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Feedback control of a nonholonomic-wheeled mobile robot for calculating the quickest straight-line trajectory planning problems

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ABSTRACT

Wheel driven mobile robots have been controlled for many years by scientists. During the development of highly nonlinear control methods the non-holonomic restrictions on wheeled robots were used. Depending on the application, a number of payloads may be connected to nonholonomic mobile robots. This may influence either statically or dynamically the total system volume, inertia and centre of mass position as well as other hardware limitations. The accuracy of straight line track planning issues is low, given the non-holonomous and motion-restricted characteristics of wheeled mobile robots. Therefore, we now study this nonholonomic wheeled technique of mobile robot tracking. This article utilises direct line measurement to get the most direct track for nonholonomic mobile robots. The cinematic model that has been created to follow straight paths is the initial phase of the construction of the robot. The implementation of a time-limited feedback control is based on a look-ahead technique. A straightline route tracking test is done to evaluate the stability characteristics of the closed loop system and asymptotic stability is shown using the Lyapunov theory. The straight line tracking shows that the static error is null. The suggested feedback route tracking control is validated using simulations and tests.

Index Key: Nonholonomic-wheeled mobile robot, Feedback control, Lyapunov concept, straight-line trajectory planning,

INTRODUCTION

In recent years, mobile robots have seen wider use in industrial activities thanks to the continuing development of the global economy. Nonholonomic systems require advanced control techniques since they are very unpredictable. In addition, while in the real world, the wheeled mobile robot suffers unpredictable internal parameters fluctuation and unpredictable interference from the environment. To compensate for these shortcomings, several control methods have been extensively explored, including sliding mode control, intelligent control, and input-output linearization. This observer, who had two additional dynamic gains added, was used to determine the states of nonlinear components that were not previously known. The study hypothesizes that a tracking controller should be developed that employs a linearization strategy for nonholonomic restricted systems. For such nonholonomic systems, the research offers a linearization tracking controller based on the pretension that the linearized system is completely controlled along the reference path chosen. An implementation of a sliding mode control (two-dimensional polar kinematics) for mobile robots is provided, which uses conditional constraints to eliminate requirements of linear velocity, angular velocity, and orientation.

Finding the upper limit of accumulated disturbance in the actual world is challenging. Therefore, a controller is often required to use adequate switching gains to suppress lumped disturbances. In the paper. There is a dynamic adaptive control method for a non-holonomic mobile robot with unknown dynamic features for the non-holonomic robot. Unknown dynamic features. To offer a mobile robot with an adaptive control method, a backstepping technology is used. The [10] research provided a new adaptive approach to stabilizing an internally damped mobile robot that is coupled to an unknown set of parameters and a constantly changing external disturbance. To follow a predetermined trajectory without regard to chatter, [11] devised an adaptive super-torsion algorithm. Many control systems have proposed this sliding mode control technique to remedy this problem. There is a dynamic adaptive control method for a non-holonomic mobile robot with unknown dynamic features for the non-holonomic robot. The proposed technique for coping with unknown-limits disruptions is a sliding-mode unit vector control method that involves the use of monitoring functions. The research [15] investigated a novel technique for system actuator failure reconstruction, using a sliding mode observer. The authors developed adaptive high-gain stabilisers for a class of time-invariant State Space Systems. However, a number of potential problems arise, such as input saturation, dead zone input, unidirectional input restrictions, etc. The first continuous controlling solution was developed for artificial pneumatic muscle systems. In[17], the parameter/structure uncertainty for ship-assembled crane systems was handled using an adaptive rule.

STATE-OF-THE-ART

A reference to the Udwadia kalaba equation and the underactuated equivalent principle was done in a study involving nonholonomic robots by Pappalardo and Guida [18]. To assess the validity of the control method, numerical tests were conducted on a dynamic model of a mobile robot. a fast and uncompulsive system for mobile robots that avoids unicity while retaining the benefits of the sliding mode control was put forth by Zhao et al. [19]. The results of the experiment show that the control method has a high degree of stability, and the robot's trajectory tracking error is negligible.

Ernesto et al.[20] propose that the robot is reverse orientated and has a limited distance to move by using a cinematic model. Spandan et al. [21] carried out a new control performance research with an approximation mistake, and there was an empirical link. Shi et al. has been provided the case controller in which the wheel speed does not lack as regards the parametric uncertainty[22]. Bessas et al. [23] developed an integrated mode controller using a film model of the system. Onat and Ozkan[24] built an adaptive recognition parameter controller using cinematic models. The controller has been relocated to various movie models to accommodate for tracking imperfections. In the Cartesian coordinate system, a research was done in which an SMC approach angle was established. The switching control method enables substantial switching gains to result in switching effects that influence the robotic system, resulting in unmodelled high frequency dynamics. The creation of nominal models for complicated systems such as WMR is long overdue.

Ernesto et al.[20] propose that the robot is reverse orientated and has a limited distance to move by using a cinematic model. A more effective response is achieved. Spandan et al. [21] performed a new analysis of the output and approximation error, and an empirical relationship was established. Shi et al. have been provided with the controller of the situation when there is no shortage of wheel speed in relation to parametric insecurity[22]. Bessas and others [23] developed an integrated mode controller based on a cinematic system concept. Onat and Ozkan [24] have built an adaptive recognition parameter controller using the cinematic models. The controller is transferred into various cinematic models to compensate for the tracking inaccuracy. A research was carried out in which a cartesian co-ordinate system discovered to have the SMC approach angle. The switching control method allows for large switching gains, which result in unmodified high-frequency dynamics which influence the robotic system. The creation of nominal models for complicated systems such as WMR takes a long time to come.

WHEELED NONHOLONOMIC MOBILE ROBOT

This trajectory planning issue aims to build a virtual mobile robot model and use it to generate a curved-line trajectory for the actual robot, so that the robot may navigate in the shortest path possible. The reference route is a sequence of straight lines that acts as a reference for the mobile robot to navigate.

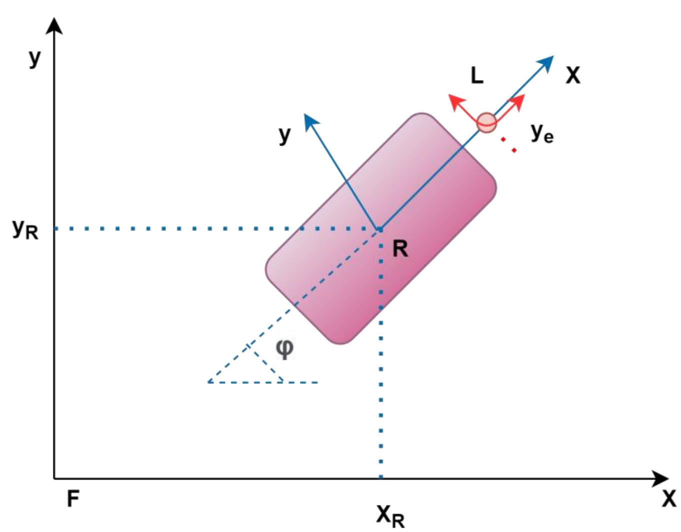

Figure 1: Mobil robot with nonholonomic wheel in flat perspective.

The robot speed, VR, is continuous in pieces, but its maximum and minimum values are limited and strictly positive. The method utilized is a reference route with a guide point ahead of point R at some distance (called look-ahead distance). The following is a formula for path tracking: Use measurements on only distance to detect a feedback control for the system with control input for the angular speed y-e of the robot, such that the state vector asymptotically tends to have a constant value. $e_s = [y_{es} \quad \varphi_{es}]^T, as\ t \to \infty$.

In this paper we analyse a non-holonomic differential drive for a mobile robot. A planar view shows the robot as depicted in Figure 1. A robot is powered independently by two classic rear wheels and a passive beaver wheel on its back. For both traditional two and four-wheel drive variants, pure rolling conditions are also essential at each wheel's point of contact with ground. A vector with the following coordinates defines a mobile robot configuration

$$\xi_R = \begin{bmatrix} x_R \\ y_R \\ \varphi \end{bmatrix} \tag{1}$$

The robot kinematic equations of motion will be used, along with the robot reference point L, to link the robot's longitudinal axis firmly to the robot and then place it ahead of the reference point R. The Lxy co-ordinate axis will be oriented to the appropriate Rxy framework axis and the Lxy co-ordinate system will be equally distributed to the centre L (Figure 1). A connection between points L and R of the Cartesian coordinates, (x_L, y_L) and (x_R, y_R), can be provided in the manner accordingly

$$\xi_L = \begin{bmatrix} x_L \\ y_L \\ \varphi \end{bmatrix} = \begin{bmatrix} x_R + l\ cos\varphi \\ y_R + l\ sin\varphi \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \tag{2}$$

The direction for the roboter in Fxy is the third part(ϕ) of the vector ξ_L. The following terms for the movable robot's movable model (control system) include points L coordinates

$$\dot{\xi}_L = B_L \eta \tag{3}$$

The form for the 3x2 matrix,B-L.

$$B_L = \begin{bmatrix} \cos\varphi & -l\ sin\varphi \\ sin\varphi & l\ cos\varphi \\ 0 & 1 \end{bmatrix} \tag{4}$$

A frame of motion is developed in such a way that the centre is on the reference route and the Cx axis on the way. The y-axis crosses the centre of Cxy to be explained in the Ljy reference robot architecture. To define Lx, Ly and Cx route tracking geometry, Cy coordinates systems will be created. For this reason the coordinates, $(x_e,\ y_e)$ Cxy may be represented as follows by point C of the Lxy co-ordinate system (tracking error) connected with the reference route, the lxy-frame, and φ-e of the frame orientation

$$e_\xi = T(\xi_C - \xi_L) \tag{5}$$

where the 3×1 vector $e_{\xi} = [x_e \quad y_e \quad \varphi_e]^T$ symbolizes the error position, and its elements are the longitudinal (x_e), lateral (y_e), and orientation error (φ_e), The matrix T is an invertible 3×3 matrix.

To safely link the mobile robot in the Lxy co-ordinating system, The e_{ξ} frame point C linked to the reference route may be expressed as the following in the robot Lxy and the orientation Lxy system robot Cxy (tracking error)

$$\dot{e} = g_1(e) + g_2(e)w \tag{6}$$

$$e = \begin{bmatrix} y_e \\ \varphi_e \end{bmatrix} \tag{7}$$

is a 2x1 vector, $g_1(e)$ and $g_2(e)$ are 2x1 vectors of the form

$$g_1(e) = \begin{bmatrix} v_R tan\varphi_e \\ \frac{v_R C_r}{cos\varphi_e} \end{bmatrix}$$

$$g_2(e) = \begin{bmatrix} -(y_e tan\varphi_e + l) \\ -\left[1 + \frac{v_R C_r}{cos\varphi_e}\right] \end{bmatrix} \tag{8}$$

FEEDBACK CONTROL

This time-varying feedback control is suggested if a circular reference route has an unknown constant curvature.

$$w = v_R k_y y_e \tag{9}$$

where k_y is a constant with a positive value and $v_R$how fast is the robot travelling? The system reaches the final form after applying (9) to (6).

$$\dot{e} = v_R g_c(e) \tag{10}$$

Where,

$$g_c = \begin{bmatrix} -lk_y y_e\left(1 - k_y y_e^2\right) tan\varphi_e \\ -k_y y_e + \frac{1 - k_y y_e^2}{cos\varphi_e} c_r \end{bmatrix} \tag{11}$$

The speed of the v-R robot is considered to be not constant but partly constant, boundary and absolutely positive (nil), which results in the algebraic reorganisation as follows: t Conjecture: If the robot's velocity is partly constant and restricted (no approaching zero), the time difference in (10) will be adjusted to the length of track s.(ds=,v-R.dt) is filled in with the robot reference point. After fully evolved, the system is a non-linear system which is totally independent of any external influences.

$$e' = g_c(e) \tag{12}$$

Whereby the symbol "e'" represents s and "$g_c(e)$" is provided by system equations of motion (11). The balance point for closed circuits is at (12)

$$e_s = \begin{bmatrix} y_{es} \\ \varphi_{es} \end{bmatrix}$$

$$= \begin{bmatrix} \frac{\left(-\sqrt{1-l^2c_r^2}+\sqrt{1-l^2c_r^2+4c_r/k_y}\right)}{2c_r} \\ a\ sin(lc_r) \end{bmatrix} \qquad (13)$$

The linearization of (12) with regard to balance (13) is

$$e' = Ae \qquad (14)$$

Where

$$A = \frac{\partial g_c}{\partial e}(e_s) \qquad (15)$$

$$= \begin{bmatrix} -k_y(1 + y_{es}\tan\varphi_{es} & -k_y\left(1 + \left(\frac{c_r y_{es}}{cos\varphi_{es}}\right)\right) \\ \left(1 - k_y y_{es}^2\right)\Big/_{cos^2\varphi_{es}} & \left(\left(1 - k_y y_{es}^2\right)\Big/_{cos^2\varphi_{es}}\right)c_r \end{bmatrix}$$

This can be shown. Reλ_i < 0, (i = 1,2) A has the smallest number of eigenvalues that have a nonzero component., For the sake of conciseness, we will omit the evidence. a globally asymptotically stable point exists, and the system (12) is locally asymptotically stable at that globally asymptotically stable point (13). asymptotically stabilizes the equilibrium point, because of the time-varying control (9) (13). So, when using a look-ahead method and feedback that utilizes just distance measures, you need to exercise extreme caution. (for the lateral error y_e), in the neighborhood of 12, local asymptotic stability is attained.

Additionally, when you consider the path of the fastest straight-line trajectory,($c_r = 0$ in (6)), the system (10) has the form

$$\dot{e} = \begin{bmatrix} \dot{y_e} \\ \dot{\varphi_e} \end{bmatrix} = v_R g_c(e)$$

$$= v_R \begin{bmatrix} -lk_y y_e\left(1 - k_y y_e^2\right)tan\varphi_e \\ -k_y y_e \end{bmatrix} \qquad (16)$$

In particular, for example, while pursuing a shortest straight-line path

$$e' = \begin{bmatrix} y_e' \\ \varphi_e' \end{bmatrix} = \begin{bmatrix} -k_y l & 1 \\ -k_y & 0 \end{bmatrix} \begin{bmatrix} y_e \\ \varphi_e \end{bmatrix}$$

$$= A_c e \qquad (17)$$

The solution to the Lyapunov equation for the linear system (17) is obtained by solving for P, Where P is a certain positive matrix Q = I, a unit matrix for 2x2.

$$PA_c + A_c^T P = -I \quad (18)$$

The unique solution of the matrix problem (19) is arrived at by first solving the matrix equation (18).

$$P = \begin{bmatrix} \frac{1+k_y}{2k_y l} & \frac{-1}{2} \\ \frac{-1}{2} & \frac{1}{2k_y^2 l}\left(1 + k_y + k_y^2 l\right) \end{bmatrix} \quad (19)$$

As the major minors of the matrix are positive the symmetrical matrix P $\left(k_y = cte > 0; l = cte > 0\right)$

$$det\left(\frac{1+k_y}{2k_y l}\right) > 0$$

$$det\begin{bmatrix} \frac{1+k_y}{2k_y l} & \frac{-1}{2} \\ \frac{-1}{2} & \frac{1}{2k_y^2 l}\left(1 + k_y + k_y^2 l\right) \end{bmatrix} = \frac{1+k_y}{k_y}\left(\frac{1}{k_y^2 l^2} + \frac{1}{4k_y l^2} + \frac{1}{4}\right) - \frac{1}{4} > 0 \quad (20)$$

Ac is therefore a matrix for stability(that is Reλi < 0 for the eigenvalues of Ac) to enable the system (17). To obtain local asymptotic stability, you need a control device (16). (9).

EXPERIMENTAL RESULTS

Robots constantly evolve in tandem with society's progression and the shifting expectations of its members, giving rise to higher intelligence and more functionality. Not only is the development of robot technology simpler in several fields, but it also serves as a measure of a country's scientific and technological advancement. Mobile robots are WMRs, and WMRs are a subset of mobile robots. This equipment provides a wide range of application possibilities, ranging from the military to healthcare to family agriculture to others. WMR is controlled only by non-holonomic systems throughout the moving process due to its structural difficulty. A tremendous amount of focus and complexity now exists in the robot space due to motion control issues. To implement motion control, you will need to use trajectory tracking. This study used motion modeling to explore the trajectory tracking control in WMR.

To verify the suggested shortest straight-line route tracking control, MATLAB numerical simulations and testing are performed. First, a 1m-radius circular reference route was assigned. It was decided on the look-ahead distance to be $l = 0.3m$. The only distance-based feedback control provided by is the controller gain. (9) was $k_y = 10$. A straight-line reference route was selected for simulation. The original circumstances were as follows: $e = \left[e_y(0)\ \ e_\theta(0)\right]^T = [-0.25\ \ -0.1]^T$. A straight-line reference route was used for simulation purposes. The circumstances were initially as follows: coordinate y_e, the error coordinates y_e and φ_e goes to zero asymptotically. From the beginning position to the destination point, Figure 3 depicts the shortest straight line route trajectory for the robot.

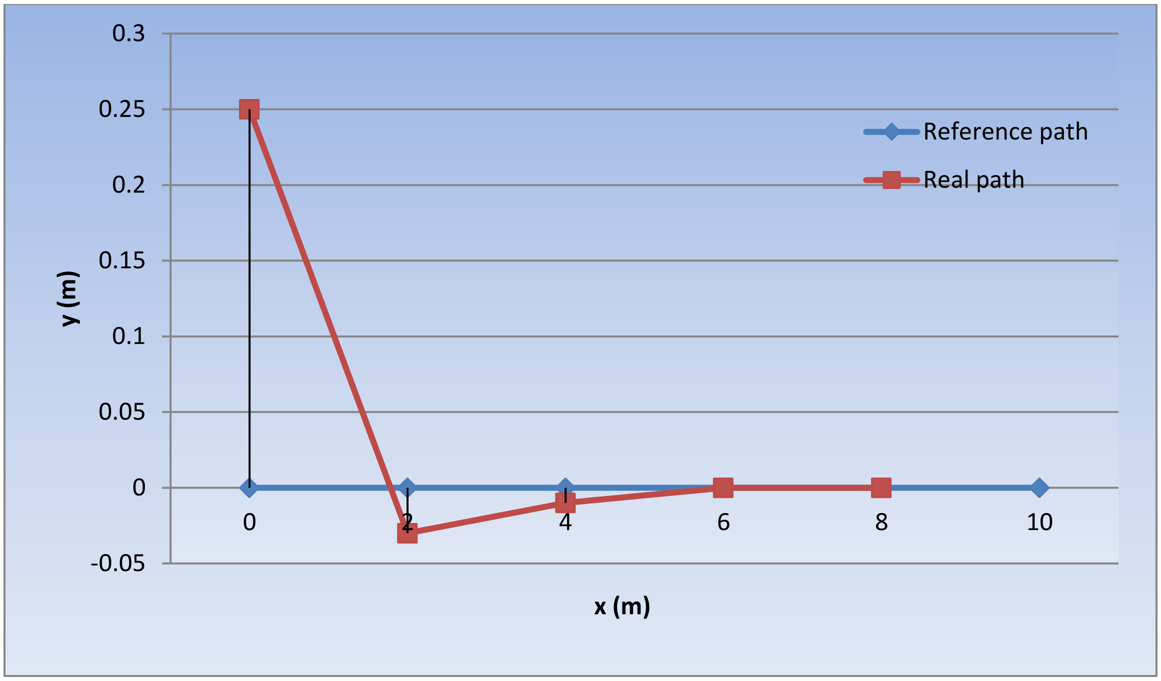

Figure 2: The straight-line reference path.

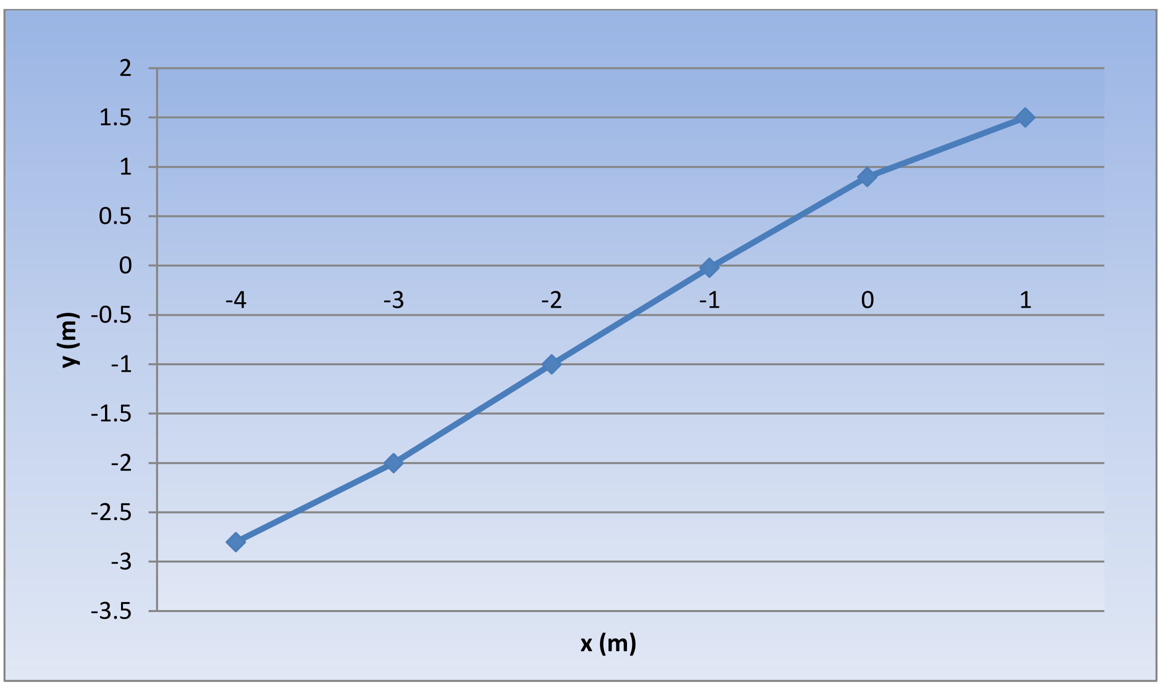

Figure 3: The quickest straight-line trajectory planning.

CONCLUSION

The provided route tracking controller for mobile robs is the most simplified since it is restricted to remote data. The initial stage was the construction of a cinematic robot model suitable for travelling accordingly. For a time-varying feedback controller, the look-ahead technique was developed. When a straight line road-tracking method was used and asymptotic stability was shown, Lyapunov's theory examined the stability characteristics of the lock system. It was demonstrated that the straight-line tracking error was zero. The suggested feedback route control was validated by a quantitative test. Future research will look into tracking of routes with different temporal curvatures.

REFERENCE

1. D. Chwa, “Sliding-mode control of nonholonomic wheeled mobile robots in polar coordinates,” IEEE Trans. on Control Systems Technology, vol. 12, no. 4, pp. 637-644, July, 2004.
2. Suresh, P., Ravikumar O, Hari Krishna Mahesh K, Sri Aashritha S, 2020 “Content Extraction Through Chatbots With Artificial Intelligence Techniques,” International Journal of Scientific & Technology Research, Vol. 9, Issue 02, pp. 1960-1963.
3. J. Zhai and Z. Song, “Adaptive sliding mode trajectory tracking control for wheeled mobile robots,” International Journal of Control, vol. 92, no. 10, pp. 2255-2262, October, 2019.
4. B. Park, S. Yoo, J. Park, Y. Choi, “Adaptive neural sliding mode control of nonholonomic wheeled mobile robots with model uncertainty,” IEEE Trans. on Control Systems Technology, vol. 17, no. 1, pp. 207-214, January, 2009.
5. H. Du, J. Zhai, M. Chen, and W. Zhu, “Robustness analysis of a continuous higher order finite-time control system under sampled-data control,” IEEE Trans. on Automatic Control, vol. 64, no. 6, pp. 2488-2494, June, 2019.
6. Suresh, P., Saravanakumar, U., Celestine Iwendi, Senthilkumar Mohan, Gautam Srivastav 2020 “Field-programmable gate arrays with low power vision system using dynamic switching” Computers & Electrical Engineering, Vol. 90, 2021, 106996.
7. J. Y. Zhai and H. R. Karimi, “Universal adaptive control for uncertain nonlinear systems via output feedback,” Information Sciences, vol. 500, pp. 140-155, October, 2019.
8. J. Y. Zhai and H. R. Karimi, “Global output feedback control for a class of nonlinear systems with unknown homogenous growth condition,” International Journal of Robust and Nonlinear Control, vol. 29, no. 7, pp. 2082-2095, May, 2019.
9. F. Pourboghrat and M. Karlsson, “Adaptive control of dynamic mobile robots with nonholonomic constraints,” Computers and Electrical Engineering, vol. 28, no. 4, pp. 241-253, April, 2002.
10. J. Huang, C. Wen, W. Wang, and Z. Jiang, “Adaptive stabilization and tracking control of a nonholonomic mobile robot with input saturation and disturbance,” System and Control Letters, vol. 62, no. 3, pp. 234-241, January, 2013.
11. I. Matraji, A. Durra, A. Haryono, K. Wahedi, and M. Khousa, “Trajectory tracking control of skid-steered mobile robot based on adaptive second order sliding mode control,” Control Engineering Practice, vol. 72, pp. 167- 176, March, 2018.
12. D. Wu, Y. Cheng, H. Du, W. Zhu, and M. Zhu, “Finite-time output feedback tracking control for a nonholonomic wheeled mobile robot,” Aerospace Science and Technology, vol. 78, pp. 574-579, July, 2018.

13. W. Ji, J. Qiu, and H. Karimi, “Fuzzy-model-based output feedback sliding mode control for discrete-time uncertain nonlinear systems,” IEEE Trans. on Fuzzy Systems, 2019. DOI: 10.1109/TFUZZ.2019.2917127.
14. L. Hsu, T. Oliveira, J. Cunha, and L. Yan, “Adaptive unit vector control of multivariable systems using monitoring functions,” International Journal of Robust and Nonlinear Control, vol. 29, no. 3, pp. 583-600, February, 2019.
15. Suresh, P., Ravikumar O, Hari Krishna Mahesh K, Sri Aashritha S, 2020 “Content Extraction Through Chatbots With Artificial Intelligence Techniques,” International Journal of Scientific & Technology Research, Vol. 9, Issue 02, pp. 1960-1963.
16. N. Sun, D. Liang, Y. Wu, Y. Chen, Y. Qin, and Y. Fang, “Adaptive control for pneumatic artificial muscle systems with parametric uncertainties and unidirectional input constraints,” IEEE Trans. on Industrial Informatics, vol. 16, no. 2, pp. 969-979, February, 2020.
17. T. Yang, N. Sun, H. Chen, and Y. Fang, “Neural network-based adaptive antiswing control of an underactuated shipmounted crane with roll motions and input dead zones,” IEEE Trans. on Neural Networks and Learning System, vol. 31, no. 3, pp. 901-914, March, 2020.
18. C. M. Pappalardo and D. Guida, “On the dynamics and control of underactuated nonholonomic mechanical systems and applications to mobile robots,” Archive of Applied Mechanics, vol. 89, no. 4, pp. 669–698, 2019.
19. Suresh. P., “Creation of optical chain in the focal region of high NA lens of tightly focused higher order Gaussian beam”, Springer – Journal of Optics, Vol. 46, p. 225 – 230, 2017.
20. E. Fabregas, G. Farias, E. E. Aranda et al., “Simulation and experimental results of a new control strategy for point stabilization of nonholonomic mobile robots,” IEEE Transactions on Industrial Electronics, vol. 67, no. 8, pp. 6679–6687, 2020.
21. S. Roy, S. Nandy, I. N. Kar, R. Ray, and S. N. Shome, “Robust control of nonholonomic wheeled mobile robot with past information: theory and experiment,” Proceedings of the Institution of Mechanical Engineers Part I Journal of Systems and Control Engineering, vol. 231, no. 3, pp. 178–188, 2017.
22. S. Shi, X. Yu, and S. Khoo, “Robust finite-time tracking control of nonholonomic mobile robots without velocity measurements,” International Journal of Control, vol. 89, no. 2, pp. 411–423, 2016.
23. A. Bessas, A. Benalia, and F. Boudjema, “Integral sliding mode control for trajectory tracking of wheeled mobile robot in presence of uncertainties,” Journal of Control Science and Engineering, vol. 2016, Article ID 7915375, 10 pages, 2016.
24. A. Onat and M. Ozkan, “Dynamic adaptive trajectory tracking control of nonholonomic mobile robots using multiple models approach,” Advanced Robotics, vol. 29, no. 14, pp. 913–928, 2015.
25. J. K. Lee, Y. H. Choi, and J. B. Park, “Sliding mode tracking control of mobile robots with approach angle in Cartesian coordinates,” International Journal of Control, Automation, vol. 13, no. 3, pp. 718–724, 2015.
26. M. Rakhra, R. Singh, T. K. Lohani, and M. Shabaz, “Metaheuristic and machine learning-based smart engine for renting and sharing of agriculture equipment,” Mathematical Problems in Engineering, vol. 2021, Article ID 5561065, 13 pages, 2021.

27. A. Arab and M. M. Fateh, "An uncertainty compensator for robust control of wheeled mobile robots," Advanced Robotics, vol. 29, no. 20, pp. 1303–1313, 2015.
28. Suresh P., Aanandha Saravanan K., Celestine Iwendi, Ebuka Ibeke, Gautam Srivastava, "An artificial intelligence based quorum system for the improvement of the lifespan of sensor networks," IEEE sensors journal, Vol. 21, Issue: 15, pp. 17373 – 17385, 2021.