Trajectory Tracking of Multiple Mobile System

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Abstract— **Thisresearch presented the trajectory tracking of multiple robot system for two-wheel differential drive mobile robots (DDMR). SMC controller is developed based on mathematical modeling of two wheels mobile robot model to control a stability of this system. The operation of an autonomous WMR is localization – the ability to locate itself within a frame of reference. The principle behind its optical tracking system can easily be applied to autonomous WMRs..Apart from a capable tracking system, a WMR also requires an effective system to control and drive it. Underpinning this control algorithm is a mathematical model of the behaviour and properties of the WMR. So, this research mainly focused on the navigation system. This navigation system is done by magnetic compass that mainly used the sensor output as the input command. It is supposed that the desired trajectory for the mobile robot is pre-specified by the velocity is controlled by SM-TT**

Index Terms—**Nonholonomic wheeled mobile robots, sliding mode control, trajectory tracking.**

1) INTRODUCTION

The basic task in mobile robot motion control is to accurately follow a given trajectory. The error between the present posture $x(t) = [x(t)y(t)\varphi(t)]^T$and the reference trajectory is to be minimized.

Mobile robots have been used in many applications and areas such as industrial, medical, etc. Wheeled Mobile Robots (WMRs) are considered as the most widely used class of mobile robots, due to their fast maneuvering and energy saving characteristics. In recent years, the issues of motion planning and control for WMRs have been widely pursued. The possible motion tasks can be classified as follows; Point-to-point motion, Path following motion and Trajectory tracking motion. In trajectory tracking problems, the robot must reach and follow a predefined trajectory in the Cartesian space, starting from a given initial position, on or off the trajectory. To recognize the trajectories; target , robot must consider the information from the working environment obtained from its sensor or vision system.

In this research, the systematics error may be the orientation error of the mobile robot. The accumulation of orientation errors will cause large position errors which increase proportional with the distance travelled by the robot. So, navigation system is mainly used to detect these errors and that navigation tasks will be simplified if magnetic compass accuracy can be improved.

Mobile robot kinematics is the dynamic model of how a mobile robot behaves without considering the forces that affect the motion.Mobile robot kinematics is used for position estimation and motion estimation. In this research, forward kinematic model is used to move the robot. In order to complete the control task for mobile, it is needed to control.

theangular velocity of motor shaft beside the position control. Actual velocity of the motor shaft have to equal the desired ones.

The design process is clearly explained in the next section with detailed information, followed by the results and finally ends with comparison results for error checking and conclusion

2) DESIGN OF MOBILE ROBOT

In this research, the two-wheel differential drive mobile robot is composed of two DC motors with each optical encoder. In order to control the velocity of mobile robot, robot positioning, mathematical model of kinematic, trajectory tracking and suitable controller is needed to know as a basic step. So the robot design involves-

A. Mathematical Modelling of the Mobile Kinematics
B. Controller Implementation
C. Trajectory Tracking
D. Software Implementation

A. Mathematical Modelling of the Mobile Kinematics

The mobile robot which is located in a 2D plane in which a global Cartesian coordinate system is defined. The robot platform in a world that possesses three degree of freedom in its positioning which are represented by a posture

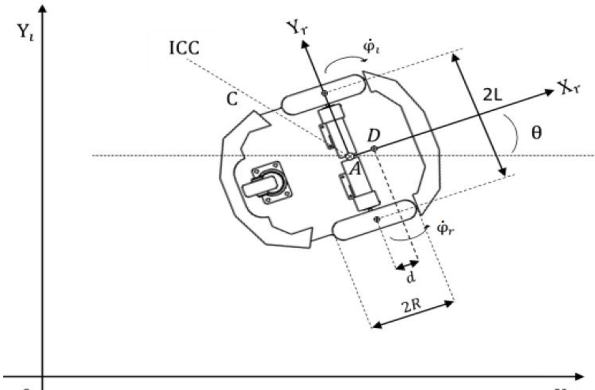

Figure 1. Coordinate Systems Mobile Robot

The parameters of the mobile robot based on the kinematic model can be written as follows-

- R =the radius of each wheel,
- d = the distance between the center of mass (point D) and mid point of the axis center of driving wheels (point A),

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- L = each wheel distance to point A, $\dot{\varphi}_l$ and$\dot{\varphi}_R$ is the right and left wheel angular speed respectively,
- θ = the degree between the robot frame (front direction) and the inertial frame,
- C =the distance between point A and instantaneous center of curvature (ICC).
- Length of mobile robot =18 cm
- Width of mobile robot = 13.5 cm
- Height of mobile robot = 6.5 cm
- Diameter of wheel = 6 cm
- Weight of mobile robot = 0.615 kg

Above parameters of differential drive mobile robot are useful as input of basic kinematics model of robot.

The purpose of the kinematic modelling is to derive robot velocities as a function of the driving wheels' velocities in predefined constraints. Robot's wheels have same angular speed according to the instantaneous curvature center. So the right wheel and the left wheel velocity relation can be obtained as below

$$\omega(C+L) = V_l \quad (1)$$
$$\omega(C-L) = V_R \quad (2)$$
$$C = \frac{l(V_R+V_L)}{(V_R-V_L)} \quad (3)$$

The linear and the angular velocity of the robot as follow, respectively;

$$V = \omega + C = \frac{V_R+V_L}{2} = \frac{R(\dot{\varphi}_l+\dot{\varphi}_R)}{2L} \quad (4)$$
$$\omega = \frac{V_R+V_L}{2} = \frac{R\,(\dot{\varphi}_l+\dot{\varphi}_R)}{2L} \quad (5)$$

In order to find velocities and the final position

$$v_x = v(t)\cos\big(\theta(t)\big), v_y = v(t) sin\big(\theta(t)\big) \quad (6)$$

$$x(t) = \int v(t)\cos\big(\theta(t)\big)\,dt \quad (7)$$

$$y(t) = \int v(t)\,sin\big(\theta(t)\big)dt \quad (8)$$

$$\theta(t) = \int \omega(t)dt \quad (9)$$

In the proposed control system, two postures will be used: the reference posture

$$q = [x_r \quad y_r \quad \theta_r]^T \quad (10)$$

and the current posture

$$q = [x \quad y \quad \theta]^T \quad (11)$$

An error $e_p$posture will be defined as follows:

$$e_p = \begin{bmatrix} e_x \\ e_y \\ e_\theta \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta & 0 \\ -sin\theta & cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_r - x \\ y_r - y \\ \theta_r - \theta \end{bmatrix} \quad (12)$$

B. Controller Implementation

$$P(s) = \frac{\dot{\theta}(s)}{V(s)} = \frac{\omega(s)}{V(s)} = \frac{K_t}{(Js+B)(Ls+R)+K_tK_e}\ [\frac{rad}{V}] (13)$$

Where, P(s) is the transfer function of DC motor. The block of DC motor transfer function can be shown as following figure 2.

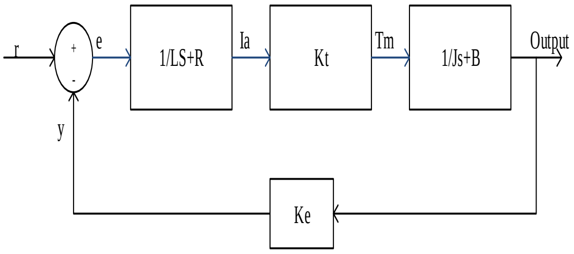

Fig.2. Block Diagram Of DC Motor

Where,
J = system moment of inertia of the rotor
b = motor viscous friction
Ke= back-EMF constant
Kt =motor torque constant
R = armature winding resistance
L= armature winding inductance
V = armature winding input voltage
I = armature winding current

The DC motor used in the robotic system is 80:1 Gear motor with 2PPR encoder. This gear motor is a powerful 12V brushed DC motor with an 80:1 gearbox and revolution of 2 pulses per revolution of the motor shaft, which corresponds to 160 pulse per revolution of the gearbox's output shaft. These units have a 19mm-long, 4mm-diameter and O-shaped output shaft. Key specification at 12V are 120PRM and 50mA free-run, 16Nm and 1.8A stall.

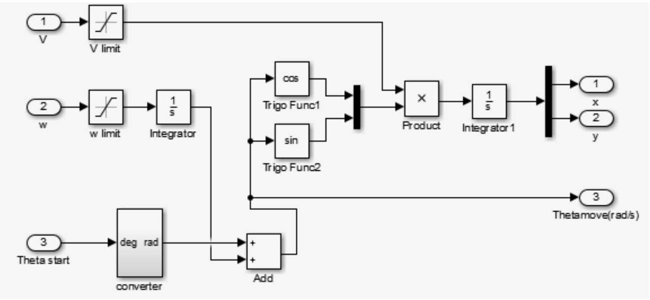

Fig.3. Simulation For The Two-Wheel Differential Drive Mobile Robotic Platform Based On Kinematic Model

By using the kinematics model of two-wheel differential drive mobile robot$V_{lin} = \frac{V_R+V_L}{2}$, Simulink model of closed loop mobile robotic platform can be created. This simulink model is shown in figure 3.

In this model, the right wheel linear speed ,

$$V_R = 0.3cm/s$$

and then the left wheel linear speed

$$V_l = 0.3cm/s$$

So, the linear speed of mobile robotic plaform, $V_{lin} = 0.3cm/s$. When both DC motors has the same speed and the same direction, the robot will move in straight line. The robot will spin at a point when the both DC motor has the same speed and the opposite direciton.

In this research, magnetic encoder is used to get the actual distance for position feedback loop. Relative position estimation is extremely dependent on the measurement of the robot's velocity. This encoder can provide 4 pulses per one revolution. Ifthe robot is moving straight ahead, we could simplycount encoder pulses to determine its new location.

$$\text{Distance traveled per pulse} = \frac{\text{wheel circumference}}{\text{no. of pulses per revolution}}$$

$$= \frac{2\pi r}{4}$$

$$= \frac{2\times\pi\times 3.3}{4}$$

$$= 5.184\text{cm/pulse}$$

While turning is centered around a circle whosediameter equals the distance between wheels.

Each pulse results in a turn = (5.184/40)*360·
=0.576· per pulse

C. *Trajectory tracking*

A control structure to ensure that the mobile robot can track trajectory. Controlling with a desired reference position, is reduced to get the distanceand deviation angle equal to zero, to achieve the objective of position control.

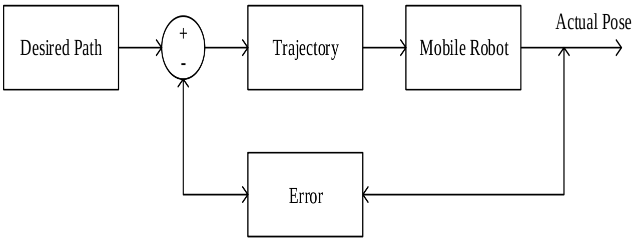

Figure.4. Block Diagram of the Mobile Robot

Error distance from following formula:

$$\boldsymbol{e} = \sqrt{(x_{target} - x_{robot})^2 - (y_{target} - y_{robot})^2 - distance}$$

Deviation angle

$$\varphi = \tan^{-1}\frac{y_{target} - y_{robot}}{x_{target} - x_{robot}}$$

The input of the system is a real-time moving point, mobile robot can reach the track by tracking this point. The target trajectory will be set into circle, ellipse and straight line. The size of the circle and ellipses, position of the straight line, speed of the trajectory points can be set arbitrarily. By changing values of K1 and K2 , different trajectory shapes and straight line can be set.

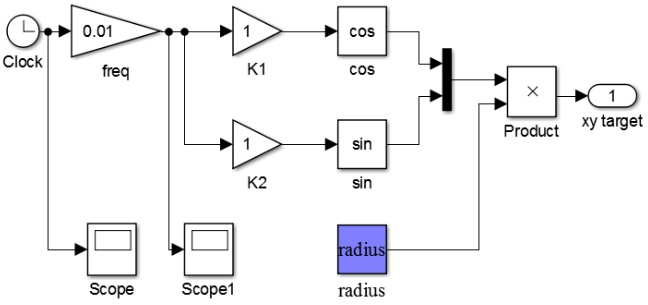

Figure.5. model of Trajectory Tracking

The trajectory tracking errors can be described by (x_e, y_e, θ_e).Design for a stable controller that generates acommand vector (v_c, ω_c). The error vector for trajectory-tracking is

$$\begin{bmatrix} x_e \\ y_e \\ \theta_e \end{bmatrix} = \begin{bmatrix} cos\phi_d & sin\phi_d & 0 \\ -sin\phi_d & cos\phi_d & 0 \\ 0 & 0 & 1 \end{bmatrix} . \begin{bmatrix} x_r - x_d \\ y_r - y_d \\ \theta_r - \theta_d \end{bmatrix}$$

Sliding surface such that lateral error,ye, and angular variable, θ_e, are internally coupled with each other in a sliding surface leading toconvergence of both variables.The sliding surfaces are purposed

$$s_1 = \dot{x}_e + k_1 x_e$$
$$s_2 = \dot{y}_e + k_2 y_e + k_0 syn(y_e)\theta_e$$

where$k_0, k_1, k_2$are positive constant parameters, xe, yeandθe are the trajectorytrackingerrors.

If $s1$ converges to zero, triviallyxe converges to zero.

If $s2$ converges to zero, insteady-state it becomes

$$\dot{y}e = -k2 \cdot ye - k0 \cdot sgn(ye) \cdot \varphi e.$$

For $ye < 0 \Rightarrow \dot{y}e > 0$

if only if $k0 < k2 \cdot |ye| / |\varphi e|$.

For $ye > 0 \Rightarrow \dot{y}e < 0$

if only if $k0 < k2 \cdot$

$$|ye| / |\theta e|.$$

Finally, it canbe known from $s2$that convergence of ye and $\dot{y}e$ leads to convergence $of\ \theta e$ to zero.

A practical form of reaching the control law is

$$\dot{s} = -\mathrm{Q.s} - \mathrm{P.sgn(s)}$$

Define $V = \frac{1}{2}.s^T.s$ as Lyapunov function candidate and its time derivative is

$$\dot{V} = S_1.\dot{S}_1 + S_2.\dot{S}_2$$

D. *Software Implementation*

The software of the present work includes motor driving system and control system. Motor driving system was done using kinematics model and its differential drive system. The control system is proposed with two separated feedback loops: a velocity feedback loop and a position feedback loop. Figure 10 shows the overall flow chat for the whole system.

The robot must reach and follow a trajectory in the Cartesian space (i.e., a geometric path with an associated timing law) starting from a given initial configuration. In the trajectory tracking task, the robot must follow the desired Cartesian path with a specified timing law (equivalently, it must track a moving reference robot).

Firstly the desired path (circle, ellipse and line) is chosen and appear in GUI. The data (coordinate and orientation) is sent to the mobile robot and then coordinate is related to the encoder and the encoder store to the rotation of the wheel and the magnetic sensor reads the desired orientation to follow the desired path. The most fundamental requirement for the successful navigation of a mobile robot is its ability to know its position with an acceptable degree of certainty at any given time.

After the leader robot get data from GUI, the mobile starts to drive and to follow the desired path. Leader robot also store data which it is driven path and sent back data to the PC. Moreover, the leader robot also send data (coordinate and orientation) to the follower robot via the wireless modules and the follower robot starts to follow the leader's path.

Fig.6. Overall Flow Chart Of The Whole Mobile Robot Control System

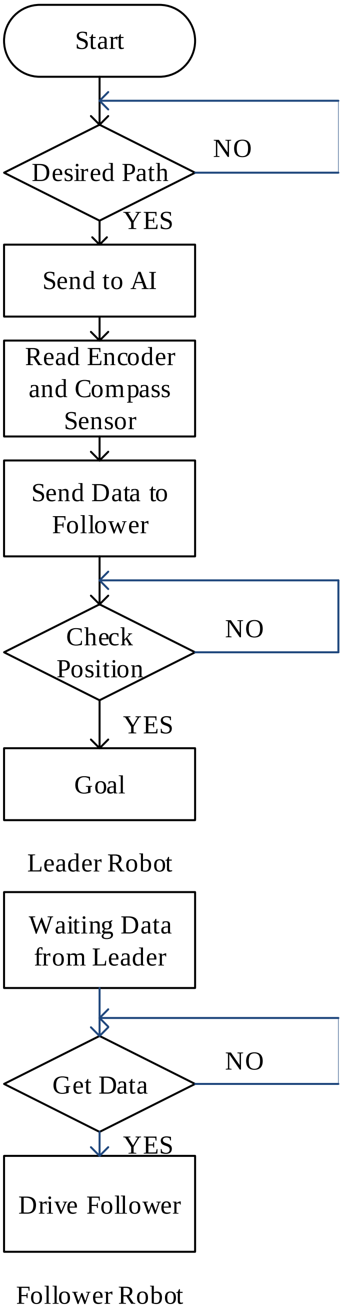

Figure6. Overall Flow Chart Of The Whole Mobile Robot Control System

3) RESULT

Tracking control of nonholonomic mobile robots aims at controlling robots to track a given time varying trajectory (reference trajectory).The reference trajectory is obtained by using a reference (virtual) robot.The control inputs are mostly obtained by a combination of feedforward inputs, calculated from reference trajectory, and feedback control law. The trajectory tracking problem for aWMR in the presence of disturbances that violate the nonholonomic constraint based on discrete-time sliding mode control.

The user can see the generalized coordinate vector in the inertial frame from the output results of kinematic models for differential drive mobile robot. The experimental result is the three forms of movement.

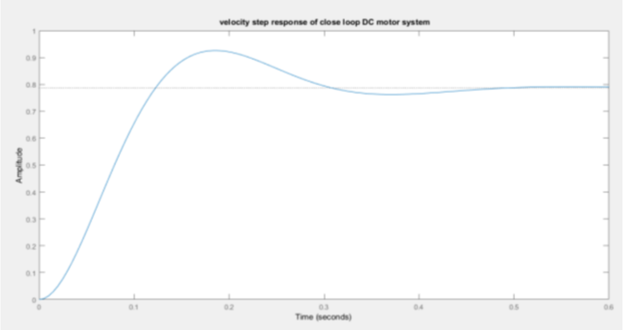

Figure 7.Velocity step response of close loop DC motor system

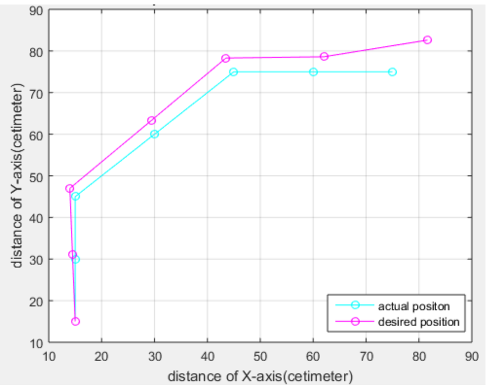

Fig.8. Graph of comparison result for actual position and desired position

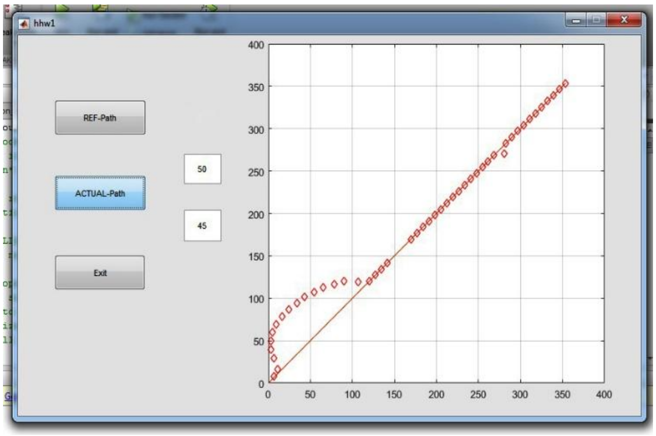

Fig.9. Graph result for actual position and desired position in GUI

For graphically presented initial pose [x, y, θ] for the first condition is [0, 0, 0]

In experimental result in figure (9), the mobile is the coordinate is (0,0,0). The predefined path is straight line is 100cm and then turn the right 90 degree and go 100 cm to straight line again. At turning position occurs slightly errors between predefined path and mobile path in figure (10). Moving in straight line occurs errors a little The mobile turns 90 degree after travelling the straight line (100cm) from (0,0) in 5 seconds in figure (11).The parameter of the robot is that the mass of the robot is 1.04 kg, the radius of the wheel is 8cm ,the height of the mobile is 4 inches and the length and the width of the mobile is 6.5 inches and 5.5 inches.

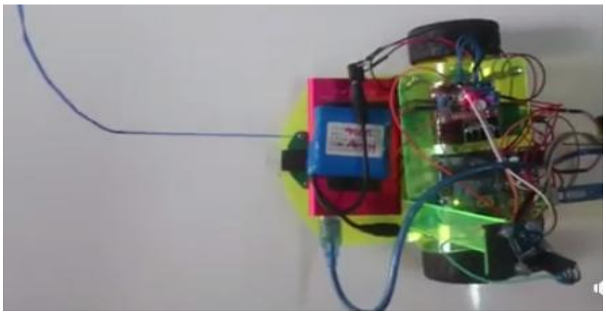

Figure 10. Experimental Result Of Mobile Starts Coordinate (1,1,0)

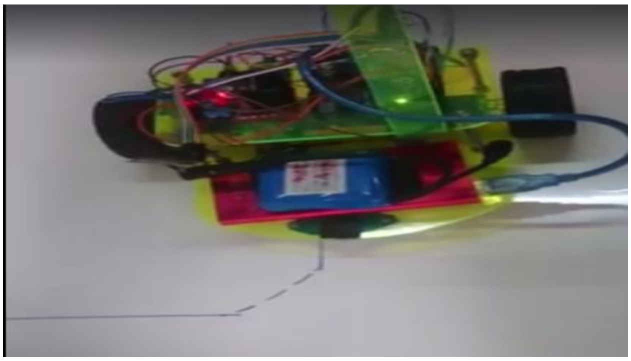

Figure11.Mobile Starts Truning At (10,10)Cm After Moving 5 Seconds

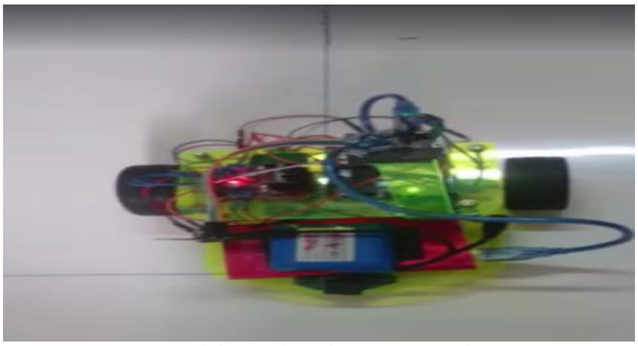

Figure 12. Mobile Reaches The Turning Angle 90 Degree

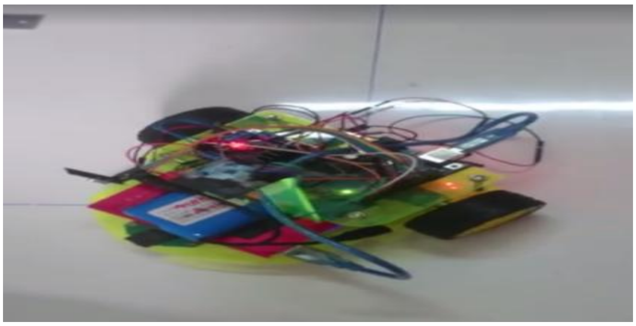

Figure 13. The Mobile Is Turning After Reach 90 Degree In 2 Seconds

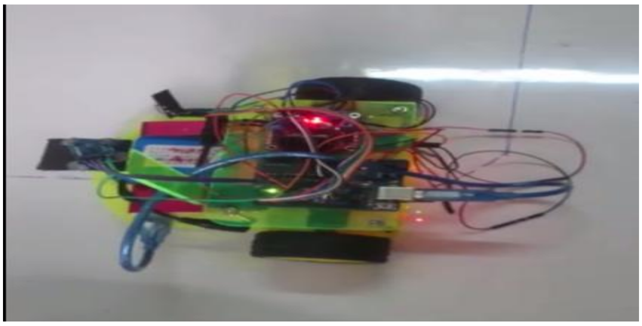

Figure14.Turning 90 Degree

4) CONCLUSION

In this present study, the stable control method, capable of dealing with the tracking trajectory of the differential drive mobile robot, had been derived using the kinematic based controller. The model with the control schemes has been able to satisfactorily track the given trajectory. The control scheme is good enough for basic tracking problems.

These conditions are depended on the accuracy of DC motor such as motor torque, load , variable power supply and controller. By satisfying these facts, the robot can track to desired without any error in distance and direction. Moreover, a trajectory planning algorithm is described that deals with comfort constraints providing smooth trajectories with low associated accelerations.

The proposed control structure is based on two nonlinear sliding surfaces ensuring the tracking of the three output variables, exploiting the nonholonomic constraint. The control law has been thoroughly eval- uated in terms of tracking performance either by simulation and real experiments And then these mobile robot can be also candidates for farming applications, as well as for transportation in nuclear plants and factories.

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