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TRAJECTORY TRACKING FOR LEADER-FOLLOWER ROBOTS

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ABSTRACT

Differential drive mobile robots are widely used due to their simplicity, easiness of control and flexibility. This paper presents trajectory tracking and control of differential drive robots along a predefined regular geometrical path. The leader mobile robot is controlled with sliding mode control (SMC) to track accurately the reference path and the follower mobile robots works like the leader mobile robot as a slave robot. The control algorithm takes user input from a user interface using commercial available software MATLAB through which one can select the type of trajectory. The results show the comparison of orientation and position of leader-follower mobile robots.

Keywords: Trajectory tracking, sliding mode control, differential drive.

I. INTRODUCTION

Need for the mobile robots and intelligent autonomous vehicles are increasing in different sectors from industry to medical to military. They are capable of performing many tasks repetitively and precisely without the help required by humans. To attain full autonomy several aspects like sensing, path planning, trajectory tracking and control, self-localization have to be addressed. The motion control of mechanical system can be classified into three groups: point stabilization, where the goal is to stabilize the vehicle at a desired robot point, trajectory tracking where the vehicle is required to track a time-parameterized reference, and path following where the vehicle is required to converge to and follow a desired path without temporal specifications. [1]

Trajectory tracking is an essential part for modern robots. In trajectory tracking problems, the robot must reach and follow a predefined trajectory in the Cartesian space. Many control algorithms have been proposed in the trajectory tracking framework, such as PID [2], Lyapunov based controllers [3], adaptive controllers [4], model-based predictive controllers [5], fuzzy controllers [6], etc. In this paper, sliding mode control law is used for solving trajectory tracking problems. The leader robot is responsibility of the system that must be track the trajectory and follower robot is similar behavior as the leader.

In this research, trajectory tracking and control of differential drive robots and vehicles is a problem of great importance. The errors of systematic may be orientation error that will cause large position errors which increase proportional with the distance travelled by the robot. So navigation system is added to detect these errors and magnetic compass can be used to improve navigation system. The control of the robot is solved by considering its kinematics model. Mobile kinematics model is used for position estimation and motion estimation.

II. MATERIAL AND METHODOLOGY

1. Mathematical modelling of mobile

Kinematic modeling deals with the geometric relationships that govern the system and studies the mathematics of motion without considering the affecting forces. The goal of the robot kinematic modelling is to find the speed of the robot in the inertial frame as a function of the wheels speeds and the geometric parameters of the robot (configuration coordinates).

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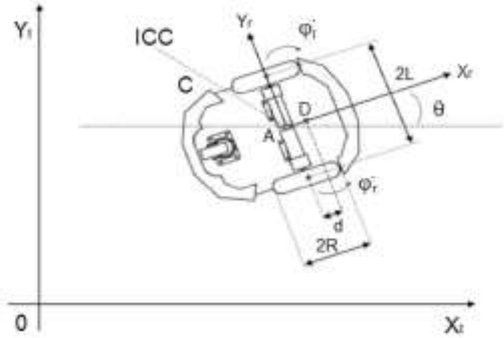

Fig: 1. Coordinate System of Mobile Robot

The parameters of the mobile robot based on kinematic model are: R is the radius of wheel, d is distance between point D (center of mass) and point A (center of driving wheels), 2L is a distance from right to left wheel, $\dot{\varphi}_l$ and $\dot{\varphi}_r$ is the angular velocity of right and left wheels, θ is degree between robot frame and inertial frame. The leader and follower are same dimensions and same characteristics of the DDMR. So, the dimensions are: length is 18 cm, width is 13.5 cm, diameter of wheels is 6 cm and weight of robot is 0.615 kg. By ignoring the analysis of the castor-free, the configuration of mobile robot can be describe into three general variables *q(t)* to describe the position of the robot and the control input *u(t)*. It can be defined in matrix:
$q(t) = [x(t)\ \ y(t)\ \ \theta(t)\ ]^T$, and $u(t) = [\dot{\varphi}_r(t)\dot{\varphi}_l(t)]^T$

The relation between the angular velocities $\dot{\varphi}_r$, $\dot{\varphi}_l$ and circumferential speeds V_R, V_L are:

$$V_R = \dot{\varphi}_r R \quad and \quad V_L = \dot{\varphi}_l R \quad \text{-----------} \quad (1)$$

A kinematic model of mobile robot can be based on the following equations:

$$\dot{x} = V\cos(\theta) \qquad V(t) = (\frac{V_R + V_L}{2})$$

$$\dot{y} = V\sin(\theta) \qquad \omega(t) = (\frac{V_R - V_L}{2L}) \quad \text{-------} \ (2)$$

$$\dot{\theta} = \omega$$

According to kinematic, the relation between the X-Y coordinate and the velocities vector is expressed as posture vector *p*.

$$\dot{p} = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \frac{\cos\theta}{2} & \frac{\cos\theta}{2} \\ \frac{\sin\theta}{2} & \frac{\sin\theta}{2} \\ \frac{1}{2L} & -\frac{1}{2L} \end{bmatrix} \begin{bmatrix} V_L \\ V_R \end{bmatrix} \quad \text{---------}(3)$$

In this paper, the robots have two identical parallel wheels, which are determined the wheel speeds (V_L and V_R) for a given position of the mobile robots. In this model, DC motors with 2PPR encoder are used for driving and constant velocities (V_L and V_R) are used in this system. For additional circuit, magnetic encoder is used to get actual signals for the position feedback loop.

2. Trajectory tracking

When mobile robot moves from one position to another to achieve a position destination, it always produces some errors. It is supposed that a feasible desired trajectory for the mobile robot is pre-specified by an open-loop path planner. The problem of controlling, with a desired reference position, is reduced to get the distance and deviation angle equal to zero, to achieve the objective of position control.

In the control system, the reference posture $q=[x_r\ \ y_r\ \ \theta_r]^T$ and the current posture $q=[x\ \ y\ \ \theta]^T$ will be used. Error distance and deviation angle can be calculated by the following equations:

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

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

The input of the system is a desired path (series of points) and the mobiles must be moved by track to track these points. Leader robot lead to the target and follower act like leader's behavior. The trajectory tracking errors can be described by (x_e , y_e , θ_e). The error vector for trajectory tracking is:

$$\begin{bmatrix} x_e \\ y_e \\ \theta_e \end{bmatrix} = \begin{bmatrix} cos\,\emptyset_d & sin\,\emptyset_d & 0 \\ -sin\,\emptyset_d & cos\,\emptyset_d & 0 \\ 0 & 0 & 1 \end{bmatrix} . \begin{bmatrix} x_r - x_d \\ y_r - y_d \\ \theta_r - \theta_d \end{bmatrix} \text{--- (4)}$$

In the paper, proposed design of sliding surfaces in the frame of Cartesian coordinates such that position variables (x, y) and deflection angle (θ) are coupled with each other in a sliding surface leading to convergence of both variables. So, the vector of sliding surfaced is defined *S=[S$_1$,S$_2$]* as

$$S_1 = \dot{x_e} + k_1 x_e$$

$$S_2 = \dot{y_e} + k_2 y_e + k_0 sgn(y_e)\theta_e$$

Where k_0, k_1, k_2 are positive constant parameters and x_e, y_e, θ_e are tracking errors.

If S_1 converges to zero, trivially x_e converges to zero. If S_2 converges to zero, steady-state it becomes.

$$\dot{y_e} = -k_2 y_e - k_0 sgn(y_e)\theta_e$$

For $\theta_e < 0 \Rightarrow \dot{\theta}_e > 0$ if only if $k_0 < k_2$

For $y_e > 0 \Rightarrow \dot{y}_e < 0$ if only if $k_0 < k_2 \cdot |y_e| / |\theta_e|$.

Finally, the SMC can be known from S_2 that convergence of y_e and $\dot{y_e}$ leads to convergence of θ_e to zero.

3. Software implementation

Firstly the desired path is chosen and appears in GUI and send data to the leader mobile robot. Then the feedback signal is sent back to GUI after moving mobile robot and also sends to the follower robot. After the leader robot get data from GUI, mobile starts to drive and to follow the desired path. When the encoder counts 40 times, the controller resets the encoder and send the feedback signals to the PC and to the follower mobile robot. After completing desired data from the PC, the leader mobile robot runs and then stops. The flow charts of control program are describe in figure (2).

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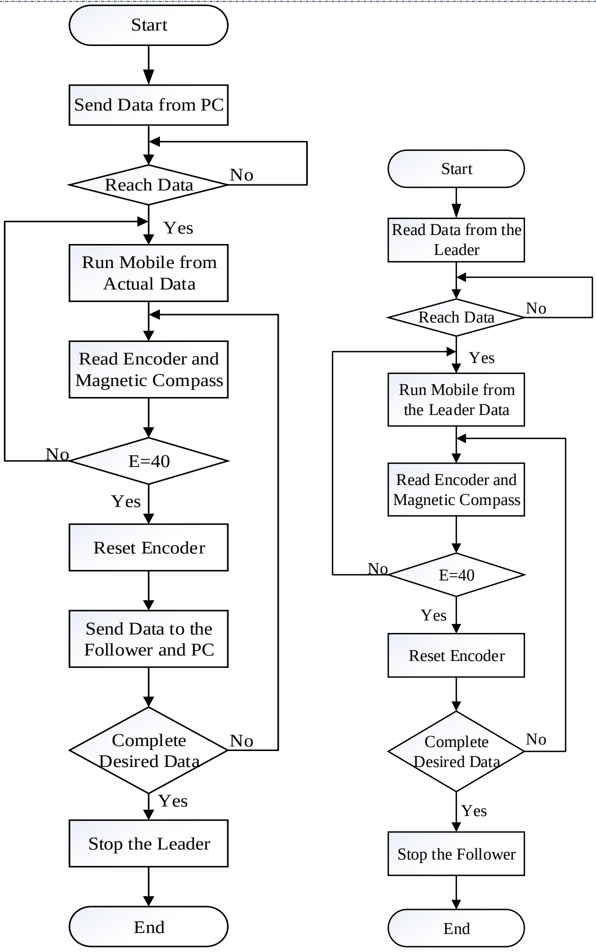

Fig: 2. Flow charts of control program.

III. RESULTS

Real-time experiments were carried out on differential drive mobile robot to overcome the position control problems incorporated in the mobile robot. A sliding mode control law is applied for stabilizing the robot around its reference trajectory even in the presence of exogenous disturbances/noises and modelling uncertainties. Furthermore, both the reference and the real trajectory should not cross the origin after starting over the initial position; and the initial position of reference trajectory is always set to be the origin of coordinates; or the angular velocity of mobile robots is assumed to be nonzero during trajectory tracking.

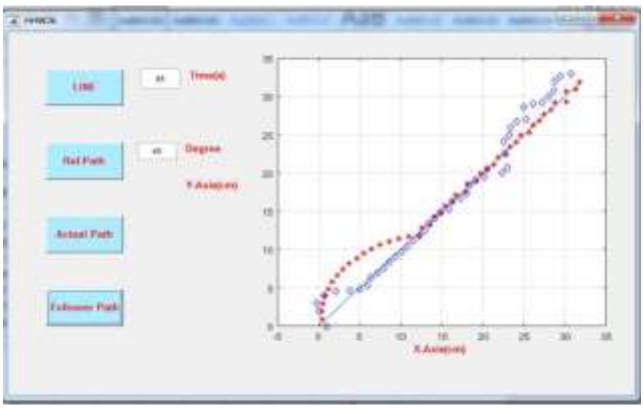

Fig: 3. Graphical user interface developed for human- robot interaction

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Figure (3) shows the developed Graphical User Interface (GUI) of the control system and feedbacks trajectory of the leader and follower robots. The user with the help of this interface running on the remote computer can change different parameters like trajectory to be generated, and dimension of the trajectory etc. The starting point of the leader mobile is at x=0 cm, y=0 cm and the heading angle is 90 degree and the follower robots is 30 cm lag behind the leader mobile robot. The red star represents the leader mobile robots path and the blue square is for the follower mobile robot.

Different between the leader robot and follower robot of trajectory signals is shown in figure (4) and figure (5).

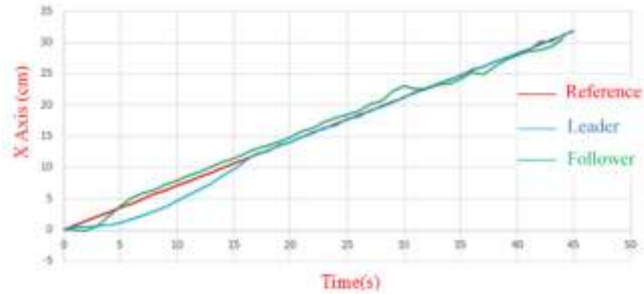

Fig: 4. Tracking errors of the leader-follower X-position

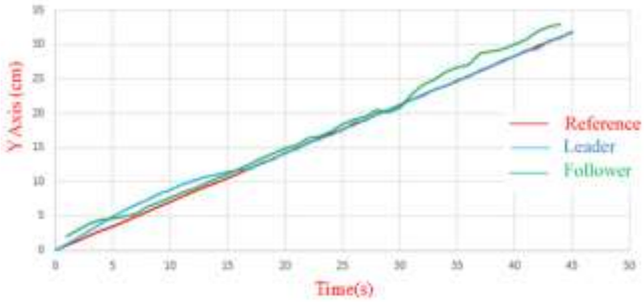

Fig: 5. Tracking errors of the leader-follower Y-position

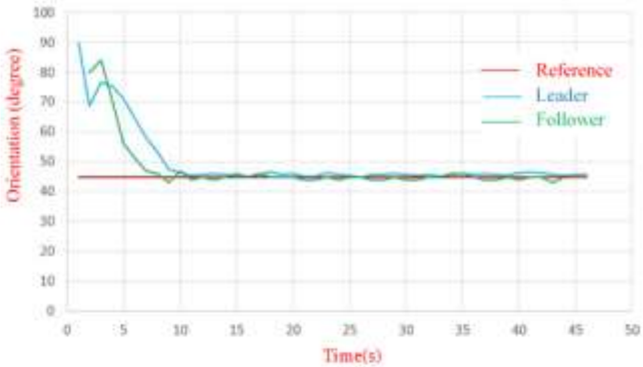

Fig: 6. Tracking errors of the Leader-Follower Orientation

According to these figures, the leader robot is gradually approach to the desired trajectory and the error may be large in the follower path at the end of the tracking task.

IV. CONCLUSION

This paper presents the position control algorithm for the differential drive mobile robot in a constrained environment. For Kinematic Model, the controller design is simpler because we can set velocity or angular velocity directly. 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.

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The proposed control structure is based on two nonlinear sliding surfaces ensuring the tracking of the three output variables, exploiting the nonholonomic constraint. The experimental tests presented in this paper represent the performance of the controllers. The sliding mode controllers are robust against perturbations and noises.

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REFERENCES

[1] P. Morin and C. Samson, "Motion control of wheeled mobile robot," inSpringer Handbook of Robotics (B. Siciliano and O. Khatib, eds),Springer Berlin Heidelberg, 2008, pp. 799-826.

[2] Y. Kanayama, Y. Kimura, F. Miyazaki, T. Noguchi, "A stable trackingcontrol method for an autonomous mobile robot," In Proceedings 1990IEEE International Conference on Robotics and Automation, LosAlamitos, CA, USA, 1990, vol. 1, pp. 384–389.

[3] Samson, K. Ait-abderrahim, "Feedback control of a nonholonomicwheeled cart in Cartesian space," In Proceedings of the 1991 IEEEInternational Conference on Robotics and Automation, vol.2,Sacramento, CA, 1991, pp. 1136–1141.

[4] Z.-P. Jiang, and H. Nijmeijer, "Tracking control of mobile robots: a casestudy in backstepping," Automatica, 1997, 33 (7), pp. 1393–1399.

[5] G. Klančar, and I. Škrjanc, "Tracking-error model-based predictivecontrol for mobile robots in real time," Robotics and AutonomousSystems, 2007, 55 (6), pp. 460–469.

[6] E.-H. Guechi, J. Lauber, M. Dambrine, G. Klančar, S. Blažič, "Controldesign for non-holonomic wheeled mobile robots with delayed outputs,"Journal of Intelligent& Robotic Systems, 2010, 60 (3), pp. 395–414.

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