MIMO Fuzzy Logic Controller of Path Following Mobile Robot

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Abstract

This paper presents a differential drive mobile robot which can automatically follow the paths was designed by using MIMO (multi-input multi-output) fuzzy logic controller. The aim of this research is to follow the unusual paths for a differential drive mobile robot. The objectives of the process are to calculate the robot position and orientation angle based on the kinematic theory and to design the two inputs and two outputs of fuzzy logic controller. These paths were created by using MATLAB Simulink. The desired posture (posture means the position and orientation of the robot) is given by the user, and then, the difference between the desired posture and the current posture of the robot is calculated. These values are used as the inputs of the fuzzy controller to control the left and right velocities of the mobile robot. The outputs of fuzzy controller are sent to PIC16F887 microcontroller by using USB to TTL converter and the received data are sent to the motor driver which drives the left and right DC motor of the differential drive mobile robot. The results of both simulation and experiments confirmed that our path following system is effective for defined paths.

Keywords- Differential Drive, MIMO Fuzzy Logic Controller, PIC16F887 Microcontroller, DC Motor

1. Introduction

Autonomous mobile robots can be used to explore environments that are difficult for humans to explore. Fundamental problems of motion control of autonomous mobile robots can be roughly classified into three groups (Morin and Samson, 2008) [1], namely point stabilization, trajectory tracking, and path following. The path following problem has been well studied and many solutions have been proposed and applied in a wide range of applications. Samson (Samson, 1995) [2] described a path following problem for a car pulling several trailers. Altafini (Altafini, 2002) addressed a path following controller for an n trailer vehicle [3]. Path following controllers for aircraft and marine vehicles were reported in (Al-Hiddabi and McClamroch, 2002) [4] and (Encarnac ̧ ao and Pascoal, 2000) [5], respectively.

The basic control tasks for a differential drive mobile robot (DDMR) in an obstacle free environment are point-to-point motion, trajectory tracking and path following [6]. For path following task, kinematic model is needed to give the required velocity depending on the desired set point's position and orientation. Mobile robot kinematics is the dynamic model of how a mobile robot behaves without considers affect the motion. The robot must reach and follow a geometric path in the Cartesian space starting from a given initial configuration. For this task, time dependence is not relevant because one is concerned only with the geometric displacement between the robot and the path.

The position error is needed to reduce by two ways. The first way is to control the desired velocity and the second one is to check whether the robot reaches its desired set points or not. In the present work, position control of DDMR for path following task is designed and analyze in order to achieve its desired positions with required time in an obstacle free environment. The important thing of this system is to stabilize the wheels' velocities while the robot moves. So, fuzzy logic controller is used to control these wheels' velocities by adjusting the motors' angular velocities.

Fuzzy controller is used for many advantages and this system is easy to design and very robust. Fuzzy controller can control its wheels' velocities by adjusting the motors' angular velocities. The speed of DC motor can be adjusted to a great extent so fuzzy controller is used to provide easy control and high performance. Therefore, this research focuses on the path following control for DDMR with fuzzy logic controller in MATLAB simulation and real world. The PIC16F887 microcontroller is used as the input/ output interface between the PC and the DDMR. It gets the data from the PC and sends the control signals to the motor driver which drives the DDMR.

This paper is organized as follows. The next section describes the methodology of the system. In Section 3, MIMO fuzzy logic controller is explained. The simulation and experimental results for path following mobile robot are discussed in Section 4. Discussion and conclusion are given in the last section.

2. Methodology of the System

2.1 Calculation of Error Position and Orientation

There are three basic control tasks for a differential drive mobile robot (DDMR) such as point-to-point motion, trajectory tracking and path following. Among them, path following is chosen as the motion task for DDMR. For path following task, kinematic model is needed to give the required velocity depending on the desired set point's position and orientation.

MIMO (multi-input, multi-output) fuzzy controller is designed for trajectory tracking of mobile robot. The values of error position, E_p and error orientation, E_o are used as the input of the MIMO fuzzy logic controller. This controller is able to deliver the appropriate action for mobile robot, velocity of left and right wheel (V_l, V_r) as two outputs. MIMO fuzzy logic controller system has two inputs (position error, E_p and orientation error, E_o) and two outputs (left velocity, V_l and right velocity, V_r) for tracking tasks. The fuzzy controller is designed on MATLAB Simulink environment and Fuzzy Toolbox. The controlled object is the DDMR.

The differential drive of kinematic mobile robot is shown in Figure 1. In this system, $\dot{x}$, $\dot{y}$ and $\dot{\theta}$ are calculated by using linear and angular velocities.
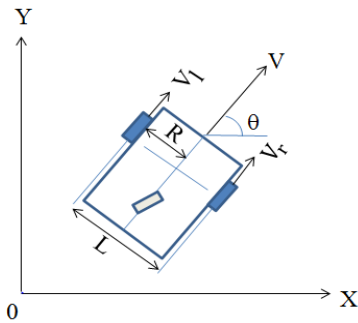

Figure 1. Scheme of Differential Drive Kinematics Mobile Robot

The kinematics models of the mobile robot equation are based on the unicycle equation.

$$\dot{x} = V \cos \theta \qquad (1)$$
$$\dot{y} = V \sin \theta \qquad (2)$$
$$\dot{\theta} = \omega \qquad (3)$$

Where, V is the linear velocity (m/sec) and ω is angular velocity (rad/sec). Error position and orientation can be estimated as follow:

$$E = \sqrt{(x_g - x)^2 + (y_g - y)^2} \qquad (4)$$

$$\theta_g = \theta_{goal} = \tan^{-1}(\frac{y_g - y}{x_g - x}) \qquad (5)$$

Error orientation, $E_\theta = \theta_g - \theta$

Corrected error, $E = \tan^{-1} (\sin (E_\theta), \cos (E_\theta))$

2.2 Hardware Implementation

The components of mobile robot are two DC gear motor with encoder, one caster wheel, VNH2SP30 Motor Driver, 12V battery and PIC16F887 microcontroller. VNH2SP30 Motor Driver is a high voltage, high current dual full-bridge driver designed to accept standard TTL logic levels and drive inductive loads such as relays, solenoids, DC and stepping motors. In DC operation, its current flows until 3.5 amps of a repetitive peak current. There are four types of DC motors are brushed DC, brushless DC, stepper and servo motor. In this system, two DC 12V dual axis gear motors (JGA25-371-34) are used for the locomotion of robot. DC gear motor reduction ratio is 1:45 gearbox and revolution of 12 pulses per revolution of the motor shaft.

In this research, RB0 and RB1 pins of PIC16F887 were used for right motors to rotate forward and track the trajectory. RB2 and RB3 pins were used for left motors. For pulse width modulation (PWM), RC1 and RC2 pins were used to control the motors. The specifications of the differential drive mobile robot are described in Table 1.

Table 1. Specifications of Differential Drive Mobile Robot

Parameters	Symbol	Value
Radius of the wheel	R	0.0325 m
Wheel span	L	0.25 m
Maximum speed	V_{max}	0.42 m/s
Minimum speed	V_{min}	0 m/s

The desired trajectories are assigned as the input of mobile robot. Error position and orientation are calculated and these values are sent as the input of the fuzzy logic controller. The position error and angle orientation error in the command speed of the mobile robot, output from the microcontroller, is changed into analog signal fed to the motor driving of the corresponding wheel to fix the position error. And then, fuzzy controller calculated the values of linear velocity and angular velocity. These values are used as the input of the unicycle. Unicycle calculated x, y, θ and left and right duty cycle rpm values. After calculating these values, the data are sent to mobile robot and target points are tracked. "To instrument" block is used for transferring the left and right duty cycles to the mobile robot. The communication of PIC and MATLAB is serial interface and its buffer size is 512 and baud rate is 115200. The block sample rate is 0.001sec. The travelling record of the mobile robot data is expressed on "Query instrument" block. Its buffer size and baud rate is similar with "To instrument" block. Implementation of differential drive mobile robot is shown in Figure 2.
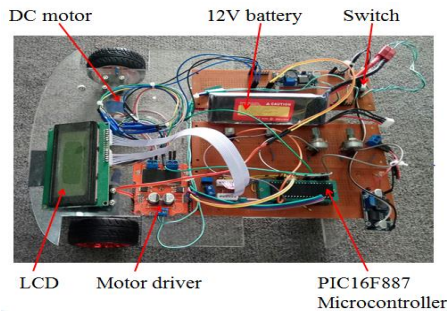
Figure 2. Implementation of Mobile Robot

3. MIMO Fuzzy Logic Controller

The rule-based fuzzy logic provides a scientific formalism for reasoning and decision making with uncertain and imprecise information. It can be implemented in hardware, software, or a combination of both. Fuzzy logic approach to control problems mimics how a person would make decisions.
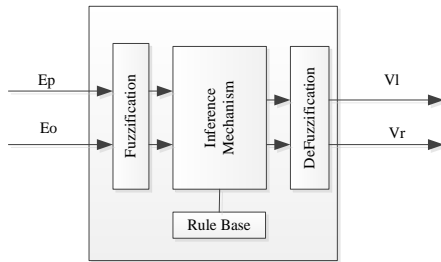

Figure 3. Block Diagram of the MIMO Fuzzy Logic Controller

MATLAB Fuzzy Logic Toolbox is used to design of fuzzy logic controller (FLC). The toolbox contains functions, graphical user interfaces and data structures that allow the user to quickly design, test, simulate and modify a fuzzy inference system. Figure 3 shows the block diagram of the MIMO fuzzy controller.

The MIMO (multi-input multi-output) closed-loop control algorithm is demonstrated in this section for path following. The calculation module calculates the error in position and orientation Δx, Δy, $\Delta \theta$ between the actual robot coordinates (x, y,) and the coordinates of the trajectory (x_d, y_d, θ_d) at each sample time. After that, the position and angle is generated to be the inputs of fuzzy controller. To control the system, the two state variables are set to be $0 \leq v$ (position) ≤ 1 (m/s); $- pi \leq \theta$ (angle) $\leq pi$ (rad).

3.1. Fuzzification

The fuzzification block matches the input data with the conditions of the rules to determine. In this research, multi-input multi-output (MIMO) fuzzy logic controller is proposed. Five membership functions are considered with all are of triangular member. The languages are Zero (Z), Positive Small (PS), Positive Medium (PM),

Positive Big (PB), Very Positive Big (VPB) for position and velocity. For orientation and heading angle, Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Big (PB) are assigned.

The membership functions of two inputs and two outputs are shown in Figure 4, where $0 \leq E_p$ (error position) ≤ 0.1 (m); $- 1 \leq E_o$ (error orientation) ≤ 1 (rad); $0 \leq V_l$ (position) ≤ 0.45 (m/s); $0 \leq V_r$ (position) ≤ 0.45 (m/s). The widths of membership functions are chosen experimentally. If the ranges of error position are greater than 0.1 m, mobile robot can't reach to the desired target.
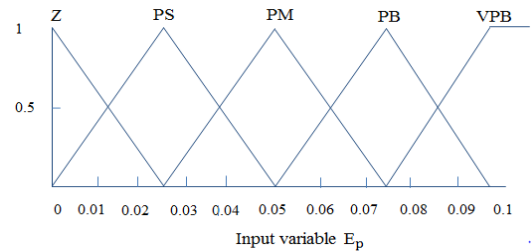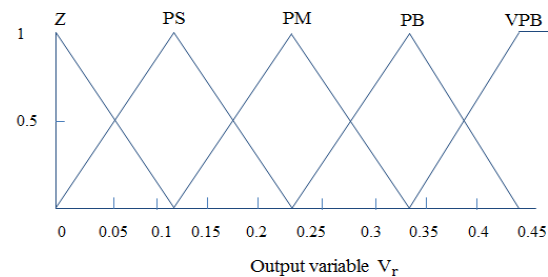

(a) Membership Function of Input Variable E_p
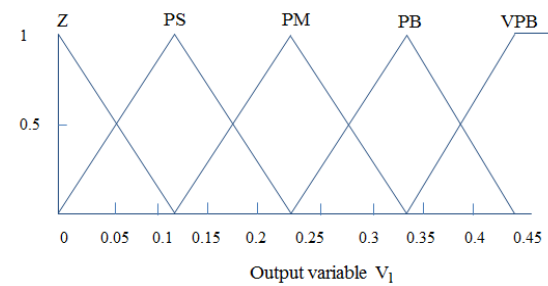
(b) Membership Function of Output Variable V_l
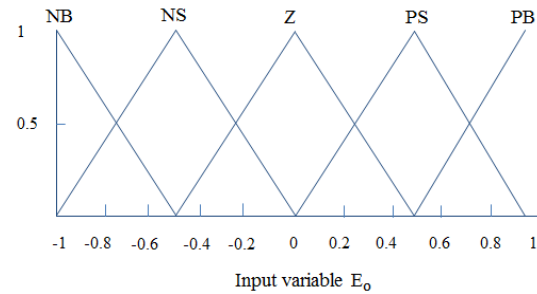
(c) Membership Function of Input Variable E_o

(d) Membership Function of Output Variable V_r

Figure 4. Membership Functions of MIMO Fuzzy Controller

3.2. Rule Base

The expert system is developed based on the IF-THEN rules as 25 rules to control the robot tracking for defined trajectories. If E_p is Z and E_o is NB, Then V_l is Z and V_r is Z. This rules quantifies the position and orientation where the predicted the position and angle of the mobile robot is much larger than the reference position and angle. Therefore, V_l and V_r are decreased to reduce the position and orientation of robot.

The control rules of FLC are shown in Table 2 below.

Table 2. Control Rules of MIMO Fuzzy Logic Controller

			E_o				
			NB	NS	Z	PS	PB
E_p	Z	V_l	Z	Z	Z	Z	Z
		V_r	Z	Z	Z	Z	Z
	PS	V_l	PB	PS	PS	Z	Z
		V_r	Z	Z	PS	PS	PB
	PM	V_l	PB	PM	PM	Z	Z
		V_r	Z	Z	PM	PM	PB
	PB	V_l	PB	PM	PB	Z	Z
		V_r	Z	Z	PB	PM	PB
	VPB	V_l	VPB	PM	VPB	Z	Z
		V_r	Z	Z	VPB	PM	PB

When E_p and E_o are not Z, the fuzzy rules are designed as below:
- If E_p is PS and E_o is NB, Then V_l is PB and V_r is Z.
- If E_p is PM and E_o is NB, Then V_l is PB and V_r is Z.
- If E_p is PB and E_o is NS, Then V_l is PM and V_r is Z.
- If E_p is VPB and E_o is PS, Then V_l is Z and V_r is PM.

3.3. Defuzzification

To achieve the result, develop the control curve of the system representing the I/O relation of the system and based on the information; define the output degree of the membership function with the aim to minimize the effect of non-linearity. There are many different methods of defuzzification.

Among of these methods, centroid of area (COA) method is used to defuzzify. The defuzzified value denoted as V_l and V_r using centroid of area method are defined as:

$$V_l = \frac{\int_0^{0.45} V_l \, \mu(V_l) \, dV_l}{\int_0^{0.45} \mu(V_l) \, dV_l} \qquad (6)$$

$$V_r = \frac{\int_0^{0.45} V_r \, \mu(V_r) \, dV_r}{\int_0^{0.45} \mu(V_r) \, dV_r}$$

Where, $\mu(V_l)$ and $\mu(V_r)$ are the membership function values of the left and right velocities.

4. Simulation and Experimental Results

4.1. Simulation Results

The mobile robot path following simulation and experimental results are described by using MIMO fuzzy logic control system. Desired and actual paths of path following mobile robot is shown in Figure 5.
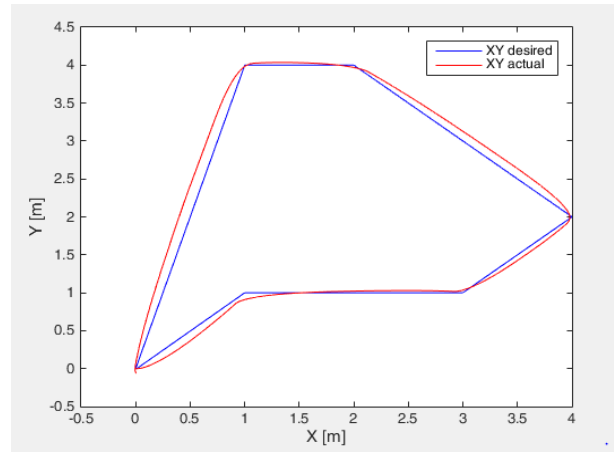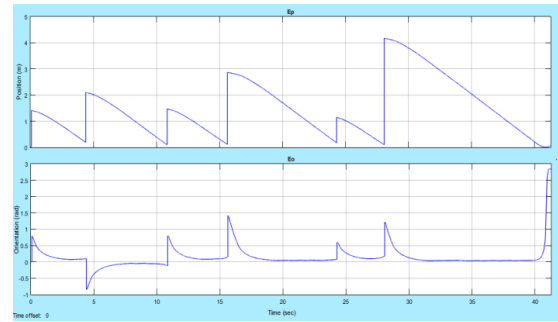

Figure 5. Desired and Actual Path of Mobile Robot

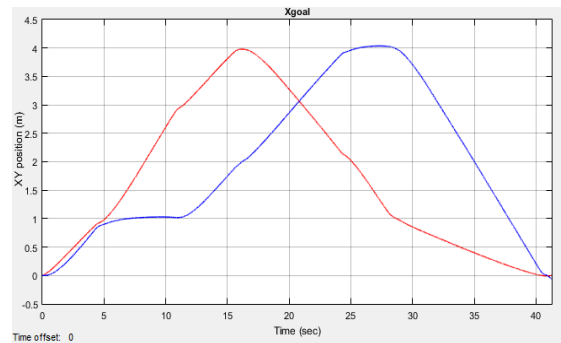**Figure 6. Error Position and Orientation of Path Following Mobile Robot**

Figure 7. XY Graph of Path Following Mobile Robot

The mobile robot tracked the outer route after turning around of every corner.

Figure 6 shows the error position and orientation of path following mobile robot. The mobile robot can follow 5 points tracking within 41 sec.

The position graph of path following mobile robot is shown in Figure 7. Red line indicate the X position and blue line express Y position.
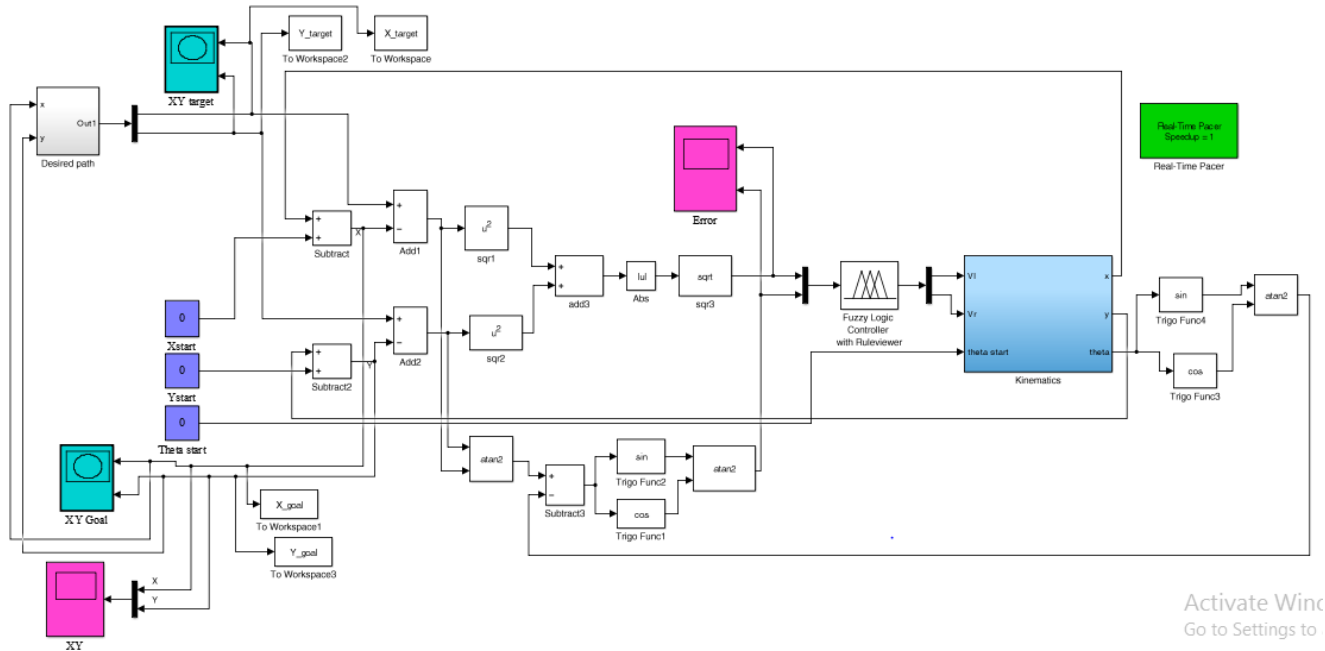

Figure 8. Simulink Block Diagram of Path Following Mobile Robot

4.2. Experimental Results

The experimental results of path following mobile robot with time is shown in Figure 9. The errors of position and orientation values for path following system are smooth and the tracking times are as less as possible with the minimum of error. That's showed that the range of membership function of E_p and E_o choosing from many experiments.

(a) Start

(b) 5 sec

(c) 10 sec

(d) 15sec
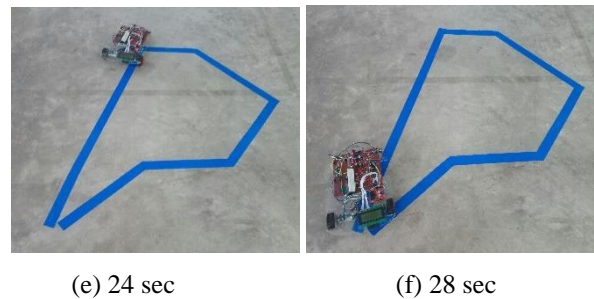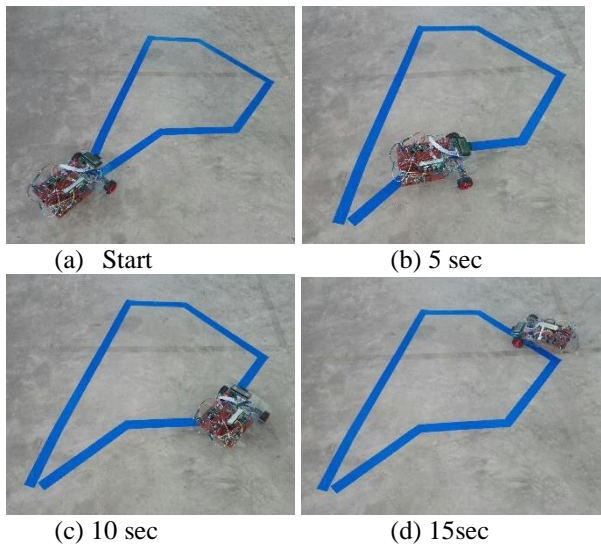

(e) 24 sec

(f) 28 sec

Figure 9. Hardware Experiment of Path Following Mobile Robot

The mobile robot followed first corner in 5 sec, second corner in 10 sec, third corner in 15 sec, fourth corner in 24 sec and fifth corner in 28 sec respectively. The values of V_l, V_r set rpm and robot tracking rpm of path following mobile robot are shown in Figure 10. The mobile robot tracked the left velocity of rpm values are nearly 110 rpm and right velocity of rpm values are nearly 105 rpm. Figure 10 shows the testing of 5 points tracking of mobile robot in which the tracking performances at from 0 second to 41 second.
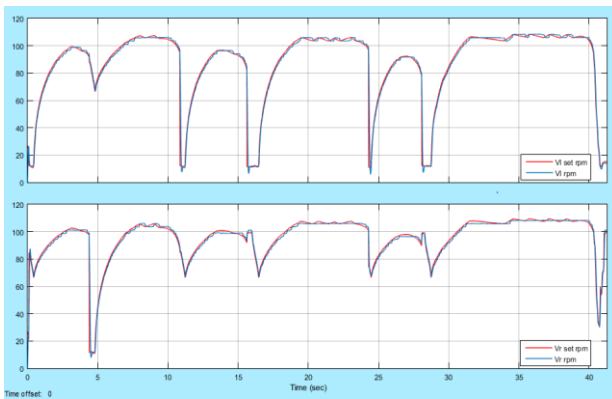
Figure 10. V_l, V_r Set rpm and Robot Following rpm

The resultant controller worked fine but when it was implemented on hardware some inherent problems came to light. It was observed that the microcontroller took a large amount of time to complete the fuzzy calculations thus degrading the performance of the controller. The response of the system was too slow in real time to actually control the motion of the robot. This was mainly of the membership functions used in the fuzzy rules. It was seen that this improved the performance of the mobile robot, but still the calculations were taking too long a time due to the speed limitations of the microcontroller used. Thus a lookup table was developed offline and was programmed into the microcontroller, thereby reducing the processing time.

5. Conclusions

In this research, the MIMO fuzzy controller design was constructed for position and angle orientation of the mobile robot based on the kinematics model of two wheels DDMR. Results in both simulation and real world experiments showed that our tracking system made the differential drive mobile robot be able to effectively follow along the referenced paths. The results showed that it is possible to make use of robots to explore and track in known environments. The mobile robot tracked the outer route after turning around of every corner. That's why; the mobile robot needs to turn more angular position for the corner. In the movement of error position and orientation, the peak of the tracking paths occurred at the corner of the path following mobile robot.

7. References

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Design, Construction and Performance Testing of Automatic Welding Machine Using Metal Inert Gas (MIG) Welding

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Abstract

Welding is the process of joining materials by using high heat to melt the parts together and allowing them to cool causing fusion. In this research the automation system for welding process was used instead of manual skill to get a good welded joint. The stability of the continuous movement of the welding torch is very important for the quality of welded joints. This paper represents the design of automatic welding machine and the performance result of the machine. Firstly, the purpose is to design the machine frame of the 3-axis co-ordinate system. And then, the designed machine frame that support X-axis, Y-axis and Z-axis movements of the welding torch is constructed. Finally, Cronos Maker 3018 CNC control board is used to control X-axis, Y-axis and Z-axis movements. On the various speed of the torch, the performance testing is done, and the measurements of the parameters (length of the weld, throat thickness) and the rate of torch travel are optimized.

Keywords- Welding Automation, Weld quality, Feed rate, Throat area

1. Introduction

In many production industry, is used automation system to improve their production process. Manufacturing industries produce many components that are assembly to get a product. In combining the components, welding is one of method to join one of component to another. In welding process, welding torch must be move gradually the line that to weld .The movement of the welding torch is mainly effect on weld quality. According to this fact, a welder must be skillful on welding operation process. To eliminate the skillful requirement, the automation system of cartesian movements was designed and then this system supported the movement of the torch gradually. The system can be adjust the speed of the torch. Thus the operator can be adjust easily the speed of the torch by given the feed of the G01 code as the requirement of the thickness of weld .In this automation system, the welding torch can be moved easily the line that the operator defined on X-Y plane . The system can be supported the movement of the torch on X-Y plane multi-layer elevation. But, in this paper the performance test of machine only single layer X-Y plane butt-joint welding. In testing the automatic welding machine, the thickness of the weld be observed upon the various feed rate that is the speed of the torch. The system has a little difference with CNC milling control system. In CNC milling program, the spindle is running before the tool reach to the starting point of milling line and do not stop the spindle until the program is end. There is no problem for CNC milling process but in welding process the automation system connect the spindle drive port and the switch of MIG welding machine switch This switch operate three kind of function simultaneously.

(i)Switch on the relay to get the source of electricity energy

(ii) Permit to supply CO_2 gas to shield around the weld pool

(iii)Switch on the relay that operate the wire feeder above functions must be operate only the welding torch move point to point that the line to be weld .Thus the spindle on command M03 Sxxx be written before the command that the torch travel to weld G01 XxxYxxFxx. The machine can weld within the work envelop (600 mm x 300 mm x 150 mm).

2. Working Principle

Firstly, working principle of metal inert gas welding (MIG) welding also known as gas metal arc welding (GMAW) be introduced. The main components of a GMAW are welding torch, wire feeding unit, gas supply unit for shielding and high voltage power supply unit.

To do the welding process on GMAW machine, switch on the switch at the handle of the welding torch and then move the handle slowly along the path to weld. By switching on, the machine operate simultaneously the main functions; high voltage energy source generate between the wire electrode and base metal, wire feeding unit and gas supply unit to shield weld pool region. According to the types of joint and thickness of base plate, the operator can be adjust the ampere of the power supply, the federate of the wire filler and flow rate of the shielding gas.
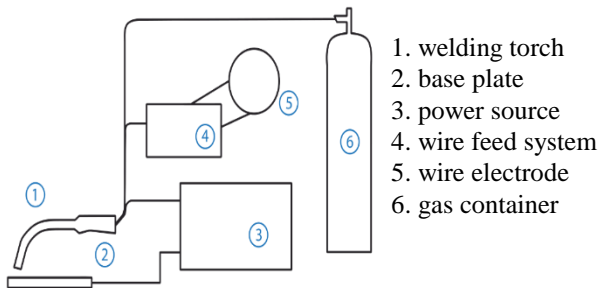
Figure 1. Components of GMAW Machine

1. welding torch
2. base plate
3. power source
4. wire feed system
5. wire electrode
6. gas container

To operate welding process automatically on the automatic welding machine, the base plate to be weld are mounted on the table of the machine that is connected to the anode of the GMAW machine. And then, setting the electrode wire tip and the datum point of the base plate by using offline controller. The offline controller can be used to move the welding torch along the X-axis, Y-axis and Z-axis with multi step 1x,2x,5x,10x and 15x. After setting between the datum point and the tip of the electrode, set X0,Y0 and Z0 on the application. Then the operator write a program on this application to run the machine automatically. Programming to run the automatic welding machine along the desired weld path is very simple because of the welding path is not complicate than the way tool movement on CNC milling process. If the path to be weld is complicate, the operator generate a program with the help of Inkscape software. Inkscape is a software that can be run on PC to draw desire profile to be weld, and then can be generate a G-code, M-code program to move the welding torch along the desired path. But the program, generated from Inkscape, is cannot be used on the automatic welding. Because the program is used for CNC milling process. There is a little difference procedure between automatic welding process and CNC milling process. In CNC milling process, the spindle is running before the tool move the desire path and then stop after finished all the path the milling process. In automatic welding machine, the port to the spindle drive was connected to the relay that is connect to the switch on the handle to operate the GMAW machine. Thus, the program must be added spindle on command M03Sxxx before the welding torch move the path to be weld and spindle off command M05 must be added after the torch move the path to be weld. There is a very simple program can be write and run on GRBL controller software. For example, to produce a weld line between (5,5) and (25,30) from the datum point (0,0), the following simple program complete this work.

```
G21
G00X5Y5Z0
M03S300
G01X25Y30F200
M05
G00Z5
```

M30

The above program is ready to run to get the welded line (5,5) to (25,30) from the recorded datum point.

3. Design of Automatic Welding Machine

In this paper, the automatic welding was designed intend to move smoothly and controllable the welding torch that will be mounted of Z-axis movable frame. The welding torch should be moveable along the X-axis, Y-axis and Z-axis. The design of the machine include three main parts of mechanism: Z-axis mechanism, Y-axis mechanism and Z-axis mechanism.
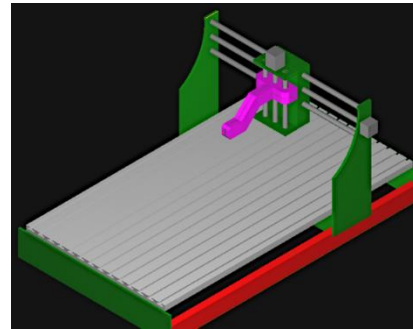

Figure 2. Base Frame and Axis Design

3.1. Design of Z-axis Movement Mechanism

To design the Z-axis movement mechanism, the total load of the components should be considered, this is maximum Z-axis base plate will be moved up and down with welding torch that connected gas pipe cable. The plate can be moved vertically up or down by driving Z-axis motor. This plate can be moved smoothly along the vertical guide line with linear bearing. Screw and nut mechanism carry the base plate and welding torch components. In this design, to lift up and down the total weight of the components; base plate, welding torch and cable, calculating with the power screw equations by trial and error method: 16mm outside diameter, 4mm pitch and 4 start lead screw be used to drive Z-axis mechanism.

Thus,

lead = pitch x number of starts = 4 x 4 = 16 mm

d_m = mean diameter of screw = 14 mm

$$\tan \alpha = \frac{lead}{\pi d_m} = \frac{16}{\pi 14} = 0.363$$

Coefficient of friction of steel, $\phi = 0.53$

Torque required, $T = P \times \frac{d_m}{2} = W \tan(\alpha + \phi) \frac{d_m}{2}$

Maximum weight to be moved = 15N

The required torque is 0.093Nm. And, Neme 17 stepper motor can be used.

3.2. Design of Y-axis Movement Mechanism

To design the Y-axis movement mechanism, bending movement should be considered for Y-axis supporting guideline shaft. All of the z-axis movement mechanism and welding torch components are moved together along two way parallel shaft. Maximum bending movement appear at the midpoint of the shaft. Maximum total weight of the components on the Y-axis beam is 40N. Length of Y-axis beam between two simply supports is 600 mm. Thus, maximum bending movement occurs at the mid-point of the beam.

Maximum bending movement,

$$M = \frac{Wl}{4} = \frac{40 \times 600}{4} = 6000 \, Nmm$$

Allowable bending stress for steel is 62.5 N/mm². By bending movement theory,

$$\frac{M}{I} = \frac{\sigma}{y}$$

M= Bending movement acting at the given section
σ = Bending stress
I= moment of inertia of the cross section about the natural axis
y = Distance from the neutral axis to the extreme fiber

According to the bending movement theory,

$$\frac{6000}{\frac{\pi d^4}{64}} = \frac{62.5}{\frac{d}{2}}$$

$$d = 9.9 \approx 10mm$$

To accomplish stable and parallel movements of the welding torch along the Y-axis, 10 mm two parallel shaft can be used to support Y-axis as beam. The components will be moved along the two parallel guideline shafts with linear bearings. Thus, the coefficient of friction between linear bearings and shaft are too small, generally below 0.001. Therefore the drive mechanism for Y-axis can be used as Z-axis drive mechanism.

3.3. Design of X-axis Movement Mechanism

All components of Y-axis and Z-axis movement mechanism will be moved along the X-axis linear ways guideline. The guideline ways are directly mounted along the base frame. Thus, there is no bending movements on this ways. Power transmission for X-axis movement should be considered because of total weight 50 N of the components will moved along this ways. In this case, power screw must have adequate strength to whist end axil load and the applied torque. Lead screw use the helix angle of the thread to convert rotary motion to linear motion. The performance of a lead screw is heavily dependent on the coefficient of friction between the nut and the screw which is turn depend upon the material used. To determine whether lead screws or ball screws are for an application, begin by looking at the required load capacity. In this design, 16mm outside diameter, 4mm pitch and 4 start lead screw be used to drive X-axis mechanism and bronze nut be used for about 80 N load.

4. Result Data of the Machine

In this paper, the following results were chosen to implement the machine. The lead screw 16 mm diameter, 4 mm pitch and 4 starts be used the axes movement mechanism. Nema 17 stepper motor be used for all drive mechanism to easy constructing the control system. For Y-axis guideline shafts as act beam use 16 mm diameter shafts. To control the motors of three axes drive system Cronos Maker 3018 CNC control board be used. It has an offline controller that can be used to control the machine manually.

5. Performance Testing of the Machine

After constructing the automatic welding machine, construct the connecting line that is convert the signal from the automatic welding machine to the switching on the main operating switch of GMAW machine. The signal from the automatic welding machine sends to the relay that connect the main switch of the GMAW machine to operate welding process.

As a first test, the gap that is between surface of the base plate and tip of the welding torch, the gap 5mm is optimized. If the gap is more than 5mm, the welded layer is too thin, thus less strength on the joint. If the gap is less than 5 mm the weld is thick, thus the molten metal is too near the tip of the nozzle. The nozzle may be too hot when long weld path operate.

Figure 3. Gap between Base Plate and Tip of Welding Torch

As a second experiment, welding operations with various federate (speed of the torch movement) are tested under the optimum gap (5mm). According to visual weld quality testing, the weld that is welding by feed-rate 200 mm/min is the best.
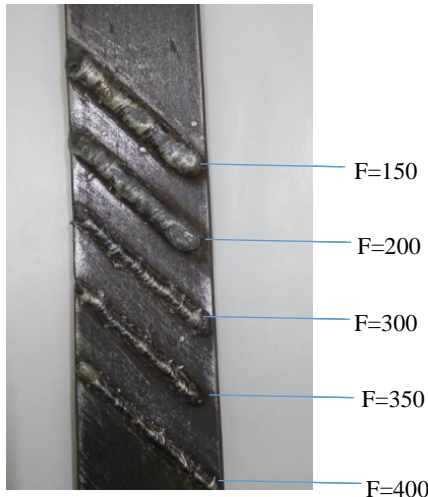
Figure 4. Tested Weld Line with Various Feed-Rate

The face of the weld is slightly convex with a reinforcement above the plate surface. The face of the weld is fine.

As a third experiment, 35 mm width, 5 mm thick two mild steel plate was joined together by butt joint method flat position. By compairing two feed rate 200 mm/min and 150 mm/min, 150 mm/min feed rate is more suitable than 200 mm/min feed rate because of the thickness of the base plates. The feed rate can be increeased when increase the ampere of the electric energy source from GMAW machine. Weldiing with high ampere electric energy source improve the peneration to the base metal.

F=200 mm/min   F=150 mm/min

Figure 5. Butt Joint Welding Testing

As a fourth experiment, 35 mm width, 5 mm thick two mild steel plate was joined together by lap joint method flat position. By compairing two feed rate 200 mm/min and 150 mm/min, 150 mm/min feed rate is more suitable than 200 mm/min feed rate because of the thickness of the base plates.

After testing some important functions of the automatic welding machine, strength of the welded joints be studied from the result data of the performance testing. The transverse fillet welds are designed for tensile strength.

P = Throat area x Allowable tensile strength

$P = 0.707s \times l \times \sigma_t$

P = load (N)

s = thickness of plate

l = length of the weld, width of the plate

σ_t = allowable tensile stress

F=200 mm/min   F=150 mm/min

Figure 6. Lap Joint Welding Testing

6. Conclusion

Automatic production is a process in the development of mechanized production in which the control and monitoring functions previously performed by humans are transferred to instruments and automatic devices. Automatic welding machine can be used for a production line of welding section to weld predetermined welding path. According to the performance test on the automatic welding machine, the machine can be weld the flat position type. It involves welding on the top side of the joint. In this position, the molten metal is drawn downward into the joint. The result is faster and easier weld. The automatic welding machine can be used to weld any path to be weld on the working area of the machine. The main limitation of the machine is the machine can be weld only flat position. To weld the other positions horizontal or vertical or overhead, the design of the welding torch mounted position must be changed.

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