Welding Seam Tracking Controller Simulation Using Fuzzy Logic

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ABSTRACT

Robotic welding processes are widely used in manufacturing and especially in the automotive industry. Quality problems in the automation of this process became a leading cause of attention by manufacturers and researchers interested in improving these processes. Within the wide range of automated welding processes that exist in the industry, the most used is the Gas Metal Arc Welding Process (GMAW) for his great versatility and good performance in applications with robots. This article presents the results of the simulation of a control system for weld tracking monitoring using a 6 DOF robot manipulator. The motion control system is based on Fuzzy Logic and it is able to compensate any part misalignment due to clamp mismatch or positioning errors from the holding tool, etc. A type I fuzzy system is used for the controller as well as a laser and a vision camera as the sensory input. Typical misalignments during operations are of linear type so the control system was simulated under this scenario and also tested against sudden changes in the preprogrammed trajectory in our initial experiments in a real-world environment.

1. Introduction

Nowadays automated welding processes are able to be more used by industry; this is the case of the automotive industry, for its wide application in welding processes that involve certain risk and hard work for human resource. There are several factors that affect the process accuracy such as the workpiece positioning; motion errors in the production line, mechanical errors, backlash, ageing of mechanisms, etc. which are error sources that make robots to operate in uncertain conditions, called unstructured environments. The scope of this article is focused on the compensation of these errors generated during the process and that the robot system needs to overcome in order to meet the required quality specification using an artificial controller based in Fuzzy Logic. To reach this goal, it is required to have an appropriate test-bed integrated with the process parameters sensing capacity (laser system, camera, proximity sensors, etc.) to follow the welding bead and to provide robust information to the robot controller.

The design solution proposed in this research is the simulation of a control tool for adjusting the robot trajectories programming at the time of the welding process. The tool set for adjustment paths is implemented in a first instance in the programming software Matlab and then moves to the programming environment Visual C ++ 2005 in order to integrate everything in the same environment with the robot, because the purpose of the software is to compensate the movement of the workpieces and self-adjust the trajectory of the robot.

There is a wide variety of solutions for these problems that arise in these processes, ranging from using a simple PID control system to the newest tools of Artificial Intelligence, as shown by Lianfang Tian and Curtis Collins (2004) in their work employ an effective method of path planning using genetic algorithms in which a robot saves some obstacles in a workspace [1]. The application of genetic algorithms to manipulator trajectory planning has gained popularity in recent years. Zhao et al. [2] addressed the path-planning problem of a mobile robot. Based on a set of task specifications, genetic algorithms were used to find an optimal sequence of base positions and robot configurations for the tasks. In addition, fine tuning of off-line programs may be necessary to adapt them to physical work-cells. Techniques to deal with programming problems due to the differences between modeled manipulators and actual work-cells had been
explored by Pathre [3]. More recently, many works has expanded the area of automated trajectory planning which is vital for the development of autonomous robots. Many techniques [4–7] have been developed to address this.

The organization of the paper is as follows. Introduction and related work is presented in section 1. A brief review of the robotic GMAW welding process and security issues is presented in Section 2. Section 3 explains the composition and structure of the fuzzy system. The algorithm for the Fuzzy Control System is explained in Section 4. The Section 5 provides the obtained results using simulation and the fuzzy controller and also present some initial experiments related to the actual implementation that envisages future work with an industrial manipulator.

2. Robotic GMAW welding process

2.1 Gas Metal Arc Welding Process

In Gas Metal Arc Welding (GMAW) process an electric arc is established between a consumable electrode fed continuously to the weld pool and the work-piece. When this process started, the weld pool was shielded by an inert gas, giving the process the popular designation of Metal Inert Gas (MIG). It can weld almost all metallic materials and is effective in all positions. Less operator skill is required than for other conventional processes because electrode wire is fed automatically (semi-automatic process) and a self-adjustment mechanism maintains the arc length approximately constant even when the distance weld torch to work-piece varies within certain limits. These advantage make the process very well adapted to be automated and particularly to robotic welding applications. [8]

2.2 Health and Safety

The major potential hazards of arc welding processes are the high-voltage electricity, which can injure and kill personnel, the fumes and gases, which can be dangerous to health, the electric arc radiation, which can injure eyes and burn skin and the noise that can damage hearing. The exposure to the high open-circuit voltage of power supplies can cause dangerous electric shocks, which can be prevented by connecting all the electrical equipment and work pieces to a suitable electrical ground. All electric cables should be suited to the maximum current and must remain insulated and dry.

3. Fuzzy Systems

Within the wide range of the artificial intelligence, A system that is a very useful tool due to its great adaptation to industrial environments, this tool is called fuzzy logic system which is based on controlling processes in the same way that our brain reasons. The called Fuzzy Logic allows deal imprecise information, such as medium height, low temperature or high strength, in terms of fuzzy sets (ultimately inaccurate.) We will see that these fuzzy sets are combined into rules to define actions. Thus, the control systems based on fuzzy logic combined input variables (defined in terms of fuzzy sets), using sets of rules that produce one or more output values. (B. Martín del Brío & A. Sanz Molina). This is what the driver wants to implement automated welding, a system that can work with values not exact. We can calculate if the robot needs to move a little to the right or slightly to the left to correct the course of welding, or that is maintained in the reference position. In fuzzy logic, we give the membership through a value between 0 and 1. If the object does not belong to the set membership value is 1. To create a fuzzy logic application requires three steps: fuzzification, fuzzy rules and defuzzification, the names may seem complex, but the concepts are very simple. In the first step, known as fuzzification, take a data system and becomes a fuzzy data. The data of the system can be a real number obtained from the environment through a sensor, in this case could be a laser sensor reading, or calculated by some function or a given input by the user. Transforming the data to a fuzzy data is carried out to find the degree of membership of that value against a series of fuzzy sets. Now we can pass the value to the fuzzy rules. These rules build them us according to the necessities of the system. After being evaluated, we know that have membership degree of each with respect to the output. In some cases it is necessary to
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return the resulting value to a specific value, this is known as defuzzification, and we get a value
that belongs to the real numbers [9].

4. Fuzzy Control System

The control systems for the tracking of welding trajectories are being used more and more
frequently, so this process is controlled through more and more sophisticated and robust
controls, it is of great importance to determine which are the main parameters to control (A.
Barcellona et. al), to be able to infer the quality of the product. The objective of the controller is
to compensate the motion in the coordinates of a robot manipulator of 6 DOF (degrees of
freedom) when making a weld, in other words, correct the trajectory of welding when an
unexpected movement in the welding piece occurs. This application only works with linear
trajectories and control gives the robot a new coordinate in the event that there is a mismatch in
the workpiece.

4.1 Fuzzy System

To create this application using fuzzy logic control, it basically requires the following steps:
normalization, fuzzification, fuzzy rules, defuzzification and De-normalization. The first step,
since information is provided by a sensor (in this case a laser), the value read is a real value,
which due to the nature of the data controller must remain encoded input from a range of zero
to one, for which you use a function called normalization. The next step known as Fuzzification,
take a data system and becomes a fuzzy data. The data to transform a fuzzy data is performed
to calculate the membership degree or ownership of that value against a series of fuzzy sets.
For example, suppose that the variable will depend on the movement of the work-piece or the
distance moved, which we can use this distance as our data, and the fuzzified, we find that both
have membership or ownership in sets to the very left, left, right or very right, etc.
Once fuzzified data, these are used to construct the fuzzy rules. These rules are built according
to our system needs. After being evaluated, we know what degree of membership of each one
in relation to the output. Finally it is necessary to return our data set of real numbers and the
output will be the new coordinate of the robot, it is used for Defuzzification and then
denormalizes the data to finally correct the weld path.

5. Design simulation and Implementation

Our system compensates the movement on the axis "y" of the robot coordinates, and the
coordinates axis "x" and "z" are fixed. So we have an input variable by a variable output, the
range within which our system is working is from -1 to 1 cm. (Being subject to any other range)
and zero is taken as the reference of the path to be welded. Below is a data matrix of the input
variable which shows a movement toward both the left and right.

\[
X = [0; 0; 0; 0; 0; 0; 0.5; 0.5; 0.5; 0; 0; 0; 0; 0; -0.5; -0.5; -0.5; -0.5]
\]

The values of 0.5 tell us that the piece moves to the right and the values of -0.5 tell us that the
workpiece moves to the left. Once data is created standard fuzzy sets determine the degree of
membership of data, in other words, if the piece moves to the left or right. To create the fuzzy
sets is necessary to use two types of membership functions, the trapezoidal and triangular. Fig.
1 shows Fuzzy sets for this application.
Once fuzzy sets are created and we know the degree of membership for each input value to the system, now it is necessary to create the fuzzy rules which are shown as follows:

- If \( \text{Yref} \) is very Left
  - Then Decrease to much \( \text{Pos}_{\text{robot}} \)
- If \( \text{Yref} \) is Left
  - Then Decrease \( \text{Pos}_{\text{robot}} \)
- If \( \text{Yref} \) is little Left
  - Then Decrease little \( \text{Pos}_{\text{robot}} \)

etc.

The rules we have established will place their evaluation in a fuzzy set output, because it is not that a rule has been met, but all have been met to some degree. The output fuzzy set is also designed by us depending on the needs of our implementation. To obtain a quantity like a response of our fuzzy system, we perform defuzzification process. Based on the fuzzy values obtained from our rules, we get real value that our application can use. To obtain the resulting value, you can use different methodologies. The application here is to find the centroid of fuzzy set output.

For a fuzzy system whose final output needs to be in a crisp (nonfuzzy) form, the next step is needed to convert the final combined fuzzy conclusion into a crisp one. This step is called the \textit{defuzzification}. A fuzzy rule-based controller, for instance, uses such a step to generate a crisp control command. There are two major defuzzification techniques: (1) the Mean of Maximum (MOM) method and (2) the Center of Area (COA) or the centroid method. The mean of maximum defuzzification calculates the average of all variable values with maximum membership degrees. The centroid (or COA) defuzzification method calculates the weighted average of a fuzzy set. The result of applying COA defuzzification to a fuzzy conclusion “\( \text{Y} \) is \( \text{A} \)” can be expressed by the formula

\[
y = \frac{\sum y_i \cdot \mu_i(y_i)}{\sum \mu_i(y_i)}
\]

If \( y \) is discrete, and by the formula

\[
y = \int y \cdot \mu_i(y) \, dy
\]

If \( y \) is continuous [10]
Since the data have been Defuzzified the last step is to De-normalize the data to obtain a real number and this can be used as the new coordinate of the robot. Next we show the result of the controller.

### 5.1 Simulation results

The simulation application was programmed in MATLAB R2007b® software and some runs were made with different input values, then the results show how movement is performed on the workpiece and the controller compensates this movement and corrects the trajectory of the robot.

In figure 3, we can observe that the trajectory to weld is in zero, the marks in red color are the points that this receiving the laser, and the line in blue color is the trajectory of the robot that it is received from the fuzzy controller, which shows us how it is compensated the movement of the piece and the robot's trajectory is corrected, in the point 7, 8, 9 we move the piece to the right and the line in blue color show us how immediately the robot receives the new coordinate and it compensates this movement, in the points 17, 18, 19 and 20 now the movement is to the left and we can observe immediately as the controller carries out this adjustment.

In figure 4, we can observe how the controller compensates in the same way the rotational movements of the workpiece.

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**Fig. 3** Robot Trajectory using Fuzzy Controller

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### 6. Conclusions and Further Work

Through the use of a fuzzy system type 1 we were able to simulate and compensate possible robot arm misalignments during welding task. The fuzzy controlled worked as expected and current work is looking at the integration with the robot controller that includes the use of laser line (to detect the trajectory change) and a CMOS camera with a high dynamic range (approx. 120 dB) due to the high luminance that is expected during welding. The system under construction is depicted in Figure 4.
Fig. 4 Application of weld seam tracking in GMAW process

References


