CONTROL OF WELDING MOBILE ROBOT USING TOUCH SENSOR FOR TRACKING SMOOTH CURVED WELDING PATH

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ABSTRACT

In this paper, a line tracking controller based on Liapunov function is studied and applied to a two-wheeled welding mobile robot for making it possible to track a reference smooth curve. The robot is equipped with two controlled wheels and two casters for balancing. A touch sensor is installed on the robot to help the robot tracking the reference path. The mobile robot moves along a reference smooth curve and keep a constant velocity at welding point during welding process. The touch sensor is used to track the distance from welding point to the reference path, as well as the head angle of robot. Welding velocity is measured to ensure a constant velocity at welding point. The simulations have been done to verify the effectiveness of the designed controller. The welding experiments are being carried out.

1. INTRODUCTION

Automating the welding process in some industries such as shipbuilding, steel component processing, is very challenging and important, as those industries rely heavily on quality welds. Conventional robotic welding systems are seldom used because the welding tasks are characterised by non-standardised workpieces which are large but small in batch sizes. Furthermore, geometries and locations of the workpieces are uncertain.

Some studies are focused on welding mobile robot using touch sensor. T.T Nguyen et al. [3] proposed a controller based on Liapunov function applied for wall-following robot with touch sensor. T.H. Bui [10] presented a controller also based on Liapunov function, and the errors tracking is performed by touch sensor, however, the velocity is not measured. T.T. Phan designed a controller for mobile manipulators for tracking horizontal smooth curved welding path. Touch sensor proposed in all of those studies designed with two rotary encoders and one linear potentialmeter. With that design, there are some open points that will be considered in this paper:

- The curve between two rollers is assumed as a line
- Angular velocity of reference point, ω_r, is assumed zero all the time
- Three errors are defined independently, however, in the measurement scheme and equations, e_1 and e_3 are not independent.

In this paper, a simple controller of mobile robot is designed for application of smooth curved welding path. Three errors are defined and the controller is designed to drive all of these errors achieve zero as fast as possible. The controller proposed in this paper is based on Liapunov function. All above mentioned points will be considered and solved with a new design touch sensor – with one more rotary encoder. The velocity of welding point is measured by rotary encoder and sent back to the controller to control the velocities of robot. The touch sensor is fixed and positioned on the axis of two controlled wheels. A rotary encoder installed on a roller with radius r_s, designed to operate without slipping. Beside that, the touch sensor is also used to estimate the curvature of the curve, that is used to calculate the angular velocity of reference point. The welding torch slider is located on robot to coincide the axis of two controlled wheels. The length of welding torch slider is also controlled. To verify the stability of designed controller, simulations have been done, and the experiments are being carried out.

2. SYSTEM MODELING

In this section, a dynamic configuration of the mobile robot is derived with a geometrical motion as shown in Fig. 1, and the problem is stated under the following assumptions:

- (i) The velocity component at the point contacted with the ground in the plane of the wheel is zero.
- (ii) The reference welding path is a smooth curve with radius sufficiently larger than turning radius of robot.
- (iii) A touch sensor is installed on the robot and positioned on the axis of two controlled wheels.
- (iv) A rotary encoder to measure the velocity is fixed on a roller with radius r_s, positioned on the axis of two controlled wheels. The roller is designed to operate without slipping
- (v) A torch slider with controlled length mounted on the robot and positioned on the axis of two controlled wheels.

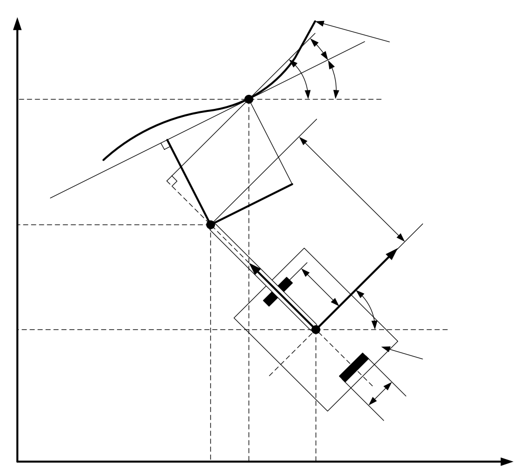

Fig. 1. Scheme for deriving the kinematic equations.

where,

(x, y) : coordinate of robot center,
r : driving wheel's radius,
b : distance from mobile robot's center to driving wheel,
R : a reference point on the line,
C : robot center,
$t\!-\!t$: tangential line of the curve at R,
ϕ_R : angle between $\vec{v}_r$ and x axis,
ϕ : heading angle of the robot,
l : controlled torch length of the torch slider,
r_s : radius of the rollers on touch sensor
W : welding point
a : distance between two roller's centers.

The kinematic equation under the nonholonomic constraints of pure rolling and non-slipping is given by

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\phi} \end{bmatrix} = \begin{bmatrix} \cos\phi & 0 \\ \sin\phi & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix} \tag{1}$$

The relationship between v, ω and the angular velocities of the two driving wheels, ω_{rw}, ω_{lw}, is given by

$$\begin{bmatrix} \omega_{rw} \\ \omega_{lw} \end{bmatrix} = \begin{bmatrix} 1/r & b/r \\ 1/r & -b/r \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix} \tag{2}$$

The coordinates and the heading angle of the welding point, $W(x_w, y_w)$, can be calculated by [10]

$$\begin{cases} x_W = x - l\sin\phi \\ y_W = y + l\cos\phi \\ \phi_W = \phi \end{cases} \tag{3}$$

Thus, the velocities are:

$$\begin{cases} \dot{x}_w = v\cos\phi - l\omega\cos\phi - \dot{l}\sin\phi \\ \dot{y}_w = v\sin\phi - l\omega\sin\phi + \dot{l}\cos\phi \\ \dot{\phi}_w = \omega_w \end{cases} \tag{4}$$

The errors between welding point, $W(x_w, y_w)$, and reference point, $R(x_r, y_r)$, are e_1, e_2, e_3

as defined in Fig. 1. The error e_1 is defined on the direction of tangential line at reference point.

$$\begin{cases} e_1 = (x_r - x_w)\cos\phi_r + (y_r - y_w)\sin\phi_r \\ e_2 = -(x_r - x_w)\sin\phi_r + (y_r - y_w)\cos\phi_r \\ e_3 = \phi_r - \phi_w \end{cases} \quad (5)$$

or in matrix form:

$$\begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} = \begin{bmatrix} \cos\phi_r & \sin\phi_r & 0 \\ -\sin\phi_r & \cos\phi_r & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_r - x_w \\ y_r - y_w \\ \phi_r - \phi_w \end{bmatrix} \quad (6)$$

The above problem becomes to design a controller which achieves $e_i \to 0$ $(i = 1 \div 3)$ as $t \to \infty$.

3. CONTROLLER DESIGN

3.1 Controller design

Defined errors:

$$\begin{cases} e_1 = (x_r - x_w)\cos\phi_r + (y_r - y_w)\sin\phi_r \\ e_2 = -(x_r - x_w)\sin\phi_r + (y_r - y_w)\cos\phi_r \\ e_3 = \phi_r - \phi_w \end{cases}$$

Their derivative yields:

$$\begin{bmatrix} \dot{e}_1 \\ \dot{e}_2 \\ \dot{e}_3 \end{bmatrix} = \begin{bmatrix} v_r - \dot{l}\sin e_3 + \omega_r e_2 \\ -\dot{l}\cos e_3 - \omega_r e_1 \\ \omega_r \end{bmatrix} + \begin{bmatrix} -\cos e_3 & l\cos e_3 \\ \sin e_3 & -l\sin e_3 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix} \quad (8)$$

The Lyapunov function candidate is chosen as follows:

$$V_0 = \frac{1}{2}e_1^2 + \frac{1}{2}e_2^2 + \frac{1}{2}e_3^2 \quad (9)$$

Its derivative yields:

$$\dot{V}_0 = (e_1\cos e_3 - e_2\sin e_3)(v_r\cos e_3 - v + l\omega) + (e_1\sin e_3 + e_2\cos e_3)(v_r\sin e_3 - \dot{l}) + e_3(\omega_r - \omega)$$

If we choose the velocities v, ω of robot and the torch length l:

$$\begin{cases} \omega = \omega_r + k_3 e_3 \\ v = v_r\cos e_3 + l(\omega_r + k_3 e_3) + k_1(e_1\cos e_3 - e_2\sin e_3) \\ \dot{l} = v_r\sin e_3 + k_2(e_1\sin e_3 + e_2\cos e_3) \end{cases} \quad (10)$$

k_i $(i = 1 \div 3)$ are positive values, $k_i > 0$.

then $\dot{V} \le 0$ and the mobile robot achieves the control problem.

3.2 . Measurement of the errors

To determine the velocities of robot, v, ω, as well as the change rate of the torch length, $\dot{l}$, the errors e_1, e_2, e_3 need to be measured, and ω_r need to be specified.

To specify the errors and calculate the angular velocity of reference point, ω_r, we need to determine the curvature of the curve at the reference point. To simplify, we assume the curve between two rollers is an arc with the radius ρ. We can calculate the radius as follows:

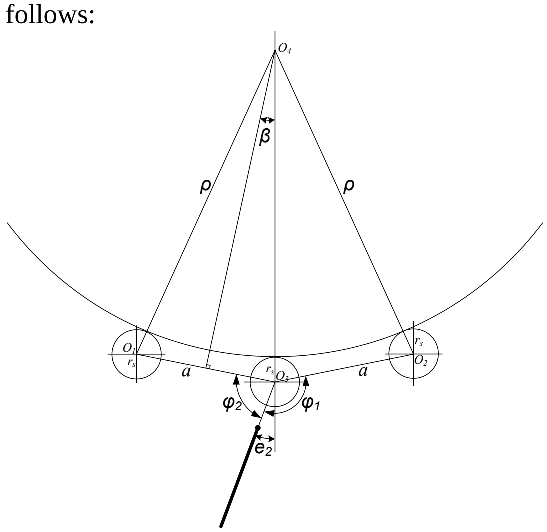

Fig. 2: Scheme for estimating the radius ρ.

$$\beta = \frac{\varphi_1 + \varphi_2}{2} - \frac{\pi}{2}$$

$$\rho = \frac{a}{2\sin\beta} - r_s$$

$$\omega_r = \frac{v_r}{\rho}$$

The errors e_2 is measured by linear potentialmeter, and the error e_1 is measured by rotary encoder.

The error e_3, deviation of angle, is measured by rotary encoders.

The error e_2, distance from welding point, $W(x_w, y_w)$, to the tangential line of the curve at reference point $R(x_r, y_r)$, is calculated as shown in Fig. 3.
The error e_1 is measured by rotary encoder (Fig. 4).

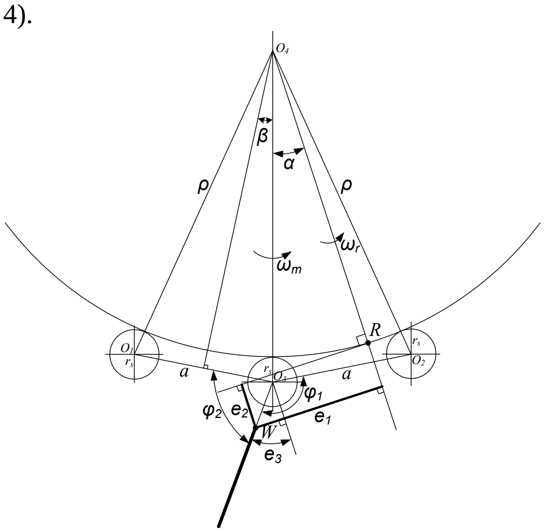

Fig. 3. Measurement scheme for e_2, e_3.

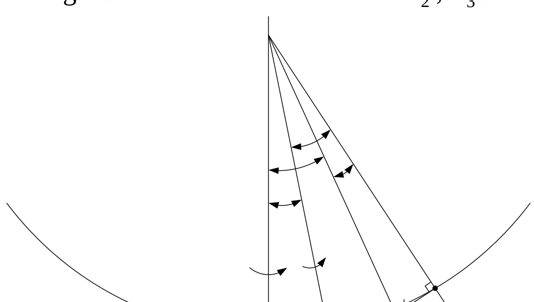

Fig. 4. Measurement scheme for e_1

$$\alpha_r = \omega_r dt = \frac{v_r}{\rho} dt$$

$$\alpha_m = \omega_m dt = \frac{v_m}{(\rho + r_s)} dt$$

$$\dot{\alpha} = \omega_r - \omega_m$$

$$\alpha_{(i)} = \alpha_r - \alpha_m + \alpha_{(i-1)}$$

$$\alpha_{(i)} = (\omega_r - \omega_m) dt + \alpha_{(i-1)}$$

$$\alpha_{(i)} - \alpha_{(i-1)} = (\frac{v_r}{\rho} - \frac{v_m}{\rho + r_s}) dt$$

$$e_3 = \frac{\varphi_1 - \varphi_2}{2} + \alpha_{(i)}$$

$$e_2 = (l_s - l)\cos e_3 + (\rho + r_s)\cos \alpha_{(i)} - \rho$$

$$e_{1(i-1)} = (l_s - l_{(i-1)})\sin e_{3(i-1)} + (\rho + r_s)\sin \alpha_{(i)}$$

$$e_{1(i)} = (l_s - l_{(i)})\sin e_{3(i)} + (\rho + r_s)\sin \alpha_{(i)}$$

$$e_{1(i)} = (l_s - l_{(i)})\sin e_{3(i)} + (\rho + r_s)\sin \alpha_{(i)}$$
$$- (l_s - l_{(i-1)})\sin e_{3(i-1)} - (\rho + r_s)\sin \alpha_{(i-1)} + e_{1(i-1)}$$

$\alpha_{(i)}$ and $\alpha_{(i-1)}$ are small values, then using:

$$\sin \alpha_{(i)} \approx \alpha_i$$

$$\sin \alpha_{(i-1)} \approx \alpha_{i-1}$$

$$\cos \alpha_{(i)} \approx 1$$

Thus

$$e_2 = (l_s - l)\cos e_3 + r_s$$

$$e_{1(i)} = (\rho + r_s)(\alpha_i - \alpha_{(i-1)}) + (l_s - l_{(i)})\sin e_{3(i)}$$
$$- (l_s - l_{(i-1)})\sin e_{3(i-1)} + e_{1(i-1)}$$

$$e_{1(i)} = (v_r - v_m + \frac{r_s v_r}{\rho}) dt + (l_s - l_{(i)})\sin e_{3(i)}$$
$$- (l_s - l_{(i-1)})\sin e_{3(i-1)} + e_{1(i-1)}$$

This formula is also applied for straight reference path ($\rho \to \infty$).

From require, v_r, and measured velocity of roller center O, v_m, the error e_1 is specified.

4. HARDWARE OF THE SYSTEM

For the control system, a PIC-based controller was developed. The hardware of the control system is composed of three sections: *the main control board*, *the motor control board*, and *the sensor processing board*. All in them, only has one master chip PIC18F452 to control the others, it is integrated in the main control board. The configuration diagram of the system is shown in Fig. 5.

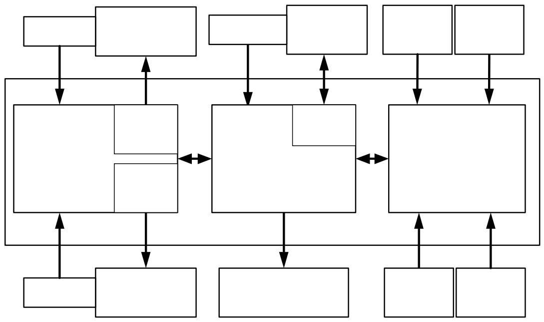

Fig. 5. The configuration of the control system

The *main control board* consists of one PIC18F452 and one PIC16F877, the PIC18F452 is the master chip which is used to gather errors, calculate required velocities, send control commands to the motor control board & torch controller by I2C standard and perform welding process. The PIC16F877 combines with a full-bridge driver LM18200 to control torch length, the position feedback gets from linear potentialmeter.

The *motor control board*, which controls the velocities of the two driving wheels by PID algorithm, uses two chips PIC16F877 with two full-bridge drivers LM18200 to drive left and right motors. The feedback velocities of two wheels are calculated from two encoders mounted directly in each motor shaft.

The *sensor processing board* consists of two chips PIC18F452, one is used to read pulses returned from two rotary encoders to calculate the error *e3* and radius of curve path *ρ*, the other reads pulses returned from the velocity measurement rotary encoder and gets e_2 from linear encoder. These errors are sent to master by parallel (PSP) interface.

5. SIMULATION RESULTS

To verify the effectiveness of the designed controller, simulations has been done (by MATLAB).

The positive constants of the controller are chosen as $k_1 = 4$, $k_2 = 4$ and $k_3 = 3$. Numerical and initial values of the robot as stated in table 1.

Table 1. Numerical and initial values

Par.	Value	Units	Par.	Value	Unit
x_r	0.300	m	y_r	0.4	m
x_w	0.290	m	y_w	0.390	m
v	0	mm/s	ω	0	rad/s
ϕ_r	0	deg.	ϕ	15	deg
l	0.15	m	ω_r	0	rad/s
b	0.1045	m	r	0.025	m

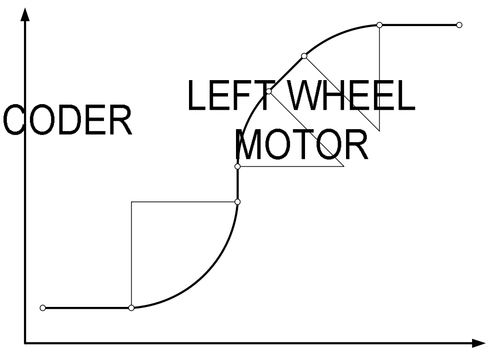

Fig. 6. Reference path used for simulation

The simulation results are shown in Fig. 7 to Fig. 13.

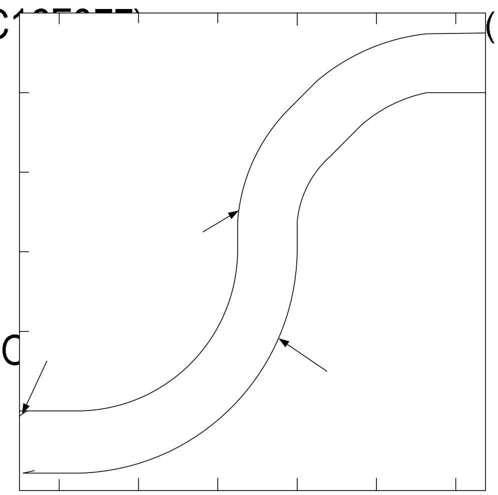

Fig. 7. Reference path and trajectory of welding points

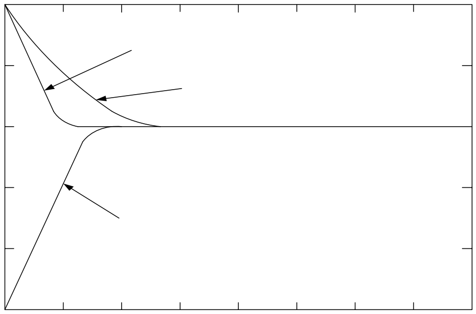

Fig. 8. The errors e_1, e_2, e_3 at beginning

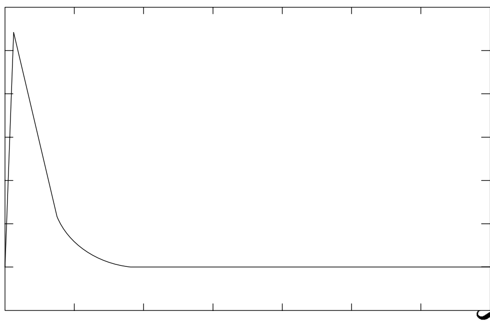

Fig. 9. Torch slider velocity at beginning

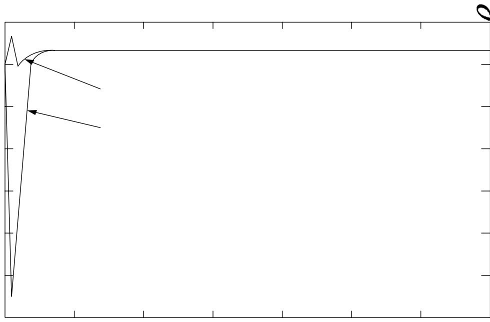

Fig. 10. Angular velocities of driving wheels at beginning

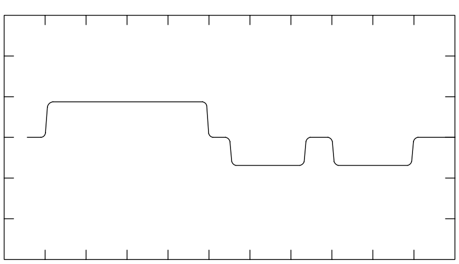

Fig. 11. The error e_2 when passes through the curved line

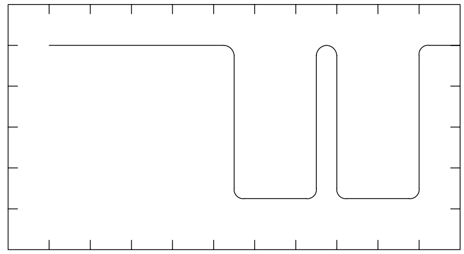

Fig. 12. The error e_3 when passes through the curved line

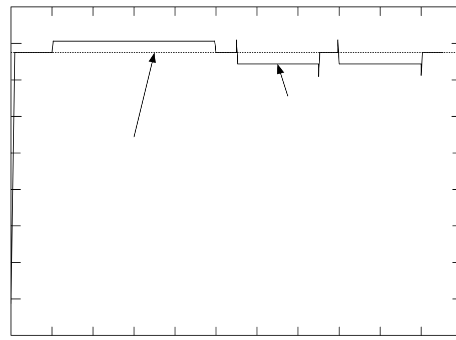

Fig. 13. Velocities of the welding point and robot center.

From the simulation, we can see:

- The errors e_1 achieve zero after 0.5s.
- The error e_2, e_3 achieve zero after 1s.

Therefore, it is hopefully that the designed controller can be used for a welding mobile robot with any smooth curved welding path.

6. CONCLUSION

This paper introduces a controller design method based on Liapunov function for welding mobile robot that is applied for smooth curved welding path, using touch sensor and rotary encoder to measure the velocity of welding points.

The touch sensor includes 3 rotary encoders and one linear encoder, two of rotary encoders are used to estimate the curvature of the curve, as well as to measure the error e_3. The error e_2, the distance from the welding point to the reference point is measured by linear encoder.

One rotary encoder is used to measure the velocity of welding point.

All of three errors are measured independently. With new design of touch sensor, we can measure not only the errors, but also the curvature of reference welding path, then we can calculate the angular velocity at reference point.

The mobile robot moves along a reference welding path with a constant speed while performing welding process. The errors are measured and sent back to the controller for further processing. The controller has been verified by mean of simulations. The welding experiments are being carried out and will be issued soon.

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