# Design of Path Tracking System on Smart Wheelchair 

${ }^{1}$ Achmad Hidayatno, ${ }^{2}$ Sumardi, ${ }^{3}$ Aghus Sofwan, ${ }^{4}$ M Hilal Bayu Aji, ${ }^{5}$ M. Arfan, ${ }^{6}$ Yosua Alvin Adi Soetrisno<br>${ }^{1}$ Department of Electrical Engineering, Diponegoro University, Semarang, Indonesia achmad.hidayatno@gmail.com<br>${ }^{2}$ Department of Electrical Engineering, Diponegoro University, Semarang, Indonesia sumardi.undip@gmail.com<br>${ }^{3}$ Department of Electrical Engineering, Diponegoro University, Semarang, Indonesia aghus.sofwan@gmail.com<br>${ }^{4}$ Department of Electrical Engineering, Diponegoro University, Semarang, Indonesia mhilalbayuaji@gmail.com<br>${ }^{5}$ Department of Electrical Engineering, Diponegoro University, Semarang, Indonesia arfan@ft.undip.ac.id<br>${ }^{6}$ Department of Electrical Engineering, Diponegoro University, Semarang, Indonesia yosua@live.undip.ac.id


#### Abstract

Wheelchairs have developed with several additional functions, namely the use of DC motors as actuators. This wheelchair is controlled with a joystick so that it is easier to operate. Then the wheelchair can map its orientation and movement position. Mapping using a rotary encoder sensor, then drawn in two dimensions on a laptop. Wheelchairs still require manual steering control during movement. Therefore, the development carried out in this design is a wheelchair able to move automatically to a predetermined position and orientation, using the path tracking method. The calculation is based on the results of mapping the position and relative orientation. Calculations produce the distance and angle that a wheelchair must travel. Integral proportional control (PI) is used to keep the actual orientation angle's value close to the reference value. In the path tracking test, the wheelchair can approach the reference position in all tests. The most significant error is equal to 0.57 cm on the $x$-axis and 1.03 cm on the $y$-axis, namely in testing the reference position of (200.1105) cm from the position (0.1105) cm


Keywords- wheelchair, path tracking, proportional-integral control

## 1. Introduction (Heading 1)

A wheelchair is a tool that is usually used by someone who has difficulty walking due to illness or accident. The use of a conventional wheelchair is quite tricky for some people because it requires others' help. If there is no one else to help, the wheelchair user must operate independently by turning it.

Wheelchairs have developed with several additional functions, namely the use of DC motors as actuators. This wheelchair is controlled with a joystick so that it is easier to operate [1,2]. Then the wheelchair can map its orientation and movement position. Mapping using a rotary encoder sensor, then drawn in two dimensions on a laptop [2]. Wheelchairs still require manual steering control during movement.

Therefore, the design's development is a wheelchair capable of moving automatically to a predetermined position and orientation. The calculation in this design is based on the relative position and orientation mapping, which will produce the distance and angle orientation that the wheelchair will travel. Hopefully, this ability to move automatically can help the user.

## 2. DESIGN AND METHOD

### 2.1 Hardware Design

The wheelchair has two wheels, which both of them are driven by a DC motor. It will use a differential motion system. Each wheel has a radius length of $29,2 \mathrm{~cm}$, and the distance between each wheel is 60 cm . Its physical form is shown in figure 1.

The DC motor is chained to the wheel and a rotary encoder sensor. The gear comparison of DC motors, rotary encoder sensor, and the wheels with values of 10:10:48. Figure 2 shows the connection of those.


Figure 1. Mechanical design, (a) front view, (b) back view, (c) side view


Figure 2. Connection of DC motor, rotary encoder sensor, and the wheels

### 2.2 Odometry System Design

Odometry is the use of data from actuator movements to estimate position changes over time. Odometry is used to estimate position relative to the initial position. The output number of pulses from the rotary encoder sensor converted to a distance unit is used to estimate the relative position of the wheelchair [3-9].

The rotary encoder resolution value or pulse value in one full rotation, read by the microcontroller, is 1920 pulses. Thus, the wheel circumference and distance can be calculated by equations (1) and (2).

$$
\begin{align*}
& \text { Circumference }=2 * \pi * r  \tag{1}\\
& \text { Circumference }=183.6 \mathrm{~cm} \\
& \text { distence }=\text { Puls } * \frac{\text { circumference }}{\text { rotary encoder resolution }} \tag{2}
\end{align*}
$$

There are two separate drive wheels in the differential drive system, namely the left wheel and right wheel. If the distance traveled by each wheel is d_Left and d_Right, and the distance between two wheels is L , then the actual distance and orientation angle can be obtained. For the equation as follows:
$d_{-}$Left $=$Puls_Left $* \frac{183.6}{1920}$
$d_{-}$Right $=$Puls_Right $* \frac{183.6}{1920}$
d_Aktual $=\frac{d_{-} \text {Left }+d_{-} \text {Right }}{2}$
angle_orientation $=\frac{-d_{-} L e f t+d_{\text {_Right }}}{L}$
angle_orientation $=\frac{-d_{-} \text {Left }+d_{\text {_Right }}}{60}$

Because angle_orientation is still in units of radians, to change it in units of degrees (heading), then use the following equation:
heading $=$ angle_orientation $* \frac{180}{\pi}$
heading $=$ angle_orientation $* \frac{180}{3,1416}$

After knowing d_Aktual and angle_orientation, it can be seen the position at Coordinate $\mathrm{X}\left(\operatorname{Pos}_{X}\right)$ and Coordinate Y $\left(\mathrm{Pos}_{y}\right)$, using the following equation:

Pos $_{X}=$ save $_{x}+d_{-}$Aktual $* \cos ($ angle_orientation $)$
(6)

$$
\begin{equation*}
\operatorname{Pos}_{Y}=\text { save_} y+d_{-} \text {Aktual } * \sin (\text { angle_orientation }) \tag{7}
\end{equation*}
$$

The actual distance value calculation will reset back to equal 0 if completed in one movement cycle. The value of $\operatorname{Pos}_{X}$ and $\operatorname{Pos}_{y}$ at the end of the movement will be the initial value on the next move saved to save_x and save_y.

### 2.3 Path Tracking System Design

Path tracking is the process of setting the distance and angle orientation so that the object, in this case, the wheelchair, can follow a specific path consisting of points (paths) to reach the specified destination [10-17]. Equations (8) and (9) are used to calculate the distance and orientation angle that a wheelchair must travel.

$$
\begin{align*}
& \text { Error }_{X}=\text { Destination }_{X}-\text { Pos }_{X}  \tag{8}\\
& \text { Error }_{Y}=\text { Destination }_{Y}-\text { Pos }_{Y} \tag{9}
\end{align*}
$$

$\operatorname{Pos}_{X}$ is the actual position of the x -axis, and $\operatorname{Pos}_{Y}$ is the actual position of the $y$-axis. While Destination $_{X}$ dan Destination $_{Y}$ are the position to be directed towards the x axis and $y$ - axis.

After the position error on each axis is known, calculating the distance and orientation angle must be taken to reach the goal with equations (10) and (12).

$$
\begin{align*}
& d_{-} \text {destination }=\sqrt{\text { Error }_{X}{ }^{2}+\text { Error }_{Y}{ }^{2}}  \tag{10}\\
& \text { angle_error }=\text { atan } \frac{\text { Error}_{Y}}{\text { Error }_{X}}  \tag{11}\\
& \text { angle } \\
& \text { destination }=\text { angle_error }- \text { angle_orientation } \\
& (12)
\end{align*}
$$

d_destination and angle_destination are the distance and angle of orientation that must be traveled to reach the goal.

An area map in the Cartesian coordinates used in this study can be seen in Figure 3.


Figure 3. The area plan

### 2.4 Design of Integral Proportional Control Systems

PI control is used to maintain the angle orientation value so that the wheelchair will move according to the angle orientation that has been set. The design of PI control uses the Ziegler Nichols II tuning method. The first step is to create a closed-loop system that then only utilizes proportional controls. The second step is to increase the proportional value so that the system response will oscillate continuously [18-25].

At a reinforcement value of 0.375 , the system undergoes continuous oscillation. System response can be seen in Figure 4.


Figure 4. System response from integral proportional control

The system response in the picture has a period for one wave of 1.062 s . Based on the Ziegler Nichols II method, the calculations for the PI control parameters are as follows:

The known value of $\mathrm{Kcr}=0.375$ and $\mathrm{Pcr}=1.062 \mathrm{~s}$.

- Proportional Control Constant Value (Kp)

$$
\begin{aligned}
& K p=0,45 * K c r \\
& K p=0,45 * 0,375 \\
& K p=0,16875 \approx 0,17
\end{aligned}
$$

- Integral Control Constant Value (Ki)

$$
\begin{aligned}
& \tau_{i}=\frac{1}{1,2} P c r \\
& \tau_{i}=\frac{1}{1,2} 1,062 \\
& \tau_{i}=0,885 \\
& K i=\frac{K p}{\tau_{i}} \\
& K i=\frac{0,16875}{0,885} \\
& K i=0,190677966 \approx 0,19
\end{aligned}
$$

## 3. RESULT AND ANALYSIS

The test will begin by putting the wheelchair at a predetermined position, namely at zero point. Then the user will set the destination position value as its input.

### 3.1 Moving Test From Zero Point to the Living Room

Based on figure 3, the area plan, the living room is at coordinates $(30,0) \mathrm{cm}$. Figure 5 shows the result of the sensor readings on the wheelchair's final position.

Based on sensor readings on the wheelchair final position, there is a slight error between position reference with the actual position. The position reference is $(30,0) \mathrm{cm}$, and the actual position is $(30.35,0.7) \mathrm{cm}$. So the error value at the $x$-axis is 0.35 cm , and the error value at the y -axis is 0.7 cm . The error occurs due to the oscillation of movement in the wheelchair, which is another effect of using the PI control to maintain the angle orientation value and continuous motion due to the dc motor's nature, which does not lock the final position.


Figure 5. The value of the final position on moving test to the living room

### 3.2 Moving Test from Zero Point to the Dining Room

The dining room is located at coordinates $(-30,545) \mathrm{cm}$. The path that a wheelchair must take is divided into two destination positions, the first destination is at coordinates $(0.545) \mathrm{cm}$, and the second destination is at coordinates $(-$ $30,545) \mathrm{cm}$.

Figure 6 shows the sensor readings' result on the wheelchair's final position in the first destination.


Figure 6. The value of the final position on the first destination of moving test to the dining room

The wheelchair carries out two motions, namely rotary and straight motions. In a rotary motion, the final position of the wheelchair is at coordinates $(0.2,-13.05) \mathrm{cm}$, then in a straight motion, the final position at coordinates ($1.94,544.96) \mathrm{cm}$. The final position of the wheelchair is close to the reference position is $(0,545) \mathrm{cm}$, so that the error value at the x -axis is 1.94 cm , and the error value at the y axis 0.04 cm . This is due to the oscillation of motion, which is another effect of PI control to maintain the orientation angle value of $89.97^{0}$. The distance tolerance for the program is $\pm 1 \mathrm{~cm}$. The final position value of the wheelchair in the second movement can be seen in figure 7 .


Figure 7. The value of the final position on the second destination of moving test to the dining room

The wheelchair can now approach the reference point of $(-30,545) \mathrm{cm}$ by doing two movements, namely turning and straight motion. The turning motion makes the wheelchair's final position at coordinates $(-2.71,544.96) \mathrm{cm}$, making that as the straight motion's initial position. The final position of the straight motion is at coordinates ($30.52,545.18) \mathrm{cm}$. From that data, we can get the error value at the x -axis is 0.52 cm and at the y -axis is 0.18 cm . This is
due to the oscillation of motion, which is another effect of PI control to maintain the orientation angle value of 179.710, and continued motion due to the dc motor's nature, which does not lock the final position.

### 3.3 Moving Test from Zero Point to the Bedroom

Based on the area plan, the bedroom is at coordinates $(30,770) \mathrm{cm}$. The path that a wheelchair must take is divided into two destination positions, the first destination is at coordinates $(0,770) \mathrm{cm}$, and the second destination is at coordinates $(30,770) \mathrm{cm}$.


Figure 8. The value of the final position on the first destination of moving test to the bedroom

Figure 8 shows the sensor readings' result on the wheelchair's final position in the first destination.

The wheelchair makes two moves, namely turning and straight motion, to reach the first destination. The turning motion's final position is at coordinates $(0.03,-6.60) \mathrm{cm}$, and the final position of the straight movement is at coordinates $(3.24,770.20) \mathrm{cm}$. Because the position reference is at coordinates $(0,770) \mathrm{cm}$, it can be seen that the error value at the x -axis is 3.24 cm and at the y -axis is 0.2 cm . This is due to the oscillation of motion, which is another effect of PI control to maintain the orientation angle value of $89.99^{\circ}$. The distance tolerance for the program is $\pm 1 \mathrm{~cm}$.


Figure 9. The value of the final position on the second destination of moving test to the bedroom

Vol. 5 Issue 4, April - 2021, Pages: 42-48

From the coordinates $(3.24,770.20) \mathrm{cm}$, the wheelchair makes a turning motion and has a final position at coordinates $(-12.73,770.49) \mathrm{cm}$ which then the wheelchair makes a straight motion and has a final position at coordinates $(29.81,770.13) \mathrm{cm}$. Based on the coordinates' final position reference $(30,770) \mathrm{cm}$, the error value at the x axis is 0.19 cm , and the error value at the $y$-axis is 0.13 cm . This is due to the oscillation of motion, which is another effect of PI control to maintain the orientation angle value of 359.570 . Continuous motion is due to the dc motor's nature, which does not lock the final position.

### 3.4 Moving Test From Zero Point to the Toilet

The toilet is at coordinates $(200,1135) \mathrm{cm}$. The path that a wheelchair must take is divided into three destination positions. The first destination is at coordinates $(0,1105) \mathrm{cm}$. The second destination is at coordinates $(200,1105) \mathrm{cm}$, and the third destination is at coordinates $(200,1135) \mathrm{cm}$.

Figure 10 shows the sensor readings' result on the wheelchair's final position in the first destination.


Figure 10. The value of the final position on the first destination of moving test to the toilet

Based on the results of sensor readings, the wheelchair can now approach the reference position at coordinates $(0,1105) \mathrm{cm}$ by making a rotary and straight motion. The final position after the wheelchair takes the turning motion is at coordinates $(0.04,-7.51) \mathrm{cm}$, and continued by the straight motion with the final position of the wheelchair is at coordinates $(-0.68,1104.28) \mathrm{cm}$. Based on the reference and the final position after taking the straight motion, the error value at the x -axis is 0.68 cm and at the y -axis is 0.72 cm . This is due to the oscillation of motion, which is another effect of PI control to maintain the orientation angle value of $89.99^{0}$. The distance tolerance for the program is $\pm 1 \mathrm{~cm}$.


Figure 11. The value of the final position on the second destination of moving test to toilet

The wheelchair can now approach its final position reference at $(200,1135) \mathrm{cm}$, which is done by making two motions: rotary and straight motion. The turning motion's final position is at coordinates $(201.19,1097.34) \mathrm{cm}$, while the straight motion's final position, which was done after making the turning motion, is at coordinates $(199.43,1136.03) \mathrm{cm}$. So based on that, it can be seen that the error value at the $x$-axis is 0.57 cm and at the $y$-axis is 1.03 cm . This is due to the oscillation of motion, which is another effect of PI control to maintain the orientation angle value of 91.80 . Continuous motion is due to the dc motor's nature, which does not lock the final position.


Figure 12. The value of the final position on the third destination of moving test to the toilet

## 4 Conclusion

Moving west from the zero point to the bedroom with a reference position of $(30,770) \mathrm{cm}$, resulting in the actual position closest to the reference position, the error value at the x -axis is 0.19 cm , and the error value at the y -axis is 0.13 cm . The moving test from the zero point to the toilet with the reference position $(200,1135) \mathrm{cm}$ produces the actual position that is mostly away from the reference position. The
error value at the x -axis is 0.57 cm and at the y -axis is 1.03 cm . The error value is not affected by the magnitude of the reference position value. The error occurs because of the oscillation of movement, which is another effect of using the PI control to maintain the actual orientation angle's value to the reference orientation angle. Also, the program's distance tolerance is $\pm 1 \mathrm{~cm}$, but the error in all tests' final destination is due to the dc motor's nature, which does not lock the final position.

## Reference

[1] Yunanto DC, Khoswanto H, Santoso P. Sistem Kendali dan Pemantauan Kursi Roda Elektrik. Jurnal Teknik Elektro. 2016 Sep 15;9(2):43-8.
[2] Setiawan I, Akrom IF, Darjat D. PEMETAAN POSISI DAN ORIENTASI KURSI RODA CERDAS BERBASIS PRINSIP DEAD RECKONING. Transmisi.;11(2):77-83.
[3] Khoswanto H, Santoso P, Lim R. Odometry Algorithm with Obstacle Avoidance on Mobile Robot Navigation. InProceedings of Second International Conference on Electrical Systems, Technology and Information 2015 (ICESTI 2015) 2016 (pp. 155-161). Springer, Singapore.
[4] Kim HS, Seo W, Baek KR. Indoor positioning system using magnetic field map navigation and an encoder system. Sensors. 2017;17(3):651.
[5] Dikairono R, Rachman AA, Sardjono TA, Purwanto D. Motion planning simulator for holonomic robot soccer platform. In2017 International Seminar on Intelligent Technology and Its Applications (ISITIA) 2017 Aug 28 (pp. 368-371). IEEE.
[6] Taufiqqurohman M, Sari NF. Odometry Method and Rotary Encoder for Wheeled Soccer Robot. InIOP Conference Series: Materials Science and Engineering 2018 Aug (Vol. 407, No. 1, p. 012103). IOP Publishing.
[7] Toledo J, Piñeiro J, Arnay R, Acosta D, Acosta L. Improving odometric accuracy for an autonomous electric cart. Sensors. 2018;18(1):200.
[8] Redden LK, Anderson K, Pell EW, Ostrowski JP, inventors; BLUE RIVER Tech Inc, assignee. System and method for automated odometry calibration for precision agriculture systems. United States patent application US 16/153,824. 2019 Mar 28.
[9] Jin J, Chung W. Obstacle Avoidance of Two-Wheel Differential Robots Considering the Uncertainty of Robot Motion on the Basis of Encoder Odometry Information. Sensors. 2019 Jan;19(2):289.
[10] Bayar G, Bergerman M, Koku AB. Improving the trajectory tracking performance of autonomous orchard vehicles using wheel slip compensation. Biosystems Engineering. 2016 Jun 1;146:149-64.
[11] Setiawan YD, Nguyen TH, Pratama PS, Kim HK, Kim SB. Path tracking controller design of four wheel independent steering automatic guided vehicle.

International Journal of Control, Automation and Systems. 2016 Dec 1;14(6):1550-60.
[12] Myint C, Win NN. Position and velocity control for two-wheel differential drive mobile robot. International Journal of Science, Engineering and Technology Research (IJSETR). 2016 Sep;5(9):2849-55.
[13] Al-Dahhan MR, Ali MM. Path tracking control of a mobile robot using fuzzy logic. In2016 13th International Multi-Conference on Systems, Signals \& Devices (SSD) 2016 Mar 21 (pp. 82-88). IEEE.
[14] Barbulescu V, Marica I, Gheorghe V, Nistor M, Patrascu M. Encoder-based path tracking with adaptive cascaded control for a three omni-wheel robot. In2017 16th RoEduNet Conference: Networking in Education and Research (RoEduNet) 2017 Sep 21 (pp. 1-6). IEEE.
[15] Zhong M, Zhao H, Yang Y, Zhang J. Design of Trajectory Tracking Controller for Four Wheel Mobile Robot Based on Lyapunov Direct Method. In2018 International Symposium in Sensing and Instrumentation in IoT Era (ISSI) 2018 Sep 6 (pp. 1-6). IEEE.
[16] Zamzuri H, Ariff MH, Hamid UZ. Path Tracking on Autonomous Vehicle for Severe Maneuvre. Telkomnika. 2018 Aug 1;16(4):1583-9.
[17] Fahmizal F, Rijalussalam DU, Mayub A. Trajectory Tracking pada Robot Omni dengan Metode Odometry. Jurnal Nasional Teknik Elektro dan Teknologi Informasi. 2019 Mar 8;8(1):35-44.
[18] Antony AP, Varghese E. Comparison of performance indices of PID controller with different tuning methods. In2016 International Conference on Circuit, Power and Computing Technologies (ICCPCT) 2016 Mar 18 (pp. 1-6). IEEE.
[19] Nafea M, Ali AR, Baliah J, Ali MS. Metamodel-based Optimization of a PID Controller Parameters for a Coupled-tank System. Telkomnika. 2018 Aug 1;16(4).
[20] Budianto A, Pambudi WS, Sumari S, Yulianto A. PID Control Design for Biofuel Furnace using Arduino. Telkomnika. 2018 Dec 1;16(6).
[21] Kang Y, She J, Xu W, Li Q, Jin H. Design of Threering Nesting Cascade PID Controller of Full-auto Twowheel Balance Vehicle. In2018 IEEE International Conference on Mechatronics and Automation (ICMA) 2018 Aug 5 (pp. 364-369). IEEE.
[22] Taşören AE, Örenbaş H, Şahin S. Analyze and Comparison of Different PID Tuning Methods on a Brushless DC Motor Using Atmega328 Based Microcontroller Unit. In2018 6th International Conference on Control Engineering \& Information Technology (CEIT) 2018 Oct 25 (pp. 1-4). IEEE.
[23] Sokunphal T, Othman WA, Alhady SS, Rahiman W. PI controller design for velocity control of a mobile robot. Journal of Fundamental and Applied Sciences. 2018;10(3S):890-902.
[24] Sulila MS, Riyadi MA. Particle swarm optimization (PSO)-based self tuning proportional, integral,

International Journal of Academic Engineering Research (IJAER)
Vol. 5 Issue 4, April - 2021, Pages: 42-48
derivative (PID) for bearing navigation control system on quadcopter. In2017 4th International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE) 2017 Oct 18 (pp. 181-186). IEEE.
[25] Al Tahtawi AR, Yusuf M. Low-cost quadrotor hardware design with PID control system as flight controller. Telkomnika. 2019 Aug 1;17(4).

