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Unmanned Vehicle Steering Control System Using Proportional Control Algorithm

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Abstract— **Teleoperation vehicles such as Unmanned Ground Vehicles can be used for surveillance or exploration, including the detection of mines. PT. Pindad plans to develop a vehicle for minesweeping. In this research, a prototype of an unmanned vehicle system was built. The vehicle had a steering system that can be remotely controlled, which allows for more maneuverability. A Proportional Integrated and Derivative control was attached to the system as a method that we used in this research. The PID control has the ability to speed up and generate system responses according to user requirements. The experiment result showed that the system got a rise time response of 1.6 seconds and a steady state error of 0%, and the percentage comparison between the angle given by the remote control and the angle read by the rotary encoder is 97.89 %**.

***Index Terms*— PID; Remote control; Steering system; Ziegler-Nichols**

I. INTRODUCTION

A steering system on a vehicle is responsible for changing the vehicle's direction through the vehicle's front wheels [1]. Ackermann Steering System is a steering system used by cars in general [2]. The steering system is divided into two types, manual steering and power steering [3]. In a manual steering system, humans power is fully needed to turn the steer. While in the power steering system, the driving force is obtained from hydraulic or electric power that uses a driving motor [4]. Technological developments in the steering system are increasingly varied. Currently, an autonomous car has also been developed that can move on its own without having to be controlled by the driver. However, this research does not use an autonomous system because the autonomous system is not ready yet for all types of environments [5]. This research is used a remote control for the controller to make it more flexible in its use.

Teleoperated driving, also called teleoperator driving, is a technology that transitions to driverless systems. Teleoperator driving, as the name suggests, is controlled by a human operator via a communication network. A key advantage of teleoperated driving is that it allows humans to drive in complex situations where an autonomous vehicle cannot. Human operators can therefore drive in situations where human drivers can still perform appropriately despite the complex environment. Another benefit of teleoperated driving is its independence from high-precision road maps, which is one of the main limitations of autonomous driving [6].

This research aims to create a steering control system on an Information and Autonomous Control System (Inacos) laboratory electric car. The research is focused on making the steer turn according to the desired angle. We were using a remote control because this research becomes a prototype that will be implemented into the Badak Panzer belonging to PT. Pindad as a UGV (Unmanned Ground Vehicle). UGV which is one type of teleoperation vehicle, is a mechanical device with manual or automatic controls that can lift things above the ground without direct human involvement [7]. They are, usually used for surveillance or exploration task likes detects mine on the ground or landmine [8] [9]. This Badak Panzer will be used as a minesweeper war vehicle. Therefore, the Badak Panzer is controlled using a remote control, so it can be controlled from afar.

II. METHOD

A. General Method

This research is using the experimental method. We did some experiments with the steering system of an electric car belonging to Inacos laboratory as a prototype of Badak Panzer. In Inacos laboratory, researchers collected data from PID parameter values obtained from calculations using Ziegler-Nichols Method, then did some testing to steering system after implementing the PID parameter values to the system.

B. PID Controllers

PID controllers that consist of Proportional, Integral, and Derivative Controller is the most common feedback control [10]. PID controllers are often used in industrial plants because they are simple and robust

[11]. The PID is also widely used in a variety of applications such as automotive, robot motion control, process control, and aeronautics. PID offers a simple control strategy for fixing past (I), present (P) as well as future (D) errors. This makes PID the preferred control strategy for engineers because it is easy to implement and performs well without a precise analytical model of the system to be controlled. [12]. The stabilization of the system is needed in this research to make a perfect output response to control the steer of an electric car. PID control also has an advantage, simple to use, and easy to implement [13].

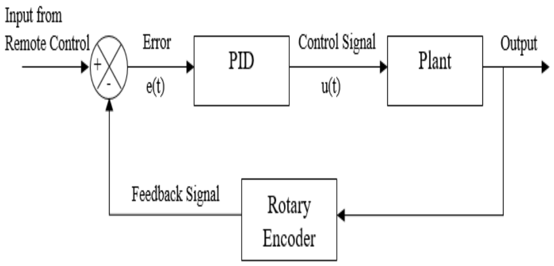

Fig. 1. PID diagram block system

The PID control block diagram is divided into several parts, there are:

- The input is the set point value of the remote control that controlled by the user and the error value that processed by the microcontroller
- PID control is a value that used to correct the error value and process it in order to eliminate/minimize errors
- The plant is a medium that controlled using an actuator in the form of a DC motor and produces an output in the form of PWM which will determine the direction of motion of the motor which will later determine the direction of the steering.

In this research, PID control is used to adjust the motor so that the output produced is not far from the rotation angle given by the remote control. To determine the PID parameter, the Ziegler-Nichols method is used. The reason for choosing PID is because it is easy to combine with other control methods such as Fuzzy and Robust. In addition, PID is a control to determine the precision of a system with the characteristics of the feedback on the system [14]. Feedback on this research is obtained from the rotary encoder.

Figure 1 shows that a rotary encoder is used as a sensor to read the direction and rotation of the DC motor. This is called as a closed loop system because the sensor is used as feedback of the system. The PID control calculates and gives a control signal value u(t) as a command for the plant to move, just as the remote control does. U(t) can be obtained from equation 1

$$U(t) = K_P e(t) + K_i \int e(t)\, dt + K_d \frac{de(t)}{dt} \qquad (1)$$

Where Kp is 20, Ki is 0, and Kd is 0. Those values were obtained based on tests that we did on the system. The value of the error system (e(t)) is obtained from the difference of input value and a feedback signal.

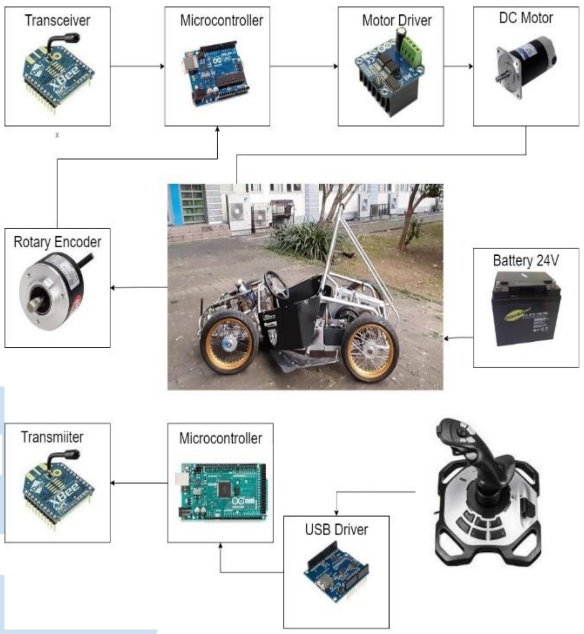

Fig. 2. Steering system using remote control

Based on figure 2, the steering system in this research is designed as a system on the steering of an electric car by adding a DC motor to the steering column to move the steering wheel according to the commands given by the remote control. To drive the steer, a DC motor is used as an actuator. The DC motor is connected to the steering column using a gear. The microcontrollers that will be used are Arduino Mega and Arduino Uno. Arduino Mega is used to forwarding commands from the remote control to the transmitter. At the same time, Arduino Uno functions as a signal processor obtained from the transceiver which is forwarded to provide pulses to drive the motor.

The communication system used for data communication from the remote control to the microcontroller is radio frequency. To ensure that the rotation on the steering wheel is in accordance with that given by the remote control, a sensor is used to check the angle generated by the motor. The controller method used is the PID method. If it is not appropriate, then the sensor will give a feedback signal or feedback to the microcontroller that the steering angle is not appropriate. Then the microcontroller will give a command to the motor to move the steering wheel to match the signal given by the microcontroller.

C. Ziegler-Nichols Method

Ziegler-Nichols method is a method that uses to looking for PID parameter values. There are many methods used for PID controllers, but none has replaced the Ziegler Nichols method [15]. PID parameter value can be obtained by calculating some value to Ziegler-Nichols tuning rule on the table I

TABLE I. ZIEGLER-NICHOLS TUNING RULE

Control Type	**Kp**	**Ti**	**Td**	**Ki=Kp/Ti**	**Kd=TdKp**
PID (classic)	0.6Ku	Tu/2	Tu/8	1.2Ku/Tu	0.075KuTu
P	0.5Ku	-	-	-	-
PI	0.45Ku	Tu/1.2	-	0.54Ku/Tu	-
PD	0.8Ku	-	Tu/8	-	0.1KuTu
Pessen Integration	0.7Ku	2Tu/5	3Tu/20	1.75Ku/Tu	0.105KuTu
Some overshoot	Ku/3	Tu/2	Tu/3	(2/3)Ku/TU	(1/9)Ku/TU
No overshoot	0.2Ku	Tu/2	Tu/3	(2/5)Ku/TU	(1/15)Ku/TU

In the design of PID control, Kp, Ki, and Kd parameters are needed. To get the value of each of these parameters, the author uses the Ziegler-Nichols method. At the time of tuning obtained the value of Ku= 50 and Tu = 0.12. To use this tuning rule, we must find the Ku and Tu values first. Ku ultimate gain is a condition of sustained oscillations. The period of sustained oscillations is designated as Tu. The first step to use the method is to insert the Kp value only. Then changes Kp value until we get the constant oscillation. After we get the constant oscillation, we obtained critical gain or Ku. Next, we can obtain Tu from the period value when the output response has constant oscillation [15]. We will take the PD parameter value as an example for the calculation. Here is an example of the calculation.

PD value is consists of Kp and Kd. Based on the table, to get the Kp and Kd we use the equation from PD row.

- Kp = 0.8Ku

  Kp = 0.8(50)

  Kp = 40

- Kd = 0.1KuTu

  Kd = 0.1(50)0.12

  Kd = 0.6

  So we get Kp = 40 and Kd = 0.6

From the calculation in this research, the PID parameter value are

TABLE II. PID PARAMETER VALUE

	Kp	**Ki**	**Kd**
PID	30	500	0.45
P	25	0	0
PI	22.5	225	0
PD	40	0	0.6

D. Remote Control 3D Pro Joystick

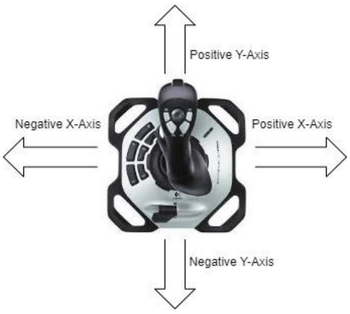

Fig. 3. 3D pro joystick axis illustration

A joystick is an electronic device that can translate the movements of a user's hand into digital signals that can be translated into computer language. Based on its basic design, a joystick consists of a flexible stick that is attached to a circuit board. This circuit board is connected to the computer. This circuit carries electricity from one point of contact to another. In the neutral position (without pushing or pulling the lever control), the conductive material on the circuit board does not generate electricity. Therefore, the circuit will not send a signal to the computer. This research using USB Host Shield to connecting remote control or joystick to the microcontroller.

The 3D Pro Joystick is the remote control used in this research. The reason for using this joystick is because it has many buttons and is very flexible in its use. In use, the joystick is defined as having two axes, namely the X-axis and the Y-axis. The illustration is shown at figure 3. The X-axis consists of a negative X-axis and a positive X-axis. The negative X-axis is a command to turn left, while the positive X-axis is a command to turn right. The Y-axis consists of a negative Y-axis and a positive Y-axis. The negative Y-axis is a command for braking and the positive Y-axis is a command for accelerating.

E. Configuration Communication Device

Fig. 4. XBee S2C module

The XBee S2C module is used as a radio communication medium to connect a remote control to the electric car. There needs to be an exchange of information, or communication, between the remote control and the steering system's microcontroller. As part of this communication, the remote control will send commands to the XBee (transmitter) for forwarding to XBee (transceiver), which will then send the commands back to the steering system's microcontroller for processing.

Digi International offers a 2.4GHz XBee model that's standardized with IEEE 802.15.4, with low power consumption for short distances [16]. There are two modules used, the first one as a transmitter and the second as a transceiver. Configuration of both S2C XBee devices can be done using the XCTU software. Here is the configuration of the two XBee S2C devices using the XCTU software.

TABLE III. CONFIGURATION TRANSMITTER AND TRANSCEIVER XBEE

Parameter	Transmitter	Transceiver
Channel	C	C
PAN ID	107	107
DH	0	0
DL	FFFF	0
MY	0	0
CE	Coordinator [1]	End Device [0]
BD	115200 [7]	115200 [7]

F. Steering System's Flowchart

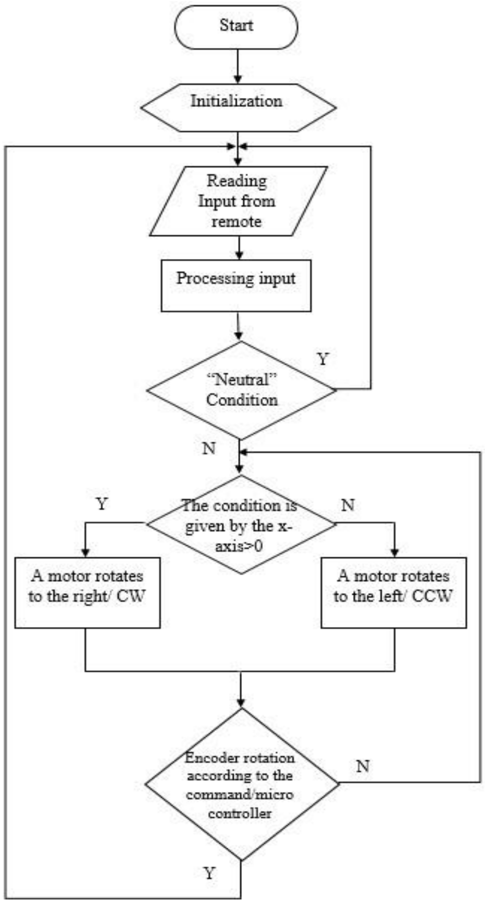

Fig. 5. Steering System's Flowchart

The figure above is a flowchart for the steering control system that has been designed. Starting from the start which is continued by initializing the input and output pins. Then read the input signal from the remote control that controlled by the user. After that, the input signal is sent by the transmitter and then the transceiver will receive and processed by the microcontroller. If there is a command to change the steering direction from the remote control, the microcontroller will send a signal to the DC motor to move the steer according to the command given. After the steer is moved, the sensor will read whether the angle that is driven is in accordance with the commands given by the remote control. If it is not suitable then the DC motor will move the steer until it gets the desired angle. If appropriate, it will return to the input reading state to wait for the next command.

III. TESTING AND RESULT

A. PID Control Parameters Testing

The PID parameter was tested using values obtained from the previous method. The values were placed on the system and compared with the predetermined set point outcome to test which response was better. The set point specified in this test is 70.

1) Kp=30, Ki=500, Kd=0.45

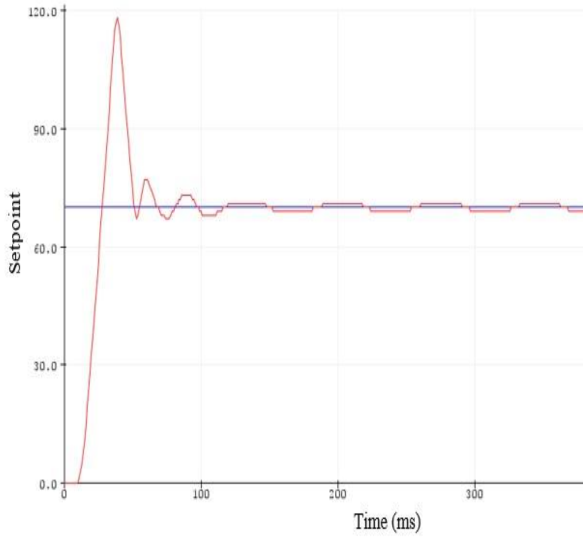

Fig. 6. Kp=30, Ki=500, Kd=0.45 response

Figure 6, shows that the DC motor's response can respond to the set point quickly, which is indicated by a rise time of 0.2 seconds. There is also a large overshoot, which is 68%. However, the steady state error is small, which is close to 5%.

2) Kp=25, Ki=0, Kd=0

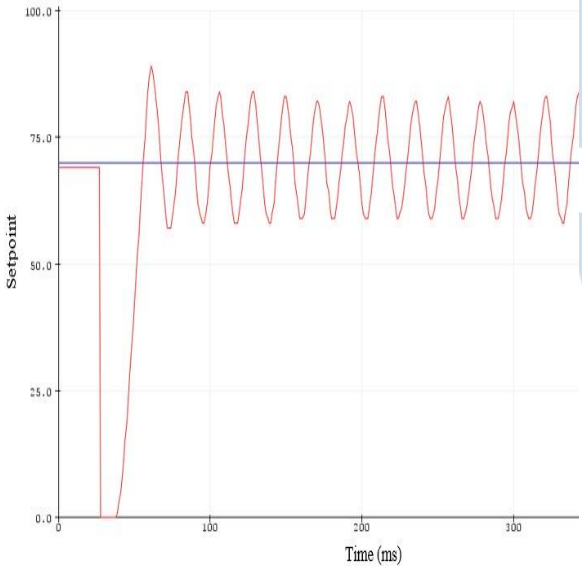

Fig. 7. Kp=25, Ki=0, Kd=0 response

Figure 7 shows that the response of the DC motor to the set point is slower than the previous PID value, indicated by a rise time of 0.4 seconds. The resulting overshoot is reduced to 22.8%. However, the steady state error increases to 14.2%.

3) Kp=22.5, Ki=225, Kd=0

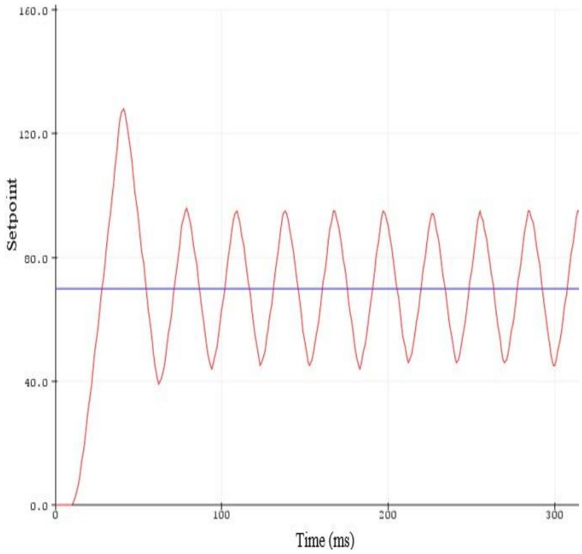

Fig. 8. Kp=22.5, Ki=225, Kd=0 response

Figure 8 shows that the DC motor's response can respond to the set point quickly as indicated by the rise time approaching 0.2 seconds. The overshoot is greater than the two previously tested PID values, which is 85%. The steady state error is also greater, namely 42.8%.

4) Kp=40, Ki=0, Kd=0.6

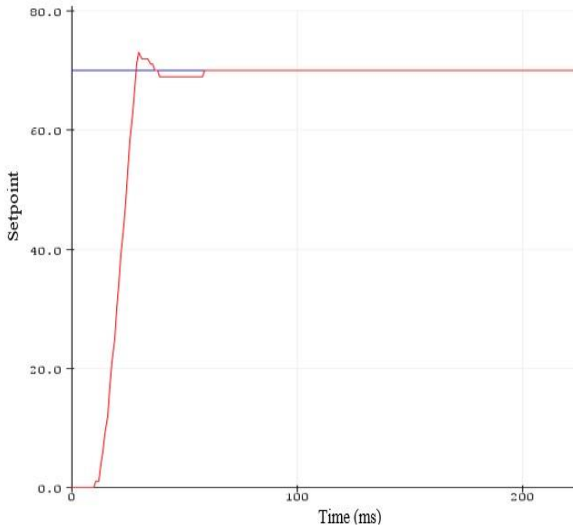

Fig. 9. Kp=40, Ki=0, Kd=0.6 response

Figure 9 shows that the system response is getting better. It was shown by 0.2 seconds of rise time and overshoot, which decreased drastically from the previous tuning value, 4.2%. The steady state error is also close to 0% and the system has received a response according to the predetermined set point. After testing several PID parameter values, the last parameter value was chosen, Kp= 40, Ki=0, Kd=0.6. However, when applied to the system using a remote control, the DC motor movement becomes very slow and does not respond according to the target given by the remote control.

As a solution, the PID parameters Kp=20, Ki=0, and Kd=0 are chosen. This value is selected based on the results of the experiment testing parameter 2. The reason is because of all the values tested, the results given are better responses because they have a fast rise time and smaller overshoot than other parameter values. The following is a graph of the output response of these parameter values.

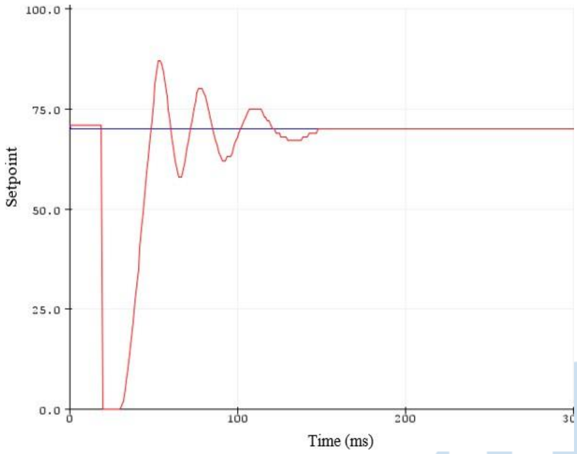

Fig. 10. Kp=20, Ki=0, Kd=0 response

Figure 10 shows that the results of the specified parameter values have a rise time of 0.3 seconds and an overshoot of 22.85%. The steady state error of the system is also close to 0%. The value of this parameter is used in the steering control system in this research.

B. *Steering System Testing*

After determining the value of the PID parameter, a trial was carried out on the steering of an electric car. The steering test on an electric car is by testing the car when turning right and turning left. There is a rotary encoder as a rotation sensor on the DC motor and feedback for the system that has been made. The rotary encoder is mounted on a DC motor using a shaft connected to the gear that is used to drive the steering column.

At testing, an additional component was used MPU6050 module, as a sensor that functions to determine the orientation of the direction based on angular momentum. As a calculation to get the angle from the rotary encoder, the formula is used to divide the PPR rotary encoder, which is 600 by 1.667, to produce an angle of 360 or can be seen in equation 2 below

$$360° = \frac{PPR}{x} \qquad (2)$$

$$x = \frac{600}{360^0}$$

$$x = 1.667$$

Where:

PPR: pulse per revolution rotary encoder (600)

x: the value of angle

After the value of x is found, the value of x is entered into the program to convert the rotary encoder value into an angle, and then testing is carried out. Here are the test results.

TABLE IV. TURNING RIGHT TEST

No	Steering angle (remote control)	Steering angle (rotary encoder)	Wheel angle	Time (second)
1	45.59°	43.19°	5.40°	01.71
2	66.59°	64.19°	11.21°	02.27
3	87.58°	90.58°	15.04°	01.58
4	95.98°	92.38°	20.28°	01.25
5	107.98°	107.38°	23.91°	01.63

TABLE V. TURNING LEFT TEST

No	Steering angle (remote control)	Steering angle (rotary encoder)	Wheel angle	Time (second)
1	41.39°	37.79°	5.65°	1.53
2	61.79°	58.79°	10.78°	1.73
3	70.98°	70.79°	15.26°	1.54
4	102.58°	97.78°	20.36°	1.68
5	107.98°	109.18°	24.36°	1.82

The test data in Tables IV and V show a big difference between the target and steering angles from the remote control and rotary encoder. While the comparison between the angle given by the remote control and the rotary encoder is not too much different. In the table, it can also be calculated that turning the wheel one degree takes 4.5-7° on the motor to achieve the desired angle according to the target. When measuring the wheel angle with the steering angle, there is a large enough difference. In table VI, there is a difference of about 30° between the angle on the wheel and the steer. This is reasonable because there are some factors from steering electric car's mechanical.

Steering electric car's mechanical this research is not using a steering mechanism as most common cars do. A common car uses a rack and pinion system for steering and Inacos' electric car does not. The mechanical of Inacos' electric car consists of the steering column and tie rod of the car's wheel connected as one. So there is a little bit difficult to calculate the error of the steering car's mechanical. This research also focused on the electrical part only which is the ratio of angle from the remote control and the angle produced by the DC motor.

TABLE VI. MANUAL TURNING STEERING TEST

No	Wheel angle	Steering angle
1	15.64º	46.72º
2	20.48º	53.65º
3	34.62º	66.83º

IV. CONCLUSION

After testing the application of PID on the electric car steering system, the ratio between the angle given by the remote control and the angle read by the rotary encoder is not too far, which is at 2-5º. The time required for the DC motor to reach the desired angle ranges from 1.5 to 2 seconds. It's just that there is a significant difference in the angle given by the remote control with the angle on the wheel. This can be caused by several factors, one of which is the steering car's mechanical. In the designed steering control system, gear connects the DC motor to the steering column.

We initially used a gear ratio of 1:1, but the DC motor cannot turn the wheels easily. As a result, the DC motor and the motor driver quickly overheat. Then the gear ratio is changed to 1:2. The existence of a gear ratio of 1:2, the difference between the steering angle, and the tire angle of 30º can make the DC motor rotate at a bigger angle to produce the wheel angle that is on target. Based on the table IV and V, the comparison or comparison between the angle produced by the remote control and the angle produced by the DC motor, which is then read by the rotary encoder, has a slight difference with an accuracy of 97.89% and a steering control system can be designed according to the direction given by the remote control using PID control with only P controller with Kp=20.

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