*Science & Technology Development Journal – Engineering and Technology 2022, 5(3):1642-1650*

Open Access Full Text Article

***Research Article***

# Path tracking control for car-like robots by pid controller with time-varying parameters

**Trinh Thi Khanh Ly[1], Nguyen Hong Thai[2,*]**

## ABSTRACT

Wheel mobile robots have been widely applied to many areas of life, from serving people in services and industrial logistics to military fields. Applications of wheeled mobile robots such as floor cleaning robots, supermarket robots, logistics robots in hospitals, autonomous robots that guide automatic guidance in intelligent factories, military robots and agricultural robots. Thereby, we can see the great potential of mobile robots in the future. However, among the wheel mobile robots, the differential-drive mobile robot structure is most commonly used because of its simplicity in structure and control. Nevertheless, the navigation and driving are done synchronously through the two drive wheels, which leads to slippage and difficulty in controlling posture errors when navigating, especially on roads curved with a small radius. In order to overcome the disadvantages of the steering and navigation of differential-drive mobile robots, the structure of the automobile has been applied to design a wheel-mobile robot called a car-like robot. Many studies have shown that the advantage of this design option is that the navigation control and robot drive are separated. As a result, the dynamic control loop can ignore the navigation part, while the kinematic model determines the navigation law. Therefore, the work proposes the design of a PID controller with time-varying parameters for a car-like robot to track a given trajectory with minimum error. The nonlinear kinematic model of the robot is linearized along a reference trajectory, and the obtained linear model is used in the controller design process. A PID controller is designed where the controller parameters are tuned to minimize the tracking error. Our model achieves a tracking error value, including the minor position is 5.1 mm, and the maximum postural error is 2$^o$. The simulation results showed the proposed controller's effectiveness in position and posture errors, and it shows we can apply this research to control car-like mobile robots in logistics services.

**Key words:** Car-like robot, trajectory tracking, PID control, NURBS curve

[1]*Electric Power University (EPU), Vietnam*

[2]*Hanoi University of Science and Technology (HUST), Vietnam*

**Correspondence**

**Nguyen Hong Thai**, Hanoi University of Science and Technology (HUST), Vietnam

Email: thai.nguyenhong@hust.edu.vn

**History**

- Received: 10-02-2022
- Accepted: 22-11-2022
- Published: 30-11-2022

**DOI :** **10.32508/stdjet.v5i3.961**

VNUHCM PRESS

## INTRODUCTION

Nowadays, mobile robots have been integrated into modern manufacturing and hospital systems as an unmanned transportation system of automated transfer and distribution equipment. This is among the most dominant trends in today's smart systems due to low operational costs and great efficiency[1–6]. Nevertheless, car-like robots are among wheeled mobile robots used in transportation and service systems[7,8]. Therefore, the car-like robot is still a topic of interest to many researchers in recent years. Including the work of Shui et al[9] have combined fuzzy neural networks and predictive control to control the car-like robot without being dependent on the robot model. Kwon et al[10] proposed a novel trajectory planner for car-like robots by utilizing the workspace tree and the state tree for feasible trajectory generation. Joseph et al[11] have time-optimal control for a car-like robot with the full kinematic model for the steering front-wheels state variables. Mohamed et al.[12] processed path-following position error and the required magnitude of input velocities to the car-like robot by digital control. Xuehao et al.[13] have developed a hybrid motion planning with a smooth velocity curve for the car-like robots to achieve optimal path and emergency dynamic obstacle avoidance. Narcis et al[14] proposed a solution for planning and controlling a car-like robot in environments cluttered has obstacles with low computational cost. Camilo et al[15] propose a control strategy for car-like robots, specifically developing the obstacles avoidance and position control to reach the desired position of the robot in an unknown environment by integrating potential fields with neuroevolution controllers and trained using a designed training environment. Zhang et al. improved the A* hybrid algorithm to find a feasible path plan of the spherical robot with smoothing curves and adding speed limit to the entire path tight bends and small. On that basis, compare the minimal turning radius of the spherical robot with the differential drive robot and the car-like robot[16]. Avinesh et al.[17] have

**Cite this article :** Ly T T K, Thai N H. **Path tracking control for car-like robots by pid controller with time-varying parameters**. *Sci. Tech. Dev. J. – Engineering and Technology;* 5(3):1642-1650.

proposed a solution to motion planning and control of a car-like robot in a randomized multiple obstacles workspace by a single-layer artificial neural network. Another study has proposed motion planning for a mobile robot to move in an environment with many random obstacles based on the geometric relationship between the environment and the robot[18].

It shows that the research of car-like robots focuses on solving the following problems: (i) Path planning and smoothing of bends; (ii) Designing various modern controllers to improve the robot's path tracking with minor errors. Meanwhile, robot control is one of the important problems determining the accuracy and stability of the robot's position and poses during path tracking. Thus, some other studies have focused on the design of path tracking controllers for mobile robots such as state feedback controllers[19–23]; Improve the traditional PID controller by combining with other advanced controllers[24–27] etc. Although many researchers studied control design and development with different controllers, the PID controller is one of the most used controllers for the mobile robot because of its simplicity, ease of implementation, and widely used in industries. However, using time-invariant parameter PID control can achieve stability and tracking control, but accuracy is not high because the system is still time-varying.

To tackle the tracking problems, a PID controller whose parameters vary as a function of the tracking errors in our previous work[28] is presented in this paper for the car-like robot. Which primarily ensures that the car-like robot adheres to its predefined desired path is complex, with the velocity continuously changing. On the other hand, to suddenly avoid the robot velocity changes, as shown above, the NURBS curve is used to design the simulation path for the robot to verify the effectiveness of the proposed controller.

The structure of this paper is as follows: First, the robot's nonlinear kinematic model was established, thereby establishing the error equation for the robot's position and pose. On that basis, linearizing the nonlinear model along the reference trajectory uses the first-order Taylor transform. Secondly, the time-varying PID controller was designed where the controller gains are the functions of the tracking error when the robot moves along the desired path. In the end, the desired path was designed using NURBS rational interpolation for simulation to verify the path-tracking performance of the designed controller.

## KINEMATIC MODEL

Attach a fixed coordinate system $\vartheta_f\ \{O_f x_f y_f\}$ in the plane of motion, simultaneously consider a car-like robot moving along any trajectory $\xi$ in the $\vartheta_f$ as shown in Figure 1. The robot's movement is controlled by two rear wheels through a set of reduction gearbox with a servo motor, while the robot's steering is performed by the front steering shaft control with a caster wheel. The passive castor wheels which have the ability to rotate in any direction is placed in the front of the robot to preserve its equilibrium.

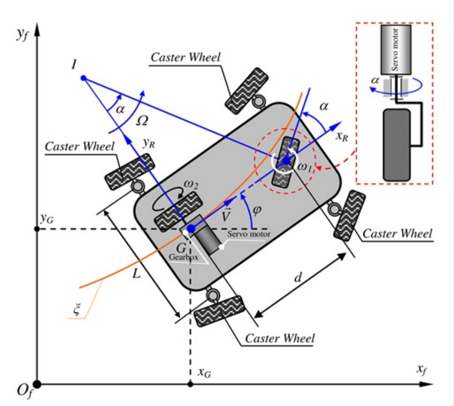

**Figure 1**: Geometric relationship of the car-like robot with an environment.

The assumption: the wheels roll on the ground with no slipping and the robot has no sideway motion. With the conventional symbols shown in Figure 1, let $\alpha(t)$ be the steering angle and $d$ the distance from the front wheel to the rear wheel, then:

$$tg\alpha\left(t\right)=\frac{d}{\rho\left(t\right)} \tag{1}$$

in which, $\rho(t) = IG$ is the instantaneous velocity center radii $I$ when the robot is following the the desired trajectory $\xi$.

Considering the coordinate system $\vartheta_R\{G_R x_R y_R\}$ mounted at $G$ on the robot, then the velocity of point $G$ is given by:

$$V\left(t\right)=\rho\left(t\right)\Omega\left(t\right) \tag{2}$$

From formulas (1) and (2), the angular velocity $\Omega\left(t\right)$ of the robot is defined as:

$$\Omega\left(t\right)=\frac{V\left(t\right)}{d}tg\alpha\left(t\right) \tag{3}$$

Thus, the system of kinematic equations of the robot in the coordinate system $\vartheta_R$ is described by:

$$\begin{cases} \dot{x}_R(t) = V = r\omega_2(t) \\ \dot{y}_R(t) = 0 \\ \dot{\varphi}_R(t) = \Omega(t) = \dfrac{r\omega_2(t)}{d} tg\alpha(t) \end{cases} \tag{4}$$

Wherein, $V(t) = V_2(t) = r\omega_2(t)$ with $\omega_2$ is the angular velocity of the rear wheels and r is the wheel radius. Let $q(t) = \begin{bmatrix} x(t) & y(t) & \varphi(t) \end{bmatrix}^T$ be the position and pose positioning vector at point $G$ of the robot in the coordinate system $\vartheta_f$ associated with the moving environment. The kinematic equation of the robot is given by:

$$\dot{q}(t) = \begin{bmatrix} \dot{x}(t) & \dot{y}(t) & \dot{\varphi}(t) \end{bmatrix}^T = M \begin{bmatrix} V(t) \\ \Omega(t) \end{bmatrix} \tag{5}$$

With $M = \begin{bmatrix} \cos\varphi(t) & 0 \\ \sin\varphi(t) & 0 \\ 0 & 1 \end{bmatrix}$

# CONTROLLER DESIGN METHOD

## Kinematic error model

Let $q_d(t) = \begin{bmatrix} x_d(t) & y_d(t) & \varphi_d(t) \end{bmatrix}^T$ be the vector of the desired position and pose of the robot in the coordinate system $\vartheta_f$, and e is the position error between the desired value and the control value. Indeed, we have:

$$e(t) = q_d(t) - q(t) = \begin{bmatrix} e_x & e_y & e_\varphi \end{bmatrix}^T \tag{6}$$

Transforming equation (6) from the coordinate system $\vartheta_f$ to the coordinate system $\vartheta_R$ mounted on the robot, we have:

$$e_r = \begin{bmatrix} e_{xr} & e_{yr} & e_{\varphi r} \end{bmatrix}^T = R^T e \tag{7}$$

Wherein $R(\varphi(t)) = \begin{bmatrix} \cos\varphi(t) & -\sin\varphi(t) & 0 \\ \sin\varphi(t) & \cos\varphi(t) & 0 \\ 0 & 0 & 1 \end{bmatrix}$

The derivative of equation (7), after reduces then the robot's nonlinear error model is given as:

$$\dot{e}_r = \begin{bmatrix} 0 & \Omega(t) & 0 \\ -\Omega(t) & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} e_{xr} \\ e_{yr} \\ e_{\varphi r} \end{bmatrix} + \begin{bmatrix} \cos e_{\varphi r} & 0 \\ \sin e_{\varphi r} & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_d(t) \\ \Omega_d(t) \end{bmatrix} + \begin{bmatrix} -1 & 0 \\ 0 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} V_G(t) \\ \Omega(t) \end{bmatrix} \tag{8}$$

## PID controller design

Linearizing the nonlinear equation (8) by first-order Taylor transformation around the working point, we have a linear error model of the system:

$$\begin{bmatrix} \dot{e}_{xr} \\ \dot{e}_{yr} \\ \dot{e}_{\varphi r} \end{bmatrix} = \begin{bmatrix} 0 & \Omega_d(t) & 0 \\ -\Omega_d(t) & 0 & V_d(t) \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} e_{xr} \\ e_{yr} \\ e_{\varphi r} \end{bmatrix} + \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} e_V \\ e_\Omega \end{bmatrix} \tag{9}$$

Where $e_V$, $e_\Omega$ are the robot's velocity and angular velocity errors, respectively.

Let $u_1$, $u_2$ be the two control variables, respectively. In which $u_1 = e_V = V_d(t) - V(t)$, $u_2 = e_\Omega = \Omega d(t) - \Omega(t)$ and the control law is defined as[29]:

$$\begin{cases} e_V = K_{px}e_{xr} + K_{ix}\int e_{xr}dt + K_{dx}\dfrac{de_{xr}}{dt} \\ e_\Omega = K_{py}e_{yr} + K_{ix}\int e_{yr}dt + K_{dy}\dfrac{de_{yr}}{dt} + B \end{cases} \tag{10}$$

wherein $B = K_{p\varphi}e_{\varphi r} + K_{i\varphi}\int e_{\varphi r}dt + K_{d\varphi}\frac{de_{\varphi r}}{dt}$

With the controller gains $K_P$, $K_I$, $K_D$ are the functions depend on the error $e_s$ when the robot moves along the desired trajectory $x_d$ and are determined by the following equation[30,31]:

$$\begin{cases} K_P = a_1 + a_2 e_s \\ K_I = b_1 - b_2 e_s \\ K_D = c_1 + c_2 e_s \end{cases} \tag{11}$$

From formula (9), the control law (10) and control parameters (11), the block diagram of the robot's controller as shown in Figure 2.

In the control system in Figure 2, the transform block is defined by equation (7), the PID controller with the control law given by equation (10), the kinematic block is defined by equation (5) with $e_s = \sqrt{e_x^2 + e_y^2}$is the error function of the robot's motion when path tracking $x_d$. Meanwhile, the coefficients $a_i$, $b_i$ and $c_i$ ($i$ = 1,2) are positive real constants dependent on $e_s$.

# SETTING PARAMETERS

## Motion trajectory design

At present, there have been many different solutions to design motion paths for mobile robots, as presented in the introduction. In this content, to generalize and smooth the motion trajectory to prevent the robot from having sudden velocity changes at bends, we choose the NURBS curve as the solution to design the desired motion trajectory of the robot.[4,20,22].

Figure 3 shows the desired path $x_d$ of the robot after performing NURBS interpolation on Matlab software with grid nodes $A_i$ ($i$= 1-10).

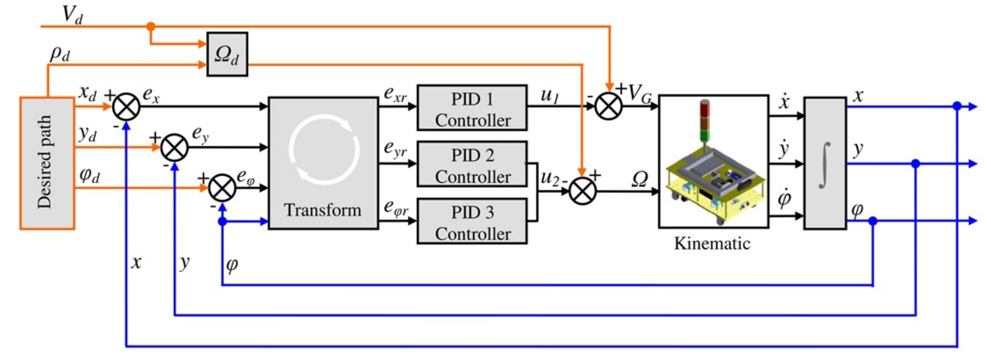

**Figure 2**: Block diagram of path tracking control for the car-like robot by the variable parametric PID controller.

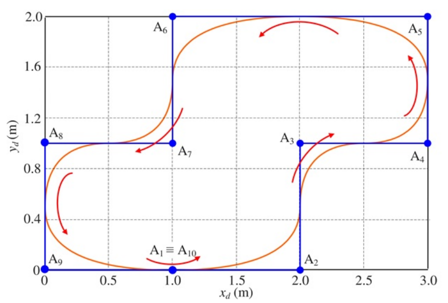

**Figure 3**: The NURBS path of the robot.

## Setting motion parameters

The time-varying velocity $V_d(t)$ of the robot is determined in terms of the desired path $x_d$ as follows:

$$V_d(t)=\frac{\triangle S}{\triangle t}=\frac{\sqrt{(x_i-x_{i-1})^2+(y_i-y_{i-1})^2}}{t_i-t_{i-1}} \tag{12}$$

With $V_{dmax}$ = 0,4 m/s is the maximum velocity of the robot setup. The desired angular velocity $\Omega_d$ of the robot when moving on curved arcs is:

$$\Omega_d(t)=\frac{V_d(t)}{\rho_d(t)} \tag{13}$$

Where, $\rho_i(t)\in[\rho_{min},\rho_{max}]$ is the radii of curvature of the desired path $\xi_d$ with i= 1,2 ..n and is defined:

$$\rho_i=\left|\frac{\left(\dot{x}_i^2+\dot{y}_i^2\right)^{\frac{3}{2}}}{\dot{x}_i\ddot{y}_i-\ddot{x}_i\dot{y}_i}\right| \tag{14}$$

Wherein:

$$\begin{cases}\dot{x}_i=\frac{\triangle x}{\triangle t}=\frac{x_i-x_{i-1}}{t_i-t_{i-1}}\\ \dot{y}_i=\frac{\triangle y}{\triangle t}=\frac{y_i-y_{i-1}}{t_i-t_{i-1}}\end{cases};\begin{cases}\ddot{x}_i=\frac{\triangle \dot{x}}{\triangle t}=\frac{\dot{x}_i-\dot{x}_{i-1}}{t_i-t_{i-1}}\\ \ddot{y}_i=\frac{\triangle \dot{y}}{\triangle t}=\frac{\dot{y}_i-\dot{y}_{i-1}}{t_i-t_{i-1}}\end{cases}$$

With $\triangle t=1\ (s)$.

## Determine the coefficients of the controller gains

With the dimensions of the robot: *(i)* Distance between 2 wheels $L$ = 400 mm; *(ii)* The distance between the two rows of wheels $d$ = 600 mm and (iii) The wheel radius $r$ = 50 mm as the design shown in Figure 4. Thus, the coefficients $a_i$, $b_i$, $c_i$ of the gains $K_P$, $K_I$, $K_D$ given by the Eq (11) are determined by trial and error technique so that the mean error $e_s$ is minimal when the robot follows the desired path $x_d$. The investigation results show the coefficients $a_i$, $b_i$, $c_i$ in Table 1. Figure 5 is the investigation results of the time-varying control parameter when the robot tracks the desired path $x_d$ according to the error function es with the coefficients that have been chosen in Table 1.

# SIMULATION RESULTS AND DISCUSSION

Figure 6 compares the desired path versus the motion trajectory of the robot when controlled by the time-varying PID controller. The orange line is the controlled trajectory and the blue line is the desired path. In Figure 6, the positions numbered 1 to 6 are inflexion points on the moving desired path at which the robot changes direction.

Thus, the robot changes the linear and angular velocities along the path.

As a result, the inflexion points are those with more significant errors on the moving trajectory of the robot.

Figure 7 describes the position and pose errors of the robot when the robot follows the trajectory desired path $x_d$. The simulation results in Figure 6 and Figure 7 verify that the robot followed the trajectory with minor errors. The maximal position error is approximately 5.1 mm at position 1 (see Figure 6). Cause at position 1, the robot reaches the maximum velocity

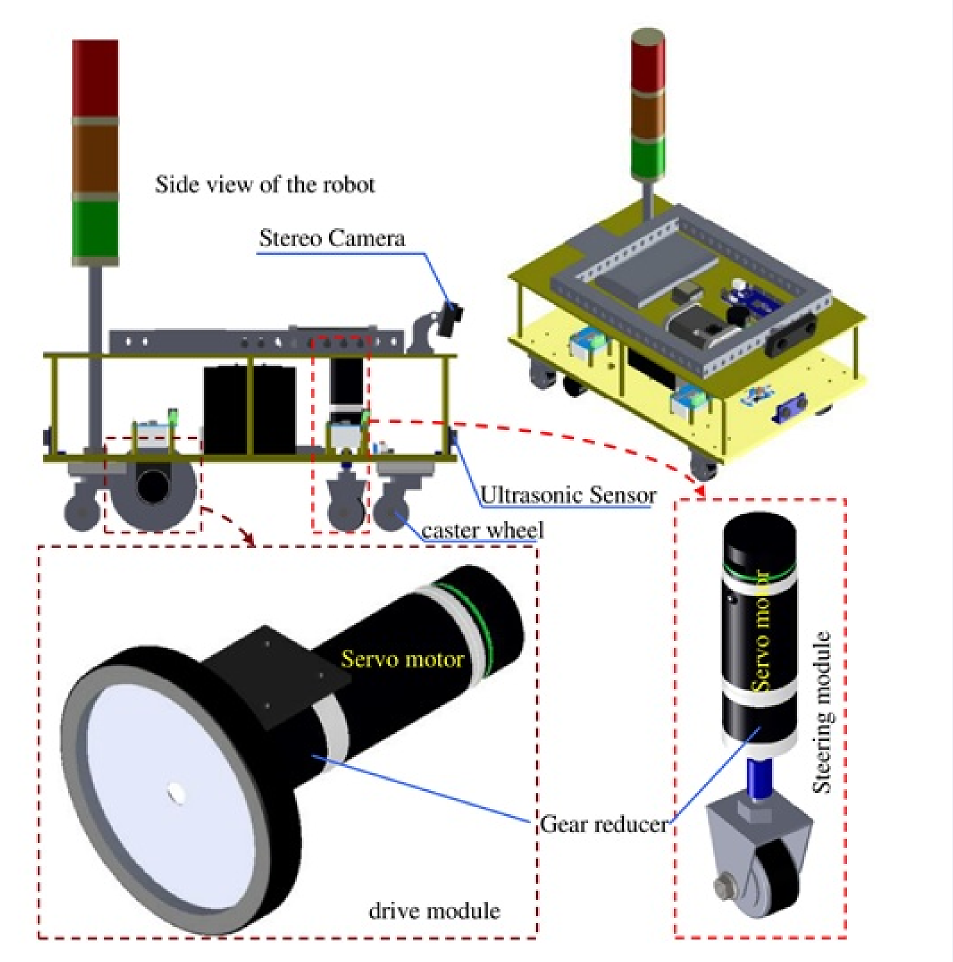

**Figure 4**: Structural design of the robot.

**Table 1: The coefficients of the parameters $K_P$, $K_I$, $K_D$.**

| $a_1$ | $a_2$ | $b_1$ | $b_2$ | $c_1$ | $c_2$ |
|---|---|---|---|---|---|
| 0.001 | 0.001 | 0.001 | 0.310 | 0.001 | 0.001 |

$V$=0.4 m/s and gradually decreases to track the desired path Figure 8 verify this. Also, the pose error of the robot is the largest at points 3, 4, 5, 6, these are inflexion points with smaller radii, and the largest pose error is approximately $2^o$.

The above results verified the simplicity and efficiency of the designed time-varying PID controller.

Figure 8 below shows the linear and angular velocities of the robot when the robot moves along the desired path shown in Figure 3 with the position and pose errors described in Figure 7. Meanwhile, Figure 9 shows the steering shaft velocity and the angular velocity of the driving wheels for the robot follows the desired trajectory.

Figure 8 and Figure 9 show that the shaft velocities are controlled symmetrically in two arcs: The first arc: 2 -> 3 -> 4 -> 1 and The second arc 1 -> 5 -> 6 – > 2. In which, the orange line is the theoretical calculation and the blue line is the controlled value.

## CONCLUSIONS

The above theoretical and simulation research results achieved the following: (i) A trajectory-tracking PID controller with time-varying parameters for a car-like mobile robot was designed and simulated. The proposed controller with a simple structure can track the desired trajectory with a small tracking error. Simulation results were presented and showed the excel-

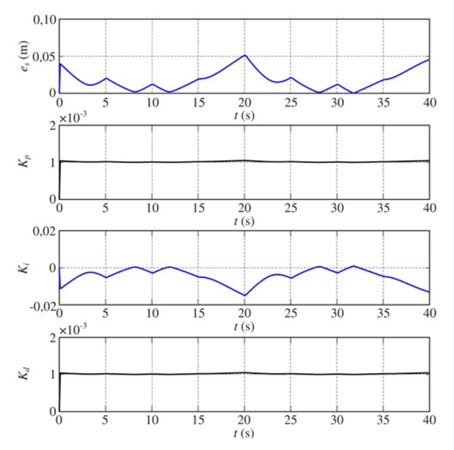

**Figure 5**: The time-varying control parameters.

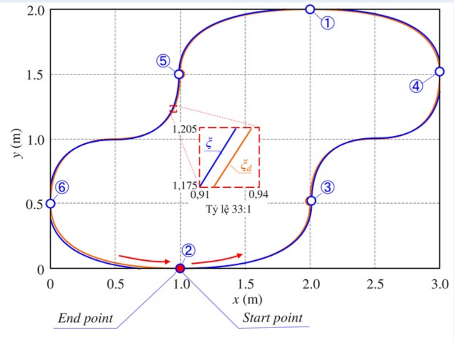

**Figure 6**: The tracking of the robot for the NURBS path.

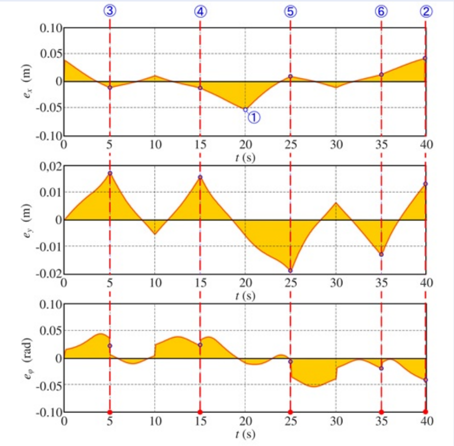

**Figure 7**: The position and pose errors of the robot when tracking the reference path.

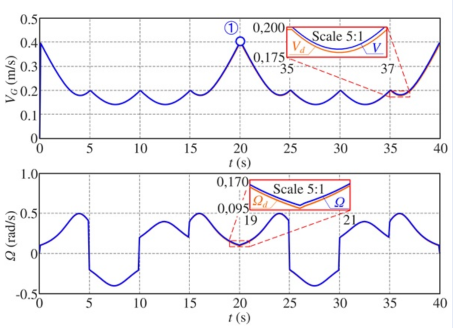

**Figure 8**: The linear and angular velocities of the robot.

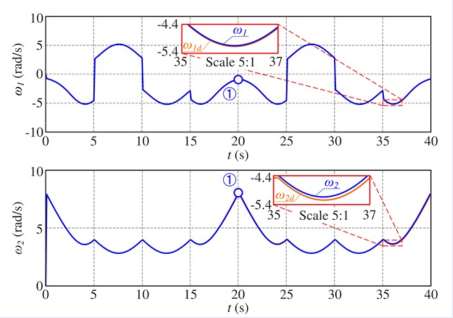

**Figure 9**: The angular velocity of the steering shaft and the driving wheel.

lent performance of the proposed controller for trajectory tracking. Therefore, this is the difference between this study versus previous studies; (ii) An investigation method has been proposed to determine variable coefficients of the PID controller. We believe this will yield guarantees on the tracking performance of the car-like robot.

Also, the problems of dynamic control, working load, and electromechanical interaction between the robot and the environment will be considered part of our future research goals.

## CONFLICT OF INTERESTS

The authors declared no potential conflicts of interest with respect to the research, authorship and publication of this paper.

## AUTHORS' CONTRIBUTION

Nguyen Hong Thai made the paper's initiative idea, theoretical modelling, implementation plan and corrected it. Author Trinh Thi Khanh Ly wrote the paper's manuscript, implemented simulation programming and consulted with Nguyen Hong Thai on significant issues. The manuscript was written through the contribution of all authors. All authors discussed the results reviewed and approved the final version of the manuscript.

## ACKNOWLEDGMENTS

This research was funded by the Ministry of Industry and Trade in a ministerial-level scientific and technological research project, conducted in 2020, code: DTKHCN.076/20.

## REFERENCES

1. Bechtsis D, Tsolakis N, Vlachos D, Iakovou E. Sustainable supply chain management in the digitalisation era: the impact of Automated Guided Vehicles. J Cleaner Prod. 2017;142:3970-84;Available from: https://doi.org/10.1016/j.jclepro.2016.10.057.
2. Thai NH, Thai NQ. A kinematic control algorithm for blast-hole drilling robotic arm in tunneling. Sci. Technol Dev J. 2017;20(K5):13-22;Available from: https://doi.org/10.32508/stdj.v20iK5.1153.
3. Vis IFA. Survey of research in the design and control of automated guided vehicle systems. Eur J Oper Res. 2006;170(3):677-709. doi: 10.1016/j.ejor.2004.09.020;Available from: https://doi.org/10.1016/j.ejor.2004.09.020.
4. Ly TTK, Thai NH, Dzung LQ, Thanh NT. Determination of kinematic control parameters of omnidirectional AGV robot with mecanum wheels track the reference trajectory and velocity. International Conference on Engineering Research and Applications; 2020. p. 319-28;Available from: https://doi.org/10.1007/978-3-030-64719-3_36.
5. Masood K, Pérez Morales DP, Fremont V, Zoppi M, Molfino R. Parking pose generation for autonomous freight collection by pallet handling car-like robot. Energies. 2021;14(15):4677;Available from: https://doi.org/10.3390/en14154677.
6. Gu D, Hu Huosheng. Neural predictive control for a car-like mobile robot. Robot Auton Syst. 2002;39(2):73-86;Available from: https://doi.org/10.1016/S0921-8890(02)00172-0.
7. Xidias EK. A decision algorithm for motion planning of car-like robots in dynamic environments. Cybernetics and systems;.
8. Wen L, Liu Y, Li H. CL-MAPF: multi-agent Path Finding for Car-Like robots with kinematic and spatiotemporal constraints. Robot Auton Syst. 2022;150:103997;Available from: https://doi.org/10.1016/j.robot.2021.103997.
9. Shui Y, Zhao T, Dian S, Hu Y, Guo R, Li Shengchuan. Data-driven generalized predictive control for car-like mobile robots using interval type-2 T-S fuzzy neural network. Asian J Control. 2022;24(3):1391-405;Available from: https://doi.org/10.1002/asjc.2531.
10. Kwon H, Cha Donggeun, Seong J, Lee Jinwon, Chung Woojin. Trajectory planner CDT-RRT* for car-like mobile robots toward narrow and cluttered environments. Sensors (Basel). 2021;21(14):4828;PMID: 34300569. Available from: https://doi.org/10.3390/s21144828.
11. Ben-Asher JZ, Rimon ED. Time optimal trajectories for a car-like mobile robot. IEEE Trans Robot. 2021;38(1):421-32;Available from: https://doi.org/10.1109/TRO.2021.3080656.
12. Elobaid M, Mattioni M, Monaco S, Normand-Cyrot D. Digital path-following for a car-like robot. IFAC PapersOnLine. 2021;54(21):174-9;Available from: https://doi.org/10.1016/j.ifacol.2021.12.030.
13. Sun Xuehao, Deng Shuchao, Zhao T, Tong B. Motion planning approach for car-like robots in unstructured scenario. Trans Inst Meas Control. 2022;44(4):754-65;Available from: https://doi.org/10.1177/0142331221994393.
14. Ghita N, Kloetzer M. Trajectory planning for a car-like robot by environment abstraction. Robot Auton Syst. 2012;60(4):609-19;Available from: https://doi.org/10.1016/j.robot.2011.12.004.
15. Cáceres Flórez CAC, Rosário JM, Amaya D. Control structure for a car-like robot using artificial neural networks and genetic algorithms. Neural Comput Appl. 2020;32(20):15771-84;Available from: https://doi.org/10.1007/s00521-018-3514-1.
16. Zhang Z, Wan Yixu, Wang Y, Guan X, Ren W, Li G. Improved hybrid A* path planning method for spherical mobile robot based on pendulum. Int J Adv Robot Syst. 2021;18(1):1-14;Available from: https://doi.org/10.1177/1729881421992958.
17. Prasad A, Sharma B, Vanualailai J. A solution to the motion planning and control problem of a car-like robot via a single-layer Perceptron. Robotica. 2014;32(6):935-52;Available from: https://doi.org/10.1017/S0263574713000982.
18. Thai NH, Ly TTK, Dzung LQ. Road map, routing and obstacle avoidance of AGV robot in the static environment of the flexible manufacturing system with matrix devices layout. Science and Technology Development [journal]. 2021;24(3):2091-9;.
19. De Luca A, Oriolo G, Samson C. Feedback control of a nonholonomic car-like robot. Robot motion planning and control. Berlin, Heidelberg: Springer; 1998. p. 171-253;Available from: https://doi.org/10.1007/BFb0036073.
20. Thai NH, Ly TTK. NURBS curve trajectory tracking control for differential-drive mobile robot by a linear state feedback controller. International Conference on Engineering Research and Applications; 2021. p. 685-96;Available from: https://doi.org/10.1007/978-3-030-92574-1_71.
21. Wang C, Wang D, Pan W, Zhang H. Output-based tracking control for a class of car-like mobile robot subject to slipping and skidding using event-triggered mechanism. Electronics. 2021;10(23):2886;Available from: https://doi.org/10.3390/electronics10232886.
22. Thai NH, Ly TTK, Long NT, Dzung LQ. Trajectory tracking using linear state feedback controller for a mecanum wheel omnidirectional. IFToMM Asian conference on Mechanism and Machine Science; 2021. p. 411-21;Available from: https://doi.org/10.1007/978-3-030-91892-7_39.
23. Thai NH, Ly TTK, Thien N. Curve trajectory tracking control for differential-drive mobile robot by a linear state feedback dynamic controller. The AUN/SEED-Net Joint Reg Conference in Transportation, Energy, and Mechanical Manufacturing Engineering; 2022. p. 1-14;Available from: https://doi.org/10.1007/978-981-19-1968-8_50.
24. Umar Z, Salinda B, Zainal Abidin M Shukri, Mahmud Mohd. Saiful Azimi and Hasan Hameedah sahib. Non-linear PID controller for trajectory tracking of a differential drive mobile robot. J Mech Eng Res Dev. 2020;43(7):255-69;.
25. Samson C. Control of chained systems: application to path following and time-varying point-stabilization of mobile robots. IEEE Trans Autom Control. 1995;40(1):64-77;Available from: https://doi.org/10.1109/9.362899.
26. Eghtesad M, Necsulescu DS. Study of the internal dynamics of an autonomous mobile robot. Robot Auton Syst. 2006;54(4):342-9;Available from: https://doi.org/10.1016/j.robot.2006.01.001.
27. Tiep DK, Lee K, Im DY, Kwak B, Ryoo YJ. Design of fuzzy-PID controller for path tracking of mobile robot with differential drive. Int J Fuzzy Logic Intell Syst. 2018;18(3):220-8;Available from: https://doi.org/10.5391/IJFIS.2018.18.3.220.
28. Thai NH, Ly TTK, Thien H, Dzung LQ. Trajectory tracking control for differential-drive mobile robot by a variable parameter PID controller. IJMERR. 2022:614-21;Available from: https://doi.org/10.18178/ijmerr.11.8.614-621.
29. Padhy PK, Sasaki T, Nakamura S, Hashimoto H. Modeling and position control of mobile robot. The 11th IEEE International Workshop on Advanced Motion Control; 2010. p. 100-5;Available from: https://doi.org/10.1109/AMC.2010.5464018.
30. Korkmaz M, Aydoğdu O, Doğan H. Design and performance comparison of variable parameter nonlinear PID controller and genetic algorithm based PID controller. Conference: In-

novations in Intelligent Systems and Applications; 2012. p. 1-5;PMID: 22569208. Available from: https://doi.org/10.1109/INISTA.2012.6246935.

31. Aydogdu O, Korkmaz M. A simple approach to design of variable parameter nonlinear PID controller. International Conference on Advancements in Information Technology; 2011. p. 81-5;.

*Tạp chí Phát triển Khoa học và Công nghệ – Kĩ thuật và Công nghệ 2022, 5(3):1642-1650*

*Bài nghiên cứu*

# Điều khiển bám đường dẫn cho rôbốt di chuyển kiểu ô tô bằng bộ điều khiển PID với thông số thay đổi

**Trịnh Thị Khánh Ly[1], Nguyễn Hồng Thái[2,*]**

Use your smartphone to scan this QR code and download this article

**TÓM TẮT**

Robot di động bánh xe đã được ứng dụng rộng rãi cho nhiều lĩnh vực khác nhau của đời sống, từ phục vụ con người trong các dịch vụ, hậu cần công nghiệp cho đến các lĩnh vực quân sự. Các ứng dụng của robot di động bánh xe như robot lau sàn, robot siêu thị, robot hậu cần trong bệnh viện, robot tự trị dẫn đường tự động trong các nhà máy thông minh, robot quân sự, robot nông nghiệp v.v.. Qua đó, chúng ta có thể thấy tiềm năng lớn của robot di động trong tương lai. Tuy nhiên, trong các loại di động bánh xe thì cấu trúc robot di động kiểu visai được ứng dụng phổ biến nhất bởi đơn giản về cấu trúc và điều khiển. Nhưng việc điều hướng và dẫn động được thực hiện đồng bộ thông qua hai bánh xe dẫn động, dẫn đến có hiện tượng trượt và khó kiểm soát sai số tư thế khi điều hướng, nhất là những cung đường có bán kính nhỏ. Để khắc phục các nhược điểm trên cấu trục dẫn động và điều hướng kiểu ô tô đã được ứng dụng vào thiết kế các robot tự hành kiểu bánh xe và có tên gọi robot giống ô tô. Nhiều nghiên cứu đã chỉ ra ưu điểm của phương án thiết kế này là điều khiển điều hướng và dẫn động robot được tách biệt. Dẫn đến vòng điều khiển động lực học có thể bỏ qua phần điều hướng, trong khi luật điều hướng được xây dựng trên mô hình động học. Do đó, bài báo trình bày thiết kế bộ điều khiển PID với các thông số thay đổi theo thời gian nhằm điều khiển robot dẫn động cầu sau kiểu ô tô di chuyển bám đường đi mong muốn với sai số nhỏ. Đầu tiên, một mô hình động học phi tuyến của robot được thiết lập. Sau đó, mô hình sai số động học phi tuyến của robot được tuyến tính hóa xung quanh điểm làm việc bằng phép biến đổi Taylor bậc một. Trên cơ sở đó, một bộ điều khiển PID với các thông số thay đổi theo thời gian đã được thiết kế. Các hệ số của các thông số điều khiển $K_P$, $K_I$, $K_D$ được xác định bằng kỹ thuật thử và sai nhằm đảm bảo robot di chuyển bám theo đường dẫn NURBS mong muốn với sai số tối thiểu. Kết quả mô phỏng đã xác minh tính hiệu quả của phương pháp thiết kế bộ điều khiển được đề xuất. Nó cho thấy có thể áp dụng kết quả nghiên cứu này để điều khiển các robot tự hành dẫn động cầu sau kiểu ô tô trong các dịch vụ hậu cần trong thực tế.

**Từ khoá:** Robot giống ô tô, bám quỹ đạo, bộ điều khiển PID, đường cong NURBS

---

[1] *Khoa Điều khiển và Tự động hóa, Trường Đại học Điện lực (EPU), Bộ Công Thương, Việt Nam*

[2] *Bộ môn Cơ sở thiết kế mày và robot, Viện Cơ khí, Trường Đại học Bách khoa Hà Nội (HUST), Việt Nam*

**Liên hệ**

**Nguyễn Hồng Thái**, Bộ môn Cơ sở thiết kế mày và robot, Viện Cơ khí, Trường Đại học Bách khoa Hà Nội (HUST), Việt Nam

Email: thai.nguyenhong@hust.edu.vn

**Lịch sử**

- Ngày nhận: 10-02-2022
- Ngày chấp nhận: 22-11-2022
- Ngày đăng: 30-11-2022

**DOI : 10.32508/stdjet.v5i3.961**

VNUHCM PRESS

**Trích dẫn bài báo này:** Ly T T K, Thái N H. **Điều khiển bám đường dẫn cho rôbốt di chuyển kiểu ô tô bằng bộ điều khiển PID với thông số thay đổi.** *Sci. Tech. Dev. J. - Eng. Tech.;* 2022, 5(3):1642-1650.