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Designed of nonlinear controller for Automated Guided Vehicle.

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Abstract: -In this paper, a nonlinear controller base on Lyapunov method is proposed and applied for wheel mobile robot (WMR). Firstly, position of the AGV is estimated based on the encoders which are mounted on the wheel of AGV. Then, this controller makes WMR follow desired trajectory which is moving with desired constant velocity. The stability of system is proved by the Lyapunov stability theory. The simulations and experimental results are shown to prove the effectiveness of the proposed controller.

Keywords:- *Lyapunovfunction ,nonlinear control , nonholonomic robot controller.*

I. INTRODUCTION

A system is called automatic and intelligent, one thatcan sense and interact with its environment, one that can integratemuch more applications into lives of human andmanufacture.As all the other high-tech products, AGV is controlled by computer or microcontroller, which is used for storing information, making decisions and executing proceeses.In practice, the AGV has the ability to make almost all the decisions and control functions.

They can schedule a time, keep inventory, manage information systems and communicate with other AGV operation at the same time.AGVhas been widely used in several manufacturing fields such as automotive, chemicals, plastic, hospital, warehouse etc.Due to AGV is a nonlinear system with nonholonomicconstraints,noises so it is very difficult and complex to control, that is a challenge for researchers.

Currently, there are many research groups in the world have made significant achievements about mobile robot with different methods.Do-Eun Kim et al [1] introduces a simple indoor GPS systemusing ultrasonic sensor to determine the position of the robot indoor.Due to the characteristics of ultrasonic sensors, noise occurs in sensor values by surrounding temperature or obstacle.Location error is minimized by prediction and correction of the noise with Linear Kalman Filter.Nguyen Van Tinh et al [2] presents methods for trajectory planning and optimal control of mobile robot for the problem of pallet's pick and place in warehouse.Vu Hong Gam et al [3]presents the path-following controller design method using input-output feedback linearization technique for the automatic guided vehicle.Peter Šuster [4] introduces a solution to the reference trajectory tracking problem done by a differential wheeled mobile robot.The purpose of the control structure was the reference trajectory tracking, which we verified using the Neural Network Toolbox of Matlab/Simulink.EdouardIvanjko et al [5] presents two approaches to modelling of mobile robot dynamics.First, approach is based on physical modelling and second approach is based on experimental identification of mobile robot dynamics features.Model of mobile robot dynamics can then be used to improve the navigational system, especially path planing and localization modules.Localization module estimates mobile robot pose using its kinematic odometry model for pose prediction and additional sensor measurements for pose correction.To solve these problems, this report presents solutions for the design trajectory and a nonlinear controller base on Lyapunov method.The simulations and experimental results are shown to prove the effectiveness of the proposed controller.

II. SYSTEM MODELING.

The WMR as shown in Fig.1 has three wheels. At the rear, two driving wheels are mounted on the same axis and one castor wheel at the front, which supports WMR is balanced.Driving wheels are driven by DC motor which are equipped with encoders.

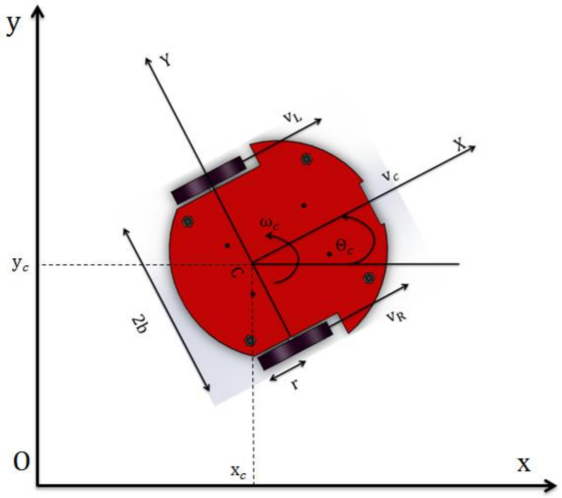

Fig.1 Kinematic model of mobile robot.

Where $r$is drive wheel radius, v_r and $v_l$are rightand left drive wheel velocities, $b$is the distance of the center of the wheel from C.In the Fig.1 shows Oxy is the global coordinate frame and CXY is a local coordinate frame.The position of AGV at point C in the global coordinate system is completely determined by the generalized coordinate vector$\mathbf{q} = [x_c \quad y_c \quad \Theta_c]^T$, where $x_C, y_C$are the coordinates of the point C in the global coordinate frame, $\Theta_c$is the orientation of the local frame CXY attached to the robot platform measured from the x-axis.We assume that the wheels roll and no slip, AGV moves with speed constraints:

$$\dot{x}_c sin\Theta_c - \dot{y}_c cos\Theta_c = 0 \qquad (1)$$

Constraints can be rewritten as follows:

$$\mathbf{A}(\mathbf{q})\dot{\mathbf{q}} = 0 \qquad (2)$$

$$\mathbf{A}(\mathbf{q}) = [-sin\Theta_c \quad cos\Theta_c \quad 0]$$

As a result, the kinematic model under the nonholonomic constraints in (2) can be derived as follows:

$$\dot{\mathbf{q}} = \mathbf{J}(\mathbf{q})\mathbf{z} \qquad (3)$$

$$\mathbf{J}(\mathbf{q}) = \begin{bmatrix} cos\Theta_c & 0 \\ sin\Theta_c & 0 \\ 0 & 1 \end{bmatrix}, \mathbf{z} = \begin{bmatrix} v_c \\ \omega_c \end{bmatrix}$$

Where $\mathbf{J}(\mathbf{q})$is a Jacobian matrix satisfying $\mathbf{J}^{\mathbf{T}}(\mathbf{q})\mathbf{A}^{\mathbf{T}}(\mathbf{q}) = 0$and $\mathbf{z}$is velocity vector.
The relationship between v_c, ω_c and the angular velocities of two driving wheels is:

$$\begin{bmatrix} \omega_{rw} \\ \omega_{lw} \end{bmatrix} = \begin{bmatrix} 1/r & b/r \\ 1/r & -b/r \end{bmatrix} \begin{bmatrix} v_c \\ \omega_c \end{bmatrix} \qquad (4)$$

Posture of AGV at reference point R(x_r, y_r, Θ_r), moving on reference path with the desired constant velocity of v_r, satisfies the following equations:

$$\begin{cases} \dot{x}_r = v_r cos\Theta_r \\ \dot{y}_r = v_r sin\Theta_r \\ \dot{\Theta}_r = \omega_r \end{cases} \qquad (5)$$

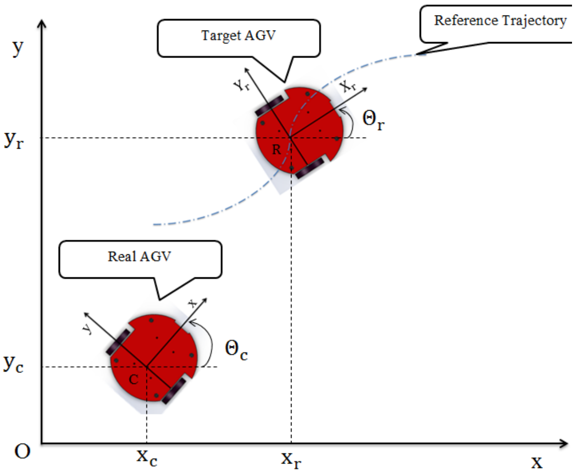

Fig.2 Trackingto target AGV.

The path error in Fig.2 are defined and can be calculate as follow:

$$\begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} = \begin{bmatrix} cos\Theta_c & sin\Theta_c & 0 \\ -sin\Theta_c & cos\Theta_c & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_r - x_c \\ y_r - y_c \\ \Theta_r - \Theta_c \end{bmatrix} \qquad (6)$$

Where e_1 is the tangential error, e_2 is the lateral error, e_3 is the orientation error.
The first derivative of error:

$$\begin{cases} \dot e_1 = \omega_c e_2 - v_c + v_r cose_3 \\ \dot e_2 = -\omega_c e_1 + v_r sine_3 \\ \dot e_3 = \omega_r - \omega_c \end{cases} \qquad (7)$$

III. CONTROLLER DESIGN AND MEASUREMENT SYSTEM.

3.1 Controllerdesign.

Our purpose is to design the controller so that real AGV follow trajectory G^{3}with desired constant velocity v_r. Controller is designed, to achieve $e_i = 0 (i = 1,2,3)$ when $t \to \infty$.
The chosen Lyapunov function and Eq.(7) are given as:

$$V = \frac{1}{2}(e_1^2 + e_2^2) + \frac{2}{k_2} sin^2\left(\frac{e_3}{2}\right) \qquad (8)$$

$$\dot V = e_1\dot e_1 + e_2\dot e_2 + \frac{\dot e_3}{k_2} sine_3$$

$$= e_1(-v_c + v_r cose_3) + \frac{sine_3}{k_2}(k_2 e_2 v_r - \omega_c + \omega_r) \qquad (9)$$

To $\dot V$ is always negative, v_c and ω_c are chosen as:

$$\begin{cases} v_c = v_r cose_3 + k_1 e_1 \\ \omega_c = \omega_r + k_2 e_2 v_r + k_3 sine_3 \end{cases} \qquad (10)$$

Where k_1, k_2, k_3 are positive values.The controller in Eq.(13) ensures $e_i = 0$ ($i = 1,2,3$) when $t \to \infty$.

3.2 Measurement system.

The motion of the AGV follow the desired trajectory is measured by encoder, linear and rotational velocity which are calculated as follow:

$$v_c\_real = \frac{r(\omega_{rw}\_real + \omega_{lw}\_real)}{2} \qquad (11)$$

$$\omega_c\_real = \frac{r(\omega_{rw}\_real - \omega_{lw}\_real)}{2b} \qquad (12)$$

Where ω_{rw}_real and ω_{lw}_real are rotational velocity of right wheel and left wheel, which are measured by encoder.

The positon of the AGV is estimated:

$$\begin{cases} x_c = x_c^p + v_c\_real.T_s cos\Theta_c^p \\ y_c = y_c^p + v_c\_real.T_s sin\Theta_c^p \\ \Theta_c = \Theta_c^p + T_s \omega_c\_real \end{cases} \qquad (13)$$

Where T_s is sampling time, x_c^p, y_c^p, Θ_c^p are the posture of the AGV at the time of the previous.

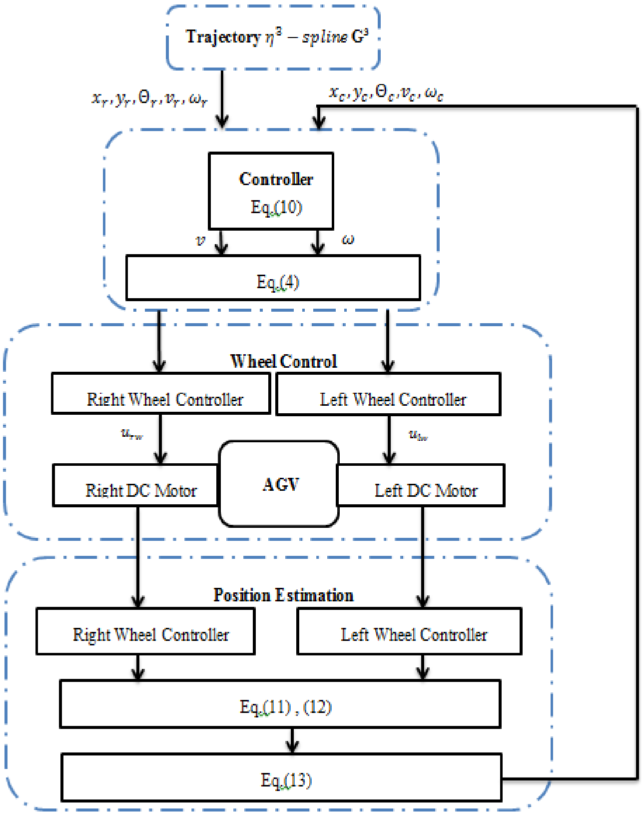

Fig.3Block diagram for tracking a reference path.

IV. SIMULATION AND EXPERIMENTAL RESULTS.

4.1 Hardware of the whole system.

Fig.4ExperimentalAGV.

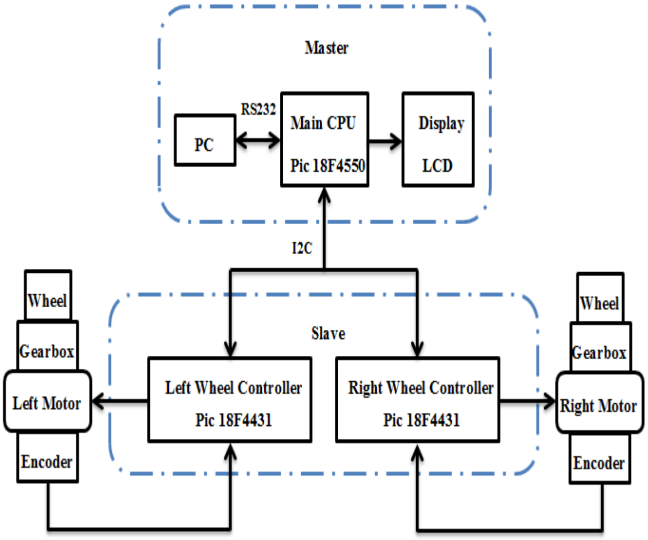

Fig.5Configuration of the control system.

The control system include : one microcontroller Pic 18F4550 is used for controller in Eq.(10), it also whose role is main CPU and two microcontroller Pic 18F4431 are used for the velocity controller of right and left wheel, which receive control signal, is calculated from Eq.(4).Main CPU communicates with two velocity controllers by the I2C standard.

4.2 Simulation and experimental results.
The results are simulated by Matlab software.The positive constants in the controller are chosen as:
$k_1 = 9 , k_2 = 4000 , k_3 = 1.$
Parameter values of the WMR:
b = 0.12 m, r = 0.051 m, T_s = 0.1 s, v_r = 0.05 m/s
v_{max} = 0.2 m/s, ω_{max} = 0.785 rad/s.
Initial values for the simulation and experiment:
x_c = 0, y_c = 0, Θ_c = 0
v_c = 0, ω_c = 0.
Trajectory G^3 from $A(0,0,0)$ to $B\left(1.4,1.4,{}^{\pi}/_{12}\right)$ is designed, as a result from [2].

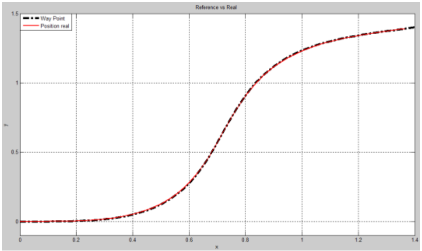

Fig.6Tracking to trajectory G^3.

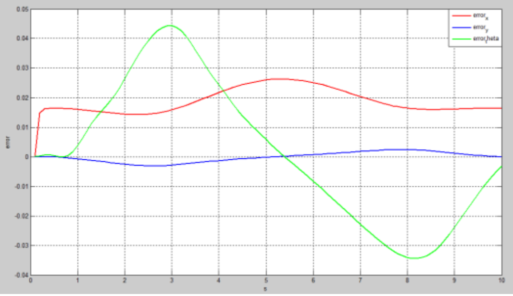

Fig.7Tracking errors.

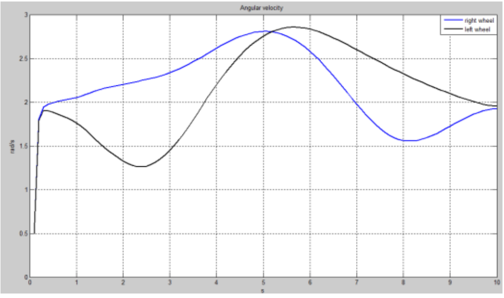

Fig.8 Control input : Angular velocity of the WMR wheels.

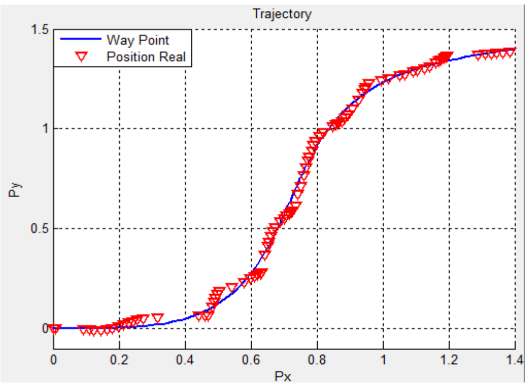

Fig.9 Estimated position is measured.

In experiment, WMR is only used encoder, to measure angular velocity and the position of WMR is estimated, so it can not accurately reflect the real position of the robot.In the future, development of an indoor GPS system for AGV using ultrasonic sensors [1] and signal of the ultrasonic sensor is filtered noises by Kalman filter, to determine the position of the AGV correctly.

V. CONCLUSIONS

A nonlinear controller base on Lyapunov method has been presented.Trajectory $\eta^3 - spline$ (G^3) with 7th order polinom is designed for WMR.The tangential, lateral,orientation error of the system asymptotically converges to zero. The stability of system is proved by the Lyapunovstability theory. The simulations and experimental results are shown to prove the effectiveness of the proposed controller.

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