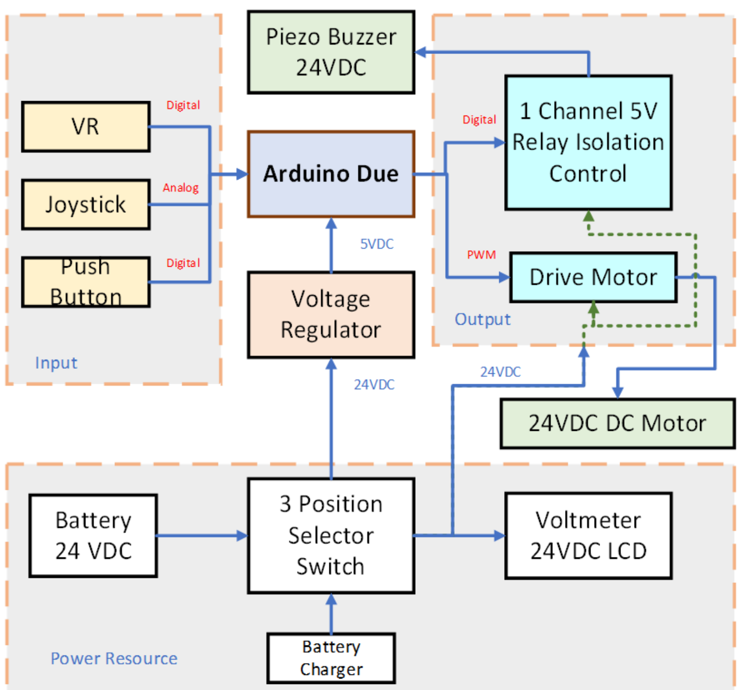

Figure 1. Schematic diagram of the electric cart control system

Figure 2 illustrates the configuration of the electric cart, which is steered by Mecanum wheels. The chosen motor for the electric cart is the LX44WG2490, featuring a torque of 60 Kg.cm at a speed of 71 RPM, an average torque of 173 Kg.cm under load, and a maximum torque of 55 Nm. Operating at 24 V, the motor weighs 0.95 kg and is specifically designed for propelling the cart's wheels, as depicted in Figure 3. To create a versatile electric wheelchair capable of moving in all directions, computer program simulation modeling software was utilized to design and analyze its movement. The design adheres to the ISO 2570-2555 standard and considers size requirements outlined in Table 1, employing stainless steel (SUS304L) as the material. The completed design, showcased in Figure 2, meets all pertinent criteria for electric wheelchairs with mecanum wheels, featuring dimensions of 1100 mm in length, 560 mm in width, and 890 mm in height.

Figure 2. Electric cart controlled by mecanum wheels

Figure 3. Mecanum wheel electric cart

Table 1. Comparison of electric wheelchair design dimensions with iso 2570-2555 requirements

Dimensions	ISO 2570-2555 requirements(mm)	Designed cart size (mm)
Overall length	1,200	1,100
Overall width	700	560
Overall height	1,090	890

2.2. The Workflow of System Operation

The system operation workflow defines the operation schedule of the cart system using mecanum wheels, allowing it to move in response to commands received from joystick. The control is approximately determined based on the joystick's movement and the generated angles to facilitate forward, left turn, right turn, or other movements. The control program resides in the motor control box. After selecting the direction, the system employs a PID system to control the movement. The program estimates the control input of the system to drive the motors. The system measures signals from the encoder, providing feedback to the control system, thus completing the program operation, as depicted in Figure 4.

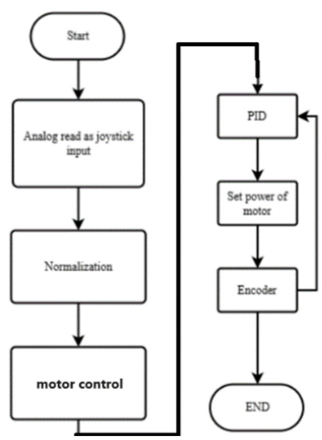

Figure 4**.** The workflow of system operation

2.3. Designing a PID Control System for the Mecanum Wheelchair

PID control system [81]-[92] is employed in closed-loop control systems, also known as feedback control systems. Ongoing advancements in modern automation continually refine techniques to enhance the efficiency of continuous control systems. The PID controller, shown in Figure 5, remains widely accepted in industrial applications due to its straightforward structure, simple design, and versatility across various control tasks. The PID control mechanism comprises three sub-controllers: 1) The Proportional term or P-controller, 2) The Integral term or I-controller, and 3) The Derivative term or D-controller. In the realm of PID control theory, the framework is presented as a Continuous-Time PID controller. However, when implemented in a Microcontroller Unit (MCU), adaptation to a Discrete-Time PID controller is necessary. The latter can be derived from the continuous-time PID controller theory, as expressed in Equation (1).

$$u(k) = K_p e(k) + K_i \sum_{0}^{k} e(k) + K_d \frac{e(k) - e(k-1)}{\Delta t} \tag{1}$$

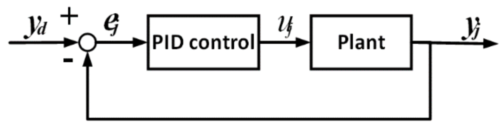

Figure 5. Block diagram of the PID control system.

For determining the Gain value of the PID controller, a Close Loop Control system is employed by setting K_p to 1 and K_i, K_d to 0. The system's response is then measured, as illustrated in Figure 6. The Cohen-Coon tuning method's table is utilized to find the system's gain, with conditions for approximating values during the selection of gain, as depicted in Table 2. The Cohen-Coon tuning method, employed in the process, builds upon The Ziegler-Nichols method, incorporating more data from the system. This method relies on three variables - the steady state gain (a), the time delay (L), and the time constant (T) - to define the process. As this method utilizes more process data, it significantly improves control performance.

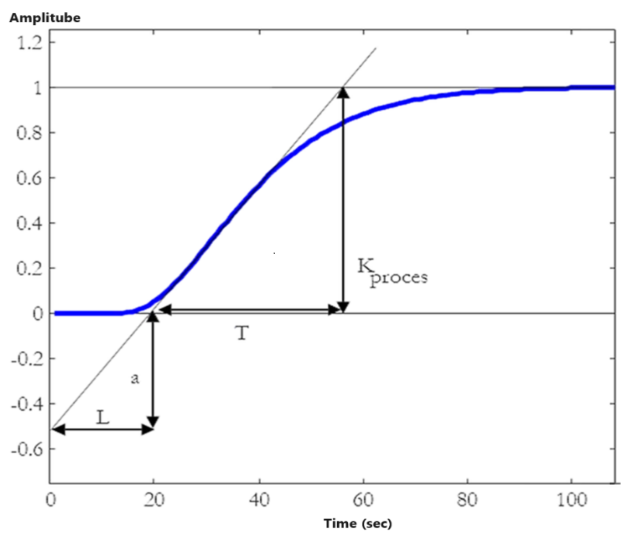

Figure 6. Block diagram of the PID control system.

Table 3. The mecanum wheelchair's system response utilizing P control

Cohen Coon	K_c	T_i	T_d
P Controller	$(1/\alpha)(1+((0.35\tau)/(1-\tau)))$		
PI Controller	$(0.9/\alpha)(1+((0.92\tau)/(1-\tau)))$	$((3.3-3.0\tau)/(1+1.2\tau))L$	
PD Controller	$(1.24/\alpha)(1+((0.13\tau)/(1-\tau)))$		$((0.27-0.36\tau)/(1-0.87\tau))L$
PID Controller	$(1.35/\alpha)(1+((0.18\tau)/(1-\tau)))$	$((2.5-2.0\tau)/(1-0.39\tau))L$	$((0.37-0.37\tau)/(1-0.81\tau))L$

$$\tau = L/(L+T) \tag{2}$$

$$a = K_p(L/T) \tag{3}$$

3. RESULTS

In the motor system's PID control testing, experiments were conducted by changing the speed from 0 RPS to 0.75 RPS using a Step input signal. The tested control systems included P Controller and PD Controller, with tuning performed using The Cohen-Coon tuning method and manual adjustments. In this design, the Integral term (I) was omitted in the PID control system for the Mecanum Wheelchair, as introducing values in the I term could compromise the stability of the motor system used in the wheelchair.

For the P Controller experiment, different K_p values (70, 80, 100) were designed for the electric wheelchair, observing the system response for each wheel (left-front, left-rear, right-front, right-rear) as depicted in Figure 7. The system responses under P control are summarized in Table 3. Notably, with a K_p value of 100, there was a high percentage overshoot (%Os) and a considerably higher setting time compared to the setpoint. In contrast, the K_p value of 70 showed a significantly lower setting time than the setpoint, lower than that of K_p = 80. However, the system did not experience %Os. The optimal performance was recorded at K_p = 80 under P control, with the lowest rise time and relatively low percent overshoot.

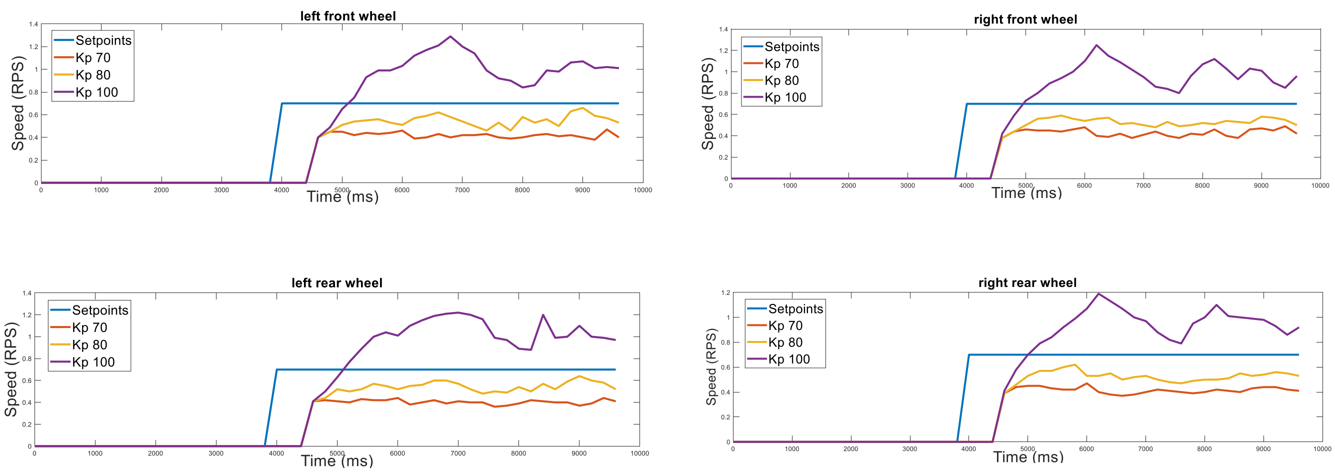

Figure 7. System response of a Mecanum Wheelchair employing P control

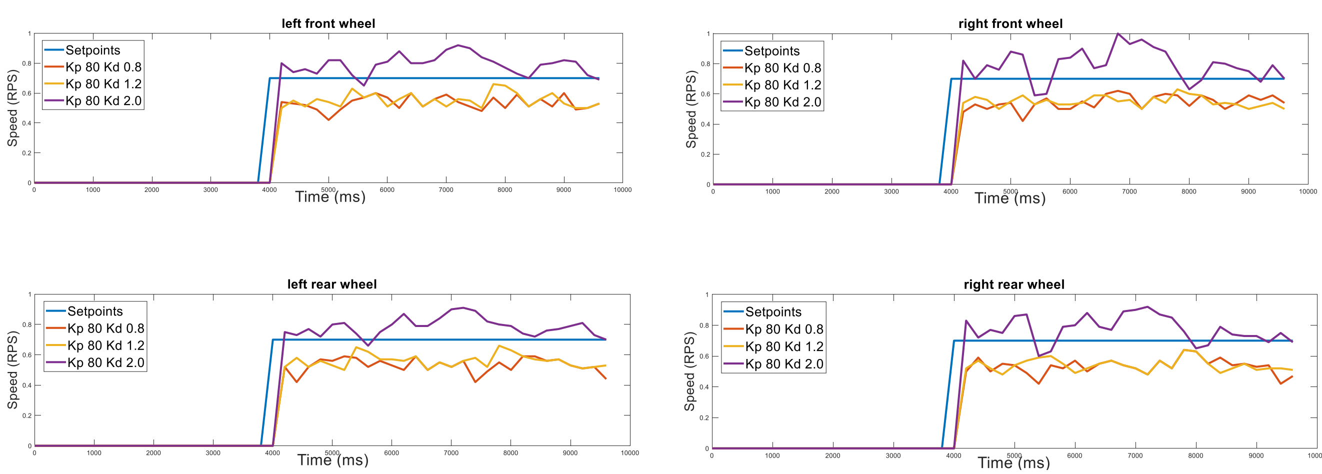

Figure 8. System response of a Mecanum Wheelchair employing PD control

Moving on to the PD Controller experiment with designed K_p at 80 and K_d at 0.8, 1.2, and 2, respectively, for the electric wheelchair, the system response for each wheel (left-front, left-rear, right-front, right-rear) was observed, as shown in Figure 8. The system responses under PD control are summarized in Table 4. With K_p = 80 and K_d = 2, there was a high %Os and a considerably higher setting time compared to the setpoint. On the other hand, Kp = 80 with K_d = 1.2 and 0.8 resulted in significantly lower setting times, closely matching each other in response. In summary, the combined proportional and derivative control under K_p = 80 and K_d = 1.2 demonstrated the best overall performance, improving system response speed, reducing rise time, improving setting time, and lowering percent overshoot.

These results highlight the effectiveness of combining proportional and derivative control in enhancing the performance of the Mecanum Wheelchair. The specific parameter values provide optimal response characteristics. The gain adjustments enable precise control, meeting the desired performance criteria for the Mecanum Wheelchair.

Table 3. The mecanum wheelchair's system response utilizing P control

Cotroller	Left front wheel			Left rear wheel			Right front wheel			Right rear wheel		
	Risetime (Sec)	Setting time (Sec)	%OS	Risetime (Sec)	Setting time (Sec)	%OS	Risetime (Sec)	Setting time (Sec)	%OS	Risetime (Sec)	Setting time (Sec)	%OS
Kp(70)	-	3.2	-32.86	-	3.2	-37.14	-	3.4	-30	-	3.4	-32.86
Kp(80)	-	3.8	-5.71	-	3.6	-8.57	-	3.8	-15.71	-	3.4	-11.43
Kp(100)	1.2	4.6	84.29	1.2	4.8	74.29	1.2	4.6	78.57	1.2	4.6	70

Table 4. The mecanum wheelchair's system response utilizing PD control

Cotroller	Left front wheel			Left rear wheel			Right front wheel			Right rear wheel		
	Risetime (Sec)	Setting time (Sec)	%OS	Risetime (Sec)	Setting time (Sec)	%OS	Risetime (Sec)	Setting time (Sec)	%OS	Risetime (Sec)	Setting time (Sec)	%OS
Kp(80), Kd(0.8)	-	1.6	-14.29	-	2	-15.71	-	2	-11.43	-	1.8	-12.86
Kp(80), Kd(1.2)	-	1.8	-5.71	-	2	-5.71	-	2.2	-10	-	2	-12.86
Kp(80), Kd(2)	0.4	2.6	31.43	0.4	2.8	30	0.4	4	42.86	0.4	4	31.43

CONCLUSIONS

In conclusion, this research investigated the application of PID control in the motor system of a Mecanum Wheelchair, employing P Controller and PD Controller configurations. The experiments involved tuning parameters using The Cohen-Coon method and manual adjustments, focusing on achieving optimal performance. For the P Controller, varying K_p values were tested, revealing that K_p = 80 yielded the most favorable outcomes, demonstrating the lowest rise time and relatively low percent overshoot. The PD Controller experiments with K_p = 80 and different K_d values indicated that K_d = 1.2 resulted in the best overall performance, exhibiting improved response speed, reduced rise time, enhanced setting time, and lower percent overshoot. The combination of proportional and derivative control, specifically with K_p = 80 and K_d = 1.2, proved to be the most effective in enhancing the Mecanum Wheelchair's performance. This study provides valuable insights into the precise parameter adjustments necessary for achieving optimal control and meeting the desired performance criteria for Mecanum Wheelchair applications.

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