STUDY ON TRACKING CONTROL OF WELDING MOBILE ROBOT USING CAMERA - STRAIGHT WELDING PATH APPLICATION

Van Khanh Nguyen, Tan Tien Nguyen*, Trong Hieu Bui*, Van Hung Hoang*

Nam Trung Co., Ltd, 91 – 93 Tran Minh Quyen Str., Dist. 10
Hochiminh City, Vietnam
*Dept. of Mechanical Eng., Hochiminh City University of Technology
268 Ly Thuong Kiet Str., Dist. 10, Hochiminh City, Vietnam

ABSTRACT

This paper a controller based on Liapunov function is studied and applied to a two-wheeled welding mobile robot for tracking a reference straight line. The robot is equipped with two controlled wheels and two casters for balancing. A camera is fixed on the side of robot to help the robot tracking the reference line. A rotary encoder is used to measure welding velocity. The mobile robot moves along a reference straight line and keep a constant velocity at welding point during welding process. Reference line is a line offseted from welding path with offset distance p. The camera is used to track the distance from camera center point to reference line, 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

So far the automation of production in some industries have been focused on the welding activity and it has greatly contributed to the improvement of productivity or quality as well as improvement of working condition for workers. In the shipyards, some studies have stated that the percentage of welders is currently 23% of the total number workers.

Welding automation is being focused due to following advantages:

- Improvement of working condition.
- Increase of weld consistency.
- Increase of productivity
- Saving welding cost

Some studies have been carried out to propose controllers of nonholonomic systems based on tracking technique. T.L Chung et all [2] proposed a controller based on Liapunov function and a camera used for tracking, however, the proposed controller is based on wall-following problem. T.H. Bui et all [10] presented a controller also based on Liapunov function, and the errors tracking is performed by touch sensor. J. M. Yang and J. H. Kim [7] proposed a robust control law for trajectory tracking of nonholonomic wheeled mobile robots using sliding mode control

This paper is the first step of our study on designing a simple welding robot using to fabricate ship blocks in shipbuilding industry in Hochiminh City.

In this paper, a simple controller of mobile robot is designed for application of straight welding path. To design that controller, the errors are defined and the objective of the proposed controller is to drive the errors to zero as fast as possible. The controller proposed in this paper is based on Liapunov function. A camera is installed on the robot to detect the deviation between the camera center (position of robot) and the reference line. The velocity of welding point is measured by rotary encoder and sent back to the controller to control the velocities of robot. The camera is fixed on the side of robot and positioned on the axis of two controlled wheels, the distance between camera center point and robot center is l. The welding torch slider is located on robot to coincide the axis of two controlled wheels. A rotary encoder installed on a roller with radius r$_s$, designed to operate without slipping. To verify the stability of designed controller, simulations have been done.

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 contacting with the ground in the plane of the wheel is zero and the robot turns around one point.

(ii) A camera sensor is attached on one side of the robot and lined on the axis of two controlled wheels.

(iii) A welding torch with fixed length is mounted on the robot and lined on the axis of two controlled wheels.

(iv) The reference straight line is the line offseted from the welding path with a offset distance p .

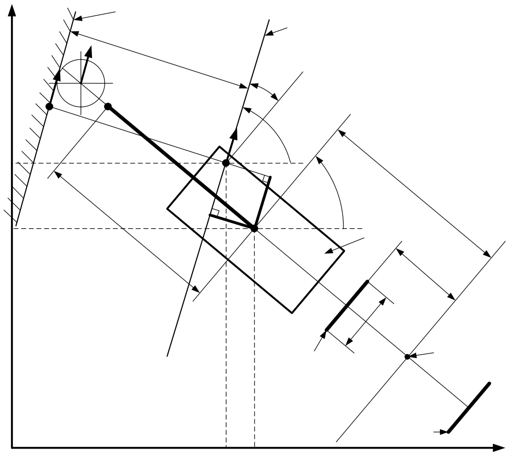

Fig. 1. Scheme for deriving the kinematic equations.

where,

(x_c, y_c) : coordinates of camera center point,
r : wheel's radius
b : distance from mobile robot's center to controlled wheel,
R : a reference point on the line,
C : camera center point,
$t\text{–}t$: reference line,
ϕ_R : reference line orientation at point R ,
ϕ : head angle of mobile robot,
p : distance between the reference line and the welding path
l : distance between camera center point and robot center.
$2a$: the width of camera frame

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

$$\begin{bmatrix} \dot{x}_c \\ \dot{y}_c \\ \dot{\phi}_c \end{bmatrix} = \begin{bmatrix} \cos\phi_c & 0 \\ \sin\phi_c & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v_c \\ \omega_c \end{bmatrix} \qquad (1)$$

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

$$\begin{bmatrix} \omega_{rw} \\ \omega_{lw} \end{bmatrix} = \begin{bmatrix} 1/r & (l+b)/r \\ 1/r & (l-b)/r \end{bmatrix} \begin{bmatrix} v_c \\ \omega_c \end{bmatrix} \qquad (2)$$

The point $R(x_r, y_r)$ satisfies the dynamic equation:

$$\begin{cases} \dot{x}_r = v_r \cos\phi_r \\ \dot{y}_r = v_r \sin\phi_r \\ \dot{\phi}_r = \omega_r \end{cases} \qquad (3)$$

where v_r is the constant velocity of point R , and $\omega_r = 0$.

The equation of the reference line is given as the following:

$$(x - x_r)\sin\phi_r - (y - y_r)\cos\phi_r = 0$$

The errors between camera center point $C(x_c, y_c)$ and reference point $R(x_r, y_r)$ are e_1, e_2, e_3, defined as shown in Fig. 1 as follows:

$$\begin{cases} e_1 = (x_r - x_c)\cos\phi_r + (y_r - y_c)\sin\phi_r \\ e_2 = -(x_r - x_c)\sin\phi_r + (y_r - y_c)\cos\phi_r \\ e_3 = \phi_r - \phi_c \end{cases} \qquad (4)$$

or in the matrix form

$$\begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} = \begin{bmatrix} \cos\phi_r & \sin\phi_r & 0 \\ -\sin\phi_r & \cos\phi_r & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_r - x_c \\ y_r - y_c \\ \phi_r - \phi_c \end{bmatrix} \qquad (5)$$

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

3. CONTROLLER DESIGN

Defined errors:

$$\begin{cases} e_1 = (x_r - x_c)\cos\phi_r + (y_r - y_c)\sin\phi_r \\ e_2 = -(x_r - x_c)\sin\phi_r + (y_r - y_c)\cos\phi_r \\ e_3 = \phi_r - \phi_c \end{cases}$$

Their derivative yields:

$$\begin{bmatrix} \dot{e}_1 \\ \dot{e}_2 \\ \dot{e}_3 \end{bmatrix} = \begin{bmatrix} \omega_r e_2 + v_r \\ -\omega_r e_1 \\ \omega_r \end{bmatrix} + \begin{bmatrix} -\cos e_3 & 0 \\ \sin e_3 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} v_c \\ \omega_c \end{bmatrix}$$

With $\omega_r = 0$, then

$$\begin{bmatrix} \dot{e}_1 \\ \dot{e}_2 \\ \dot{e}_3 \end{bmatrix} = \begin{bmatrix} v_r \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} -\cos e_3 & 0 \\ \sin e_3 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} v_c \\ \omega_c \end{bmatrix} \qquad (6)$$

The Lyapunov function candidate is chosen as follows

$$V_0 = \frac{1}{2}e_1^2 + \frac{1}{2}e_2^2 + \frac{1-\cos e_3}{k_2} \qquad (7)$$

Its derivative yields:

$$\dot{V}_0 = e_1(v_r - v_c\cos e_3) + \frac{\sin e_3}{k_2}(-\omega_c + k_2 e_2 v_c)$$

If we choose v_c, ω_c of camera center point

$$\begin{cases} v_c = \dfrac{v_r + k_1 e_1}{\cos e_3} \\ \omega_c = k_2 e_2 v_c + k_3 \sin e_3 \end{cases} \qquad (8)$$

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.

4. MEASUREMENT OF THE ERRORS

To determine the velocities of camera center point, v_c, ω_c, the errors e_1, e_2, e_3 need to be measured.

In this study, the errors e_2, e_3 are determined by a CMU camera, and the error e_1 is measured by rotary encoder, which is used to specify the velocity of welding point.

In this paper, camera is operated at Line Mode (LM), some information of the images can be extracted such as: coordinates of camera frame, binary bitmap of the images. Those information are used to determine the errors e_2, e_3.

The errors e_2, e_3 are measured as shown in the Fig. 2

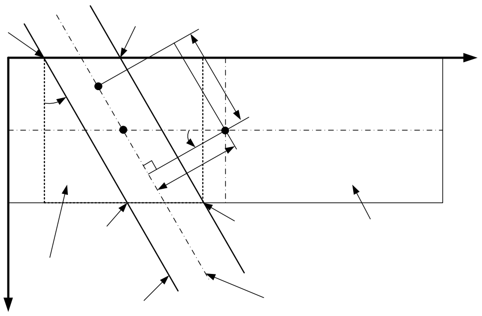

Fig. 2. Measurement scheme of e_2, e_3.

$$e_3 = arctg\left(\frac{x_{2a} - x_{1a}}{2a}\right) \qquad (9)$$

$$e_2 = (71 - \frac{x_{1a} + x_{2b}}{2})\cos e_3 \qquad (10)$$

The orientation of the reference line is also determined from binary bitmap of the images by comparing the coordinates (x_{1a}, y_{1a}), (x_{1b}, y_{1b}), (x_{2a}, y_{2a}) and (x_{2b}, y_{2b}). The error e_1 is measured by rotary encoder (Fig. 1).

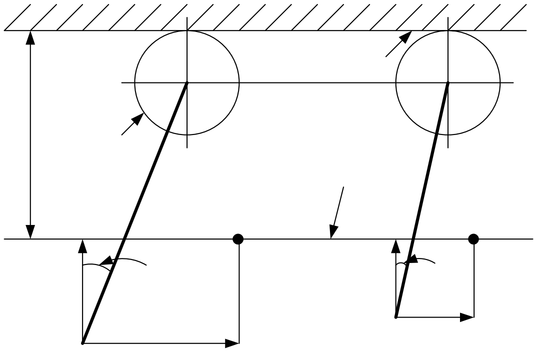

Fig. 3. Measurement scheme of e_1

Within a sampling time dt, the movements of the reference point R, camera center point C, and center of roller O, are given by following equations

$$R_{(i-1)}R_{(i)} = v_r dt$$

$$O_{(i-1)}O_{(i)} = v_m dt \ \ (v_m \text{ : measured velocity})$$

The error e_1 can be calculated as follows:

$$e_{1(i)} = (v_r - v_m)dt - (e_{2(i-1)} + p - r_s)tge_{3(i-1)} + (e_{2(i)} + p - r_s)tge_{3(i)} + e_{1(i-1)}$$

where $e_{1(0)} = 0$ is the initial value.

5. HARDWARE OF THE SYSTEM

For the control system, a PIC-based controller was developed. The control hardware of system is composed of three parts: a camera module, a rotary encoder sensor and the control circuits. All in them, only has one master chip PIC18F452 to control the others, it's integrated in the main control board.

The *camera module CMUCAM-1* (Photo.1) used in this application has been developed by Carnegie Mellon University, Pittsburgh, PA, USA.

The camera is used in Line Mode (LM) with Track Color command (TC command is called), in this mode , we'll receive a binary bitmap of the image, the value 0xAA begins at each data stream and the end is two bytes 0xAA 0xAA. After the binary bitmap, it is a C packet containing of two coordinates of line in tracked region.

Photo.1. CMU CAM 1 overview

The *rotary encoder* used in this application is 3600 Pulse revolution.

The *control circuits* are very simple due to its functionality offered by Microchip PIC18F458 and PIC16F877. The configuration of the system is shown in Fig.4.

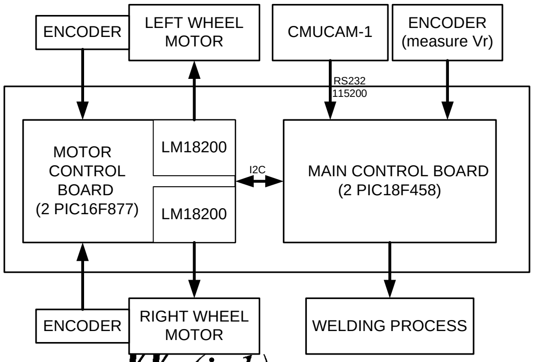

Fig. 4. The configuration of the control system

Photo 2. Control board of experimental robot

In this diagram, the *main control board* uses two chips PIC18F458, one gets information from camera sensor by RS232 – 115,200 baudrate, calculates and sends errors to the master by parallel port PSP, the other is the master chip which gathers errors, calculates velocities, sends the information (Velocity, Direction, Run/Stop command) to the motor control board by I2C and performs welding process.

The *motor control board*, which controls the velocity of the two 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.

6. SIMULATION AND RESULTS

To verify the effectiveness of the designed controller, simulations has been done (using MATLAB program). The parameters are chosen as follows: $b = 104.5\,mm$, $r = 25\,mm$, $v = 75\,mm/s$ and $p = 140\,mm$. The camera setting parameters are as follows:

LM 1: Line Mode – binary bitmap of the images is returned. Detailed data of the images is used for further processing.

PM 0: data stream is continuous. This feature will decrease sampling time of camera.

SM 0: enable of color tracking which return its normal *C* or *M* color packet.

SW 1 1 80 143: set the window size of camera

The tracking color command is sent to the camera sensor at the sampling time of 116*ms*

The simulation results are shown in Fig. 5 and Fig. 6. The positive constants are chosen as $k_1 = 3.4$, $k_2 = 26{,}000$, $k_3 = 3$.

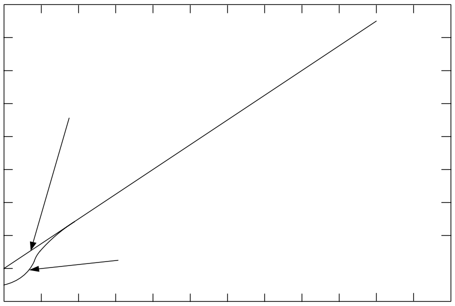

Fig. 5. Reference line and trajectory of camera center point.

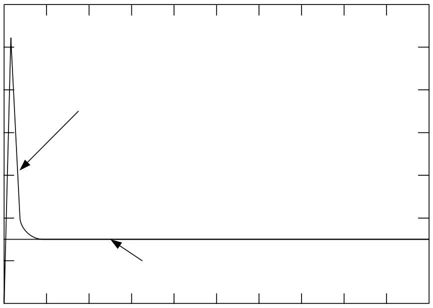

Fig. 6. Velocity of camera center point

To study influence of noises, simulations have also been done with assumed random noises of max. ±10% of errors, those simulation results are shown in Fig. 7 and Fig. 8.

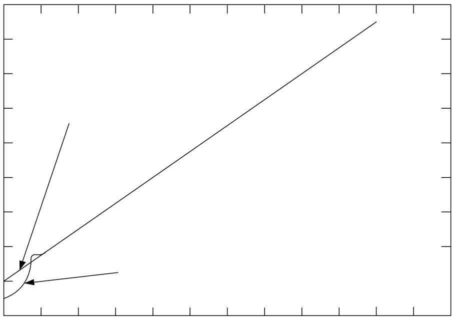

Fig. 7. Reference line and trajectory of camera center point with assumed noises.

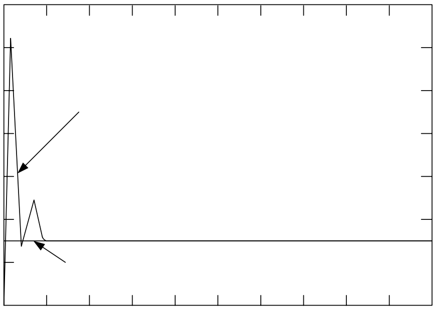

Fig. 8. Velocity of camera center point with assumed noises

Some experiment results are shown in Fig. 9 and Fig. 10.

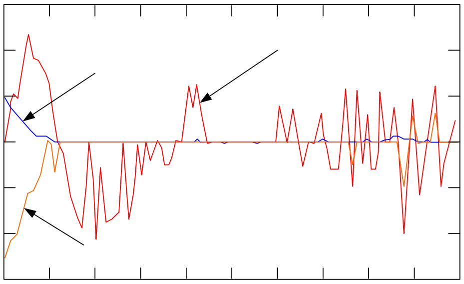

Fig. 9. Tracking errors.

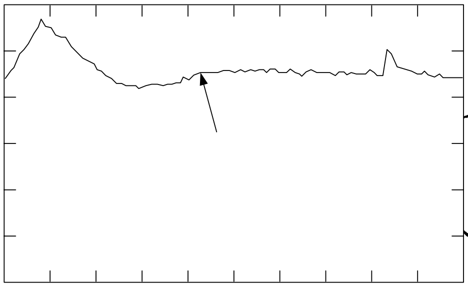

Fig. 10. Velocity of welding point

From the simulation results, we can see the welding mobile robot can track well the reference line very fast. In the experiment result, we can see that errors e_2 and e_3 achieve zero very fast. The error e_1 fluctuates with big value. Within a sampling time approx. 100ms, the number of pulses generated from rotary encoder is approx. 20. With a such small number of pulses, the sensor is highly effected by noises. We are now trying to reduce that effect by using new design of touch sensor.

The simulation has been done with assuming that the initial point was set up with $e_i \neq 0$. In real application, the welding mobile robot is operated with initial zero errors, therefore, the designed controller can be applied for tracking straight reference line of a welding mobile robot with more effective.

7. CONCLUSION

This paper introduces a controller design method based on Liapunov function for welding mobile robot that is applied for straight welding application. The robot is equipped with a camera to measure the distance between camera center and the reference line, as well as the orientation of robot. A rotary encoder is used to measure the velocity of welding points. The mobile robot moves along a reference straight line with a constant speed while performing welding process. The errors are measured to derive the controller. The controller has been verified by mean of simulations. At this moment, the welding experiments are being carried out and not yet finished, however, we hope that all of the welding experiment results will be issued in the near future to verify the proposed controller.

REFERENCES

1. T.L. Chung, T.H. Bui, T.T. Nguyen, and S.B. Kim, Proceedings of the 8th Conference on Science and Technology, Hochiminh City, Vietnam, (2002), pp. 51-55.
2. T.T. Nguyen, T.H. Bui, T.L. Chung and S.B. Kim, Tracking control of a spot bead welding mobile robot using camera sensor,.
3. T.T. Nguyen, T.L. Chung, T.H. Bui and S.B. Kim, Wall-Following Control for Two-Wheeled Mobile Robot.
4. Yataka Kanayama, Yoshihiko Kimura, Fumio Miyazaki, Tetsuo Noguchi, A Stable Tracking Control Method for A Non-Holonomic Mobile Robot.
5. Yataka Kanayama, Yoshihiko Kimura, Fumio Miyazaki, Tetsuo Noguchi, A Stable Tracking Control Method for an Autonomous Mobile Robot.
6. Jung-Min Yang and Jong-Hwan Kim, Sliding Mode Control for Trajectory Tracking of Nonholonomic Wheeled Mobile Robots.
7. Jung-Min Yang, In-Hwan Choi and Jong-Hwan Kim, Sliding Mode Control of a Nonholonomic Wheeled Mobile Robot for Trajectory Tracking.
8. Hachemi Mechlih, Sliding Mode Path Control for an Autonomous Vehicle.
9. Alberto Bemporad, Mauro Di Marco and Alberto Tesi, Wall-Following Controllers for Sonar-Based Mobile Robots.
10. T.H. Bui, Control of Two-Wheeled Welding Mobile Robots for Tracking Smooth Curved Welding Path, Thesis for the Degree of Doctor of Philosophy
11. Charles Rosenberg and Illah Nourbakhsh, CMUcam Manual