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# Discrete-Time Sliding Mode Control for Wheeled Mobile Robot Trajectory-Tracking

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***Abstract:*** *By implementing this idea, we can overcometrajectory tracking problem of wheeled mobile robot by using discrete-time sliding mode controller. The mobile robot having two differentially driving wheels (2DW) and two balancing caster taken into account as powerboat. It is an automated guided system which is specially equipped and designed for intelligent delivery, autonomous and handling of large payload. Mobile robot member is one of the powerboat of pioneer family of mobile robot, which have research development platform which share a common architecture of, employ-intelligent based client-server robotic controls and foundation software. PowerBot is perfect robot for both, indoor and outside transportation because it has high load carrying capacity and small size. The algorithm which is in the form of discrete-time domain which is used to avoid problem caused by discretization of persistent time controllers. The adequacy of the proposed controller is proved by simulation result and real time result.*

***Keywords:*** *Sliding mode control, discrete-time tracking control, non-holonomic system.*

## I. Introduction

In the industries, carts or trucks are drove by the human to carry products from one manufacturing plant to another which are usually in different buildings. So, by implementing the idea mentioned in paper the cart can follow the track of path and it will be more safe and convenient. This system are also suitable for different applications such as delivering medications or food in hospital, as a room cleaner, mowing lawns, agriculture tasks and so on. Wheeled mobile robots are most important out of all mobile robot because of their straightforwardness and vigour. Wheeled portable robots aresimple to construct than other type of robots.For controlling the problem of wheeled mobile robot we can use the variable structure control (VSC) methodology. The sliding mode control of robot is an important point while designing real robots and its theory is connected to numerous control frameworks [1]-[4], in light of the fact that it has properties that robustness against large parameter variations and disturbances which making the SMC technique is suitable for the direction following of portable robot.One important type of variable structure control is sliding mode control (SMC) methodology [2].

Designing switch functions of output variables or state variables to form sliding surfaces insure that the directions are continued the surfaces, yielding the coveted framework progress, however the SMC experiences the jabbering sensation brought on by high recurrence exchanging over intermittence of the control signal. All the applications of mobile robot require precise control and this precise control can be achieved by using trajectory tracking algorithm [6]-[10].

Basically sliding mode control has been considered for continuous time system, but as of late the examination of sliding mode control started more focus on discrete time sliding mode control (DSMC) to eliminate the problem caused by the discretization of continuous-time controller. This paper presented discrete-time sliding mode control of wheeled mobile robot with two differentially driving wheels and two balancing caster. Powerboat is an automated guided system which is specially equipped and designed for intelligent delivery, autonomous and handling of large payload. Mobile robot member is one of the powerboat of pioneer family of mobile robot, which are research development platform which share a common architecture of, employ-intelligent based client-server robotic controls and foundation software. PowerBot is perfect robot for both, indoor and outside transportation because it has high load carrying capacity and small size. The designed algorithm is in the form of discrete-time domain which is used to avoid problem caused by discretization of constant time controllers. The adequacy of the proposed controller is proved by simulation result.

## II. Problem Definition

Due to the nonappearance of sliding mode controller it is impractical to keep the control signal steady between the intervals. Discretization issue of constant time framework is happens because of the nonattendance of sliding mode controller. It does not offers invariance to indeterminate parameters, adjusting for the vulnerabilities that exist in genuine mobile robot application. In this paper a discrete-time sliding mode control issue is happened, which perform the estimation and control signal applications at standard interim of time.

There are two possible mechanisms which produce problem. First, problem may be caused by the switching on-ideal ties, such as time delay sort constants, which exist in any implementation of switching devices, typically including both analog and digital circuits as well as micro processor based implementations. Second, even if the switching device is considered ideal and capable of switching at an unbounded recurrence. The vicinity of parasitic flow, i.e., un modelled dynamics, also causes problem to appear in the neighbourhood of the sliding surface. The parasitic dynamics are those of fast dynamics of actuators, sensors and other high frequency modes of the controlled process, which are usually ignored in the open-circle model utilized for control outline if the related posts are very much damped and outside the wanted transfer speed of the criticism control framework. However, in sliding mode controlled systems, due to the discontinuity of the control signal, the interactions between the parasitic dynamics and the switching term may result in a non-decaying oscillation with finite amplitude and frequency ,i.e., problem. If the switching gain is large, such kind of problem may even cause
Un predict table instability.

## III. Wheeled Mobile Robot Kinematic Model And Trajectory-Tracking Control

The discrete-time sliding mode controller is a variable structure controller, which performs estimations and control signal applications at standard between times of time and keeps the control signal reliable between breaks. A fundamental property of discrete-time sliding mode control can't avoid being that the control signal can't avoid being figured and vacillated only at assessing minutes, realizing a broken control.

Discrete-time sliding mode controller offers invariance to dubious parameters, adjusting for the vulnerabilities that exist in genuine mobile robot applications, along these lines settling on it great decision for the direction following issue.

Discrete-timesliding mode control offers in-fluctuation to uncertain parameters, compensating for the dangers that exist in certifiable portable robot applications, subsequently settling on it a nice choice for the bearing after issue. The model of a wheeled portable robot is displayed in Fig. 1.

Drive wheels of sweep R, the separation between the wheels (2L), the precise rates of the drive wheels$(w_L, w_R)$,the middle point (CP) of the robot. The stance of the robot is considered $p = (x_r, y_r, \theta_r)$, where $x_r$ speak to the position on the x-axis, $y_r$ the position on the y-pivot and $\theta_r$ the heading of the robot. $v_r$ Speak to the direct speed while $w_r$ speak to the precise speed of the robot.
The WMRmodelis shown in fig.1:

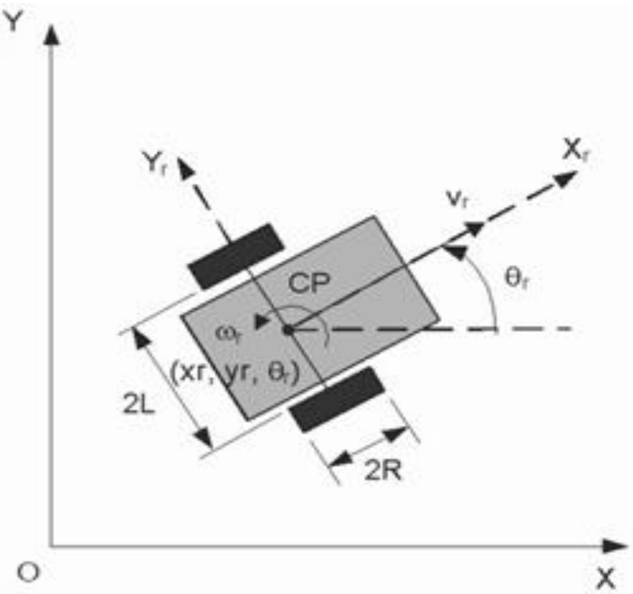

**Fig.1**. WMR model.

The kinematic model for the robot can be communicated as:

$$\begin{bmatrix}\dot{x}_r\\ \dot{y}_r\\ \dot{\theta}_r\end{bmatrix} = \begin{bmatrix}\cos\theta_r & 0\\ \sin\theta_r & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}v_r\\ w_r\end{bmatrix} \qquad (1)$$

The kinematic model of the robot can in like manner be imparted as:

$$\begin{cases} \dot{x}_r = v_r . \cos\theta r \\ \dot{y}_r = v_r . \sin\theta r \\ \dot{\theta}_r = w_r \end{cases} \tag{2}$$

Considering an example break Ts and a zero-appeal hold, (2) movements in discrete-time to:

$$\begin{cases} x_r[k+1] = x_r[k] + v_r[k].\cos\theta_r[k].Ts \\ y_r[k+1] = y_r[k] + v_r[k].\sin\theta_r[k].Ts \\ \theta_r[k+1] = \theta_r[k] + w_r[k].Ts \end{cases} \tag{3}$$

The bearing after issue is the best approach to lay out a controller fit for taking after a fancied course. Consequently a virtual robot, with the looked for heading $q_d(t) = [x_d(t)\ y_d(t)\theta_d(t)]$,is viewed as coming about the accompanying kinematic model of the virtual robot:

$$\begin{bmatrix} \dot{x}_d \\ \dot{y}_d \\ \dot{\theta}_d \end{bmatrix} = \begin{bmatrix} \cos\theta_d & 0 \\ \sin\theta_d & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v_d \\ w_d \end{bmatrix} \tag{4}$$

Where $p_d = (x_d, y_d, \theta_d)$ represents the desired pose, $v_d$the desired linear speed, $w_d$the desired angular velocity.Mathematical statement (4) can be communicated as:

$$\begin{cases} \dot{x}_d = v_d . \cos\theta_d \\ \dot{y}_d = v_d . \sin\theta_d \\ \dot{\theta}_d = w_d \end{cases} \tag{5}$$

Considering an example interim Ts and a zero-request hold, (5) progressions in discrete-time to:

$$\begin{cases} x_d[k+1] = x_d[k] + v_d[k].\cos\theta_d[k].Ts \\ y_d[k+1] = y_d[k] + v_d[k].\sin\theta_d[k].Ts \\ \theta_d[k+1] = \theta_d[k] + w_d[k].Ts \end{cases} \tag{6}$$

The following mistakes of the robot demonstrated in fig. 3 are communicated as:

$$\begin{bmatrix} x_e \\ y_e \\ \theta_e \end{bmatrix} = \begin{bmatrix} \cos\theta_d & \sin\theta_d & 0 \\ -\sin\theta_d & \cos\theta_d & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_r - x_d \\ y_r - y_d \\ w_r - w_d \end{bmatrix} \tag{7}$$

The direction following issue is the way to plan a controller fit for following a coveted direction. For this reason a virtual robot is considered.

The tracking errors of the robot indicated in fig. 2 are communicated as:

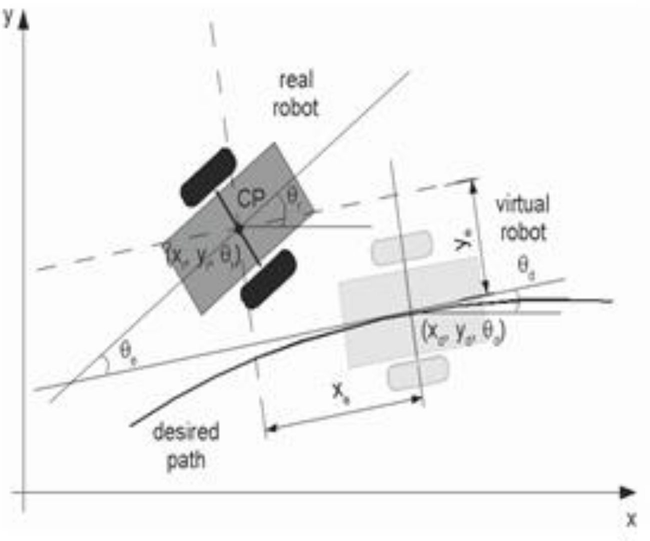

**Fig.2.** Trajectory tracking errors

Considering a specimen interim Ts and a zero-request hold, (7) progressions into discrete-time:

$$\left\{\begin{matrix} x_e[k] = x_{rd}[k].\cos\theta_e[k] + y_{rd}[k].\sin\theta_e[k] \\ y_e[k] = -x_{rd}[k].\sin\theta_e[k] + y_{rd}[k].\cos\theta_e[k] \\ \theta_e[k] = \theta_r[k] - \theta_d[k] \end{matrix}\right\} \quad (8)$$

$$x_{rd}[k] = x_r[k] - x_d[k] \quad (9)$$

$$y_{rd}[k] = y_r[k] - y_d[k] \quad (10)$$

The error dynamics for direction following are characterized as:

$$\left\{\begin{matrix} \dot{x}_e = -v_d + v_r.cos\theta_e + w_d.y_e \\ \dot{y}_e = v_r.sin\theta_e - w_d.x_e \\ \dot{\theta}_e = \dot{\theta}_r - \dot{\theta}_d \end{matrix}\right\} \quad (11)$$

In discrete-time eq$^n$ (11) changes into:

$$\left\{\begin{matrix} x_e[k+1] = x_e[k] + (v1 - v_d[k] + y_e[k].w_d[k]).Ts \\ x_e[k+1] = y_e[k] + (v2 - x_e[k].w_d[k]).Ts \\ \theta_e[k+1] = \theta_e[k] + (w_r[k] - w_d[k]).Ts \end{matrix}\right\} \quad (12)$$

Where,

$$v1 = v_r[k].cos\theta_e[k] \quad (13)$$

$$v2 = v_r[k].sin\theta_e[k] \quad (14)$$

## IV. Sliding Mode Control For Wmr

Discrete-time sliding mode controller offers invariance to indeterminate parameters, adjusting for the vulnerabilities that exist in genuinemobile robot applications, therefore making it good choice for the trajectory tracking problem.

The sliding mode control condition is given as follows:

$$s[k].(s[k+1] - s[k]) < 0 \quad (15)$$

The reaching law is:

$$s[k+1] = (1 - q.Ts).s[k] - \epsilon.Ts.sgn(s[k]) \quad (16)$$

$$0 < 1 - q.T < 1 \quad (17)$$

$$0 < \varepsilon.Ts < 1 \quad (18)$$

Where,
$Ts > 0$is the sampling period,
$\varepsilon > 0$is the reaching velocity &
$q > 0$is the converging exponential.

The sliding mode direction will move inside the semi sliding mode band:

$$|s[k]| = \frac{\varepsilon.Ts}{1 - q.Ts} \quad (19)$$

The sliding surfaces are defined as:

$$\left\{\begin{matrix} s_1[k] = x_e[k+1] + k_1.x_e[k] \\ s_2[k] = y_e[k+1] + k_2.y_e[k] + k_0.sgn[k].\theta_e[k] \end{matrix}\right\} \quad (20)$$

$$sgn[k] = sgn(y_e[k]) \quad (21)$$

Where, $k_0, k_1, k_2$ are positive constant &$x_e, y_e, \theta_e$are trajectory tracking errors.

From eq$^n$ (16) & (20), we get:

$$s_1[k+1] = x_e[k+2] + k_1.x_e[k+1]$$

$$s_1[k+1] = (1 - q.T_s).s_1[k] - \varepsilon.T_s.sgn(s_1[k] \quad (22)$$

$$s_2[k+1] = y_e[k+2] + k_2 y_e[k+1] + k_0.sgn(y_e[k]).\theta_e[k]$$

$$s_2[k+1] = (1 - q.T_s).s_1[k] - \varepsilon.T_s.sgn(s_1[k]) \qquad (23)$$

If $s_1[k+1]$ converges to zero, trivially $x_e[k+2] = -k_1 x_e[k+1]$
If $s_2[k+1]$ converges to zero, in steady-state it becomes$y_e[k+2] = -k_2.y_e[k+1] - k_0.sgn(y_e[k]).\theta_e[k]$
For $y_e[k+1] < 0 \Rightarrow y_e[k+2] > 0$if and only if $k_0 < k_2.|y_e[k+1]| \, / \, |\theta_e[k]|$
For $y_e[k+1] > 0 \Rightarrow y_e[k+2] < 0$if and only if $k_0 < k_2.|y_e[k+1]| \, / \, |\theta_e[k]|$

Finally it can be known from the $s_2[k+1]$ that convergence of $y_e[k+1]$&$y_e[k+2]$ leads to convergence of $\theta_e[k]$to zero.
A practical general form of reaching the control law is:

$$\dot{s} = -(1 - q.T_s).s - (\varepsilon.T_s).sgn(s)$$

By adding proportional rate term $-(1 - q.T_s).s$the state is compelled to approach the exchanging manifold faster when s is large.
From the time derivation of eq$^n$. (22) & (23), what's more, understanding that

$$\dot{\theta}_e = \dot{\theta}_r - \dot{\theta}_d = w_r - w_d$$

The discrete-time sliding mode controller is acquired from eq$^n$. (8), (12), (22) & (23)

$$v[k+1] = \frac{1}{cos\,\theta_e[k].T_s}.[-(1 - q_1.T_s).s_1[k] + \varepsilon_1.T_s.sgn(s_1[k]) - x_e[k+1].[1 + k_1] - v_d[k+1] - (v_r[k].\theta_e[k+1].sin\theta_e[k] - w_d[k+1].y_e[k] - w_d[k].y_e[k+1]).T_s)] \qquad (24)$$

$$w[k] = \frac{1}{v_r[k].cos\,\theta_e + k_0.sgn\,y_e[k+1]}.[-(1 - q_2.T_s).s_2[k] + \varepsilon_2.T_s.sgn(s_2[k]) - \theta_e[k] - y_e[k+1].(k_2 + 1) - (v_r[k+1].sin\theta_e[k] + w_d[k+1].x_e[k] - w_d[k].x_e[k+1]).T_s)] + w_d[k] \qquad (25)$$

## V. Result

Simulation results will be displayed in this segment in place to approve the proposed control law. Tests completed on the direction following issue of wheeled versatilerobots shows the viability of the proposed discrete-time sliding- mode controller.

There-enactment obliged the robot to track a direction comprising of a blend between a straight direction and a roundabout direction. Fig.3shows the sought direction with a blue intruded on line and with a persistent red line the came about direction.

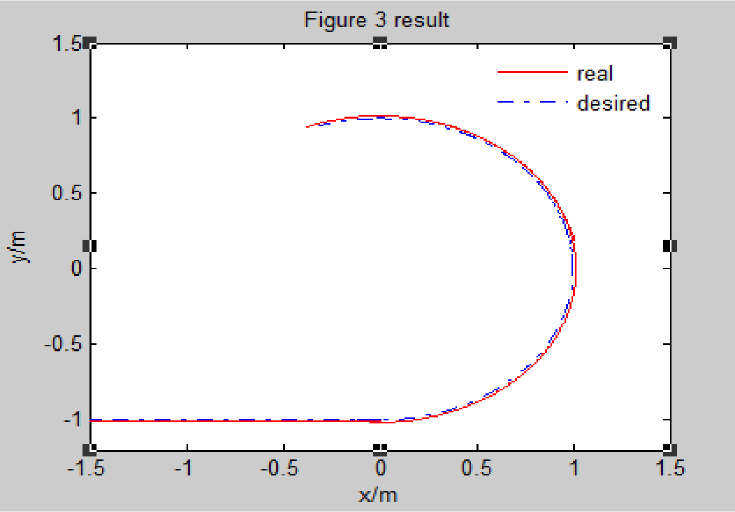

**Fig. 3.** Realand desired trajectory

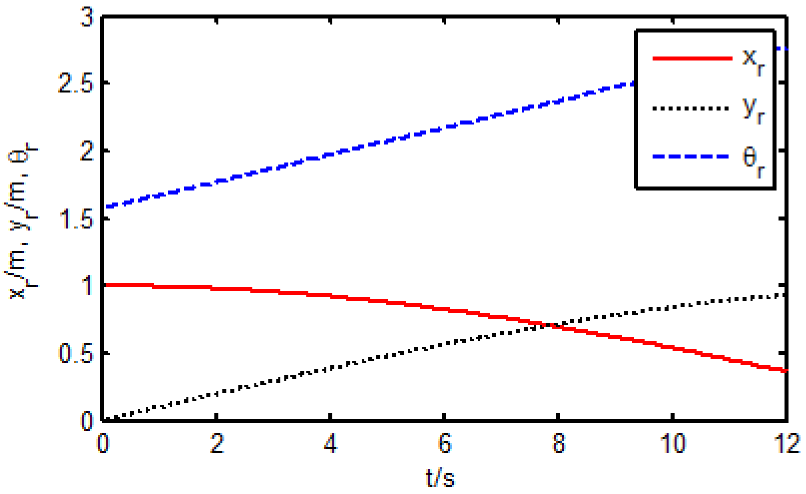

**Fig.4.** Real robot trajectoryon x, y and $\theta$ directions.

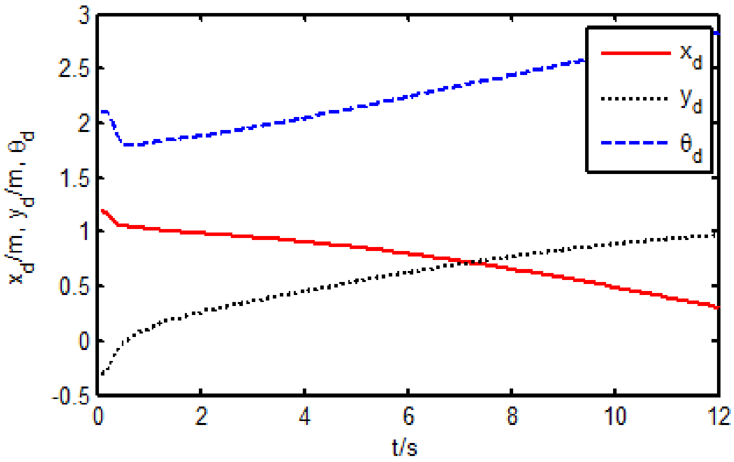

**Fig .5** shows the desired robot trajectory on x, y and $\theta$:

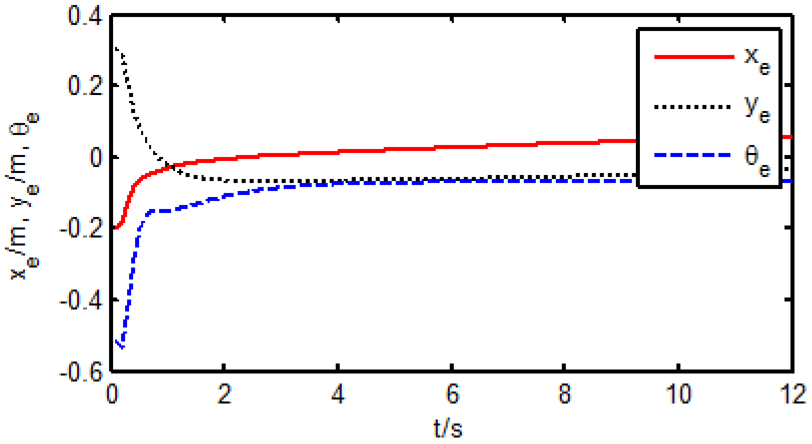

**Fig .6** shows the trajectory tracking error on x, y and $\theta$ direction:

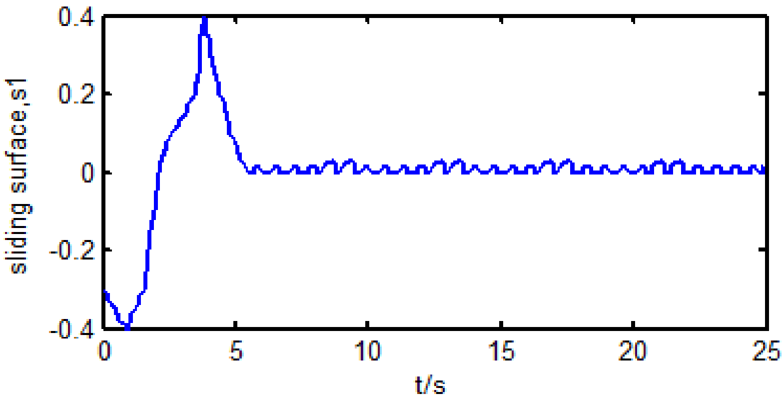

**Fig .7** shows the surface error $s_1$:

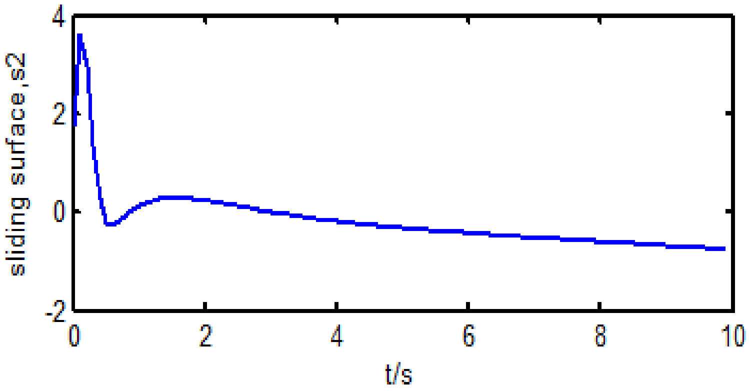

**Fig .8** shows the surface error$s_2$:

## VI. Conclusion

A discrete-time sliding-mode controller for direction following of wheeled mobile robots is exhibited in this paper. The sufficiency of the proposed discrete-time sliding-mode controller is plot utilizing reproduction and continuous tests. The wanted exhibitions for this controller are attained to. The controller is basic and simple to utilize. The PowerBot mobile stage controlled by the proposed sliding- mode controller can beutilized as a part of numerous handy execution how could be to help people transport their products indoor and outside their homes. The desired input for the system and system errors are to be calculated and also the control block parameters are to be estimated to reduce the errors in the system. Then parameters after error reduction are applied to obtain the desired response i.e. the desired trajectory.

## References

[1]. Z.JinagandH.Nijmeijer, “Arecursive technique fortracking control of nonholonomic systems in chained form”, IEEE Trans. Automatic Control,vol44,pp.265-279,1999
[2]. V.I.Utkin, J.GuldnerandJ.Shi, “Sliding mode control in electromechanical systemsTaylor&Francis, London, 1999.
[3]. Z.P. Jinag and H. Nijmeijer, “Tracking control of mobile robots: a case study in back stepping”Automaticvol. 33, pp. 1393-1399,1997.
[4]. V. I. Utkin, “Sliding modes in optimization and control, Springer- Verlag, New York, 1992
[5]. R.Solea,“Sliding mode control applied in trajectory-tracking of WMRs and autonomous vehicles”, PhDThesis, University of Coimbra, Portugal, 2009
[6]. Z.P.Yuan, Z.P.WangandQ.J.Chen,“Trajectory trackingcontrolofa nonholonomicmobile robot”,8th IEEEInternationalConferenceon ControlandAutomation, pp. 2207–2211,Xiamen, China,June2010.
[7]. Trackingusingfinite-time convergenceslidingmodecontroller,” 8th IEEEInternationalConferenceonControlandAutomation, pp.460–464, Xiamen, China, June2010.
[8]. R.Solea, A .Filipescu,S Filipescu and B. Dumitrascu,“Sliding-mode Controller for Four-Wheel-Steering Vehicle: Trajectory-TrackingProblem”, Proceedings of the 8th World Congress on Intelligent ControlandAutomation,pp.1185-1190,2010.
[9]. R Solea, A. Filipescu andG. Stamatescu, “Sliding-mode real-time mobileplatformcontrolinthepresenceof uncertainties”,Proceedings of the 48th IEEE Conference on Decision and Control and 28th Chinese Control Conference, Shanghai, pp. 7747-7752, 2009.
[10]. R Solea, A. Filipescu, U. Nunes, “Sliding-mode control for trajectorytracking ofa wheeled mobile robot in presence of uncertainties”, Proceedings ofthe7thAsianControlConference, Hong Kong,pp.1701-1706,2009.