Artificial Life Intelligent Contour Following Industrial Robot

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Abstract: Contour following is very important topic to be studied since the outcome of robot to follow contour automatically can simplify robot teaching process. Normal teaching to make robot capable of following contour is quite tedious and time consuming. It requires three points in order to model an arc. If the curve is quite complex it requires curve fitting of several points not to mentions teaching iterations in order to get correct overall curve path and speed. This research will empower industrial robot life artificially and can behave like intelligent entity whereby the industrial robot capable of self learning the curve and has the power to judge and discriminate the number of sampling points between simple curve and complex curve. Specifically this work will employ Fuzzy logic as a means to discriminate and to distribute the amount of sampling points adapted to the complexity of the curve. More points to approximate complex curve and less points to approximate simple curve. The impact of this research will transform the existing tedious manual training scenario of Industrial robot where the new robot will follow contour automatically while capturing points intelligently adapting to curve in order to be used later in repetitive playback process

Key words: Contour Tracking, Fuzzy Logic,.

1. Introduction

Robot is an essential added value tool in spray painting, arc welding and sealing application due to the complex nature of the process where the working condition is quite dangerous and undesirable to human being. In order to use robotics for such application two sequence of steps need to be considered, the programming phase and the playback phase. In the programming phase, teaching a group of points is required while for playback phase, the robot Tool Centre Point (TCP) will follow the taught points recorded previously. This programming phase especially for contour tracking application such as in arc welding, sealing and painting application is quite tedious and time consuming. For example, in order to track an arc, the robot programmer needs to manually use teaching box or teaching pendant to jog (powered motion) the robot Tool Centre Point to three points that enclosed an arc. For a complex contour, several series of three points must be taught, besides finding the optimum process parameter (voltage, current and electrode speed for arc welding application) related to those [(1) (2)(3)]. Next, the motion instruction, speed and type of termination that describes the closeness of zoning radial distance to the taught points needs also to be defined. The programmer must iterate the points and process parameters several times until the optimum combination are achieved. In comparison to assembly operation where the programmer just need to teach few points (approach, insert and depart points), contour tracking for painting, arc welding and sealing application requires a large number of points recorded and at the best location. After all the best program and process parameters are achieved for one sample part, the same quality is expected for the subsequent parts in a batch. This expectation alone poses difficult challenges to the industry since parts do vary dimensionally due to inaccuracy in manufacturing and joining operation. For example, in welding job such as gas-metal arc welding (GMAW) process the part expands dimensionally since the volume of molten material in the weld bead is proportional to the heat input[(4)(5)] . Furthermore, the current Flexible Manufacturing System concept requires different kind of parts variations for one production run. This means that a great number of robot programming is required to cater parts variations and uncertainties per production run compared to the old days

From these explanations, it can be justified that the effort to automate the robotics tedious teaching process in contour tracking application is really required in order to solve the abovementioned problems. Several actions will be studied in order to implement abovementioned task. First autonomous contour tracking algorithm for industrial robot is developed. Sweeping Radius Method will be used to implement this autonomous tracking[(1)(4)]. Second intelligence to the contour tracking algorithm developed previously will be increased by adding fuzzy logic algorithm to read the adjacent slope different and the local slope value for determining the sweeping radius distance and the number of sampling points, adapting to the curve . This algorithm will be tested on circular shape contour and the data will be presented in this paper The application of fuzzy logic control in robotics is to produce an intelligent robot with the ability of autonomous behavior and decision [(7)(8) (9)] .Fuzzy logic is a way of interfacing inherently analog processes, which move through a continuous range of values, to a digital computer, that likes to see things as well-defined discrete numeric values. They consist of an input stage, a processing stage, and an output stage. The input stage maps sensor or other inputs, to the appropriate membership functions. The processing stage invokes each appropriate rule and generates a result for each, then combines the results of the rules. Finally, the output stage converts the combined result back into a specific control output value[(9) (10)].

2. Generation of Autonomous Sweeping Radius Contour Tracking

2.1 TASK PLANNING FORMULATION

Users need to specify the contour length by recording the initial and final location of robot TCP (Tool Centre Point); smart sensors feed back and programming will guide the TCP to approximate the curve with a straight line segments that knot from points to points in three dimensional Cartesian XYZ plane. The measured knot points and segment slope will be stored in the database and will be used again and again in robot part program playback mode. Four degree of freedom SCARA ADEPT industrial robot will be used in this . The initial and final location of robot TCP will be recorded in joint coordinates and being transformed into world coordinate describing both orientation and position of the gripper Tool Centre Point refer to robot base world coordinate system as follow

$$P_{final} = P_{initial} T(N) \quad (1)$$

And after some manipulation

$$T(N) = (P_{initial})^{-1} P_{final} \quad (2)$$

Task planning matrices show the gross final tool position P_X , P_Y , P_Z and orientation yaw angle θ_Z which becomes

$$Px = n_A \bullet (p_B - p_A) \quad (3)$$

$$Py = s_A \bullet (p_B - p_A) \quad (4)$$

$$Pz = a_A \bullet (p_B - p_A) \quad (5)$$

$$\theta_Z = \tan^{-1}\left\{ \frac{\left[(n_A \bullet a_B).^2 + (s_A \bullet a_B)^2 \right]^{\frac{1}{2}}}{a_A \bullet a_B} \right\} \quad (6)$$

$$0 \le \theta \le \pi$$

which n_X , $s_{A,} a_A$ and θ_Z becomes input into next segment differential chord planning which will be discussed below. Modifying [7] Drive Transform Equation for four degree of freedom SCARA robot which only has yaw orientation angle, the chord segment relative path transformation drive transform is being simplified into one rotation matrices to orientate tool about *Z axis* and a straight line translation (one rotation about approach angle and another translation along tool axis) to achieve the motion between two consecutive Cartesian knot points. Motion from i to $i+1$ is related to drive transform as

$$T_4(i+1) = C_{Workobject} P_i D(i+1)({}^{tool}T_{i+1})^{-1} \quad (7)$$

is the input stored to the database and contain both tool position and orientation at any points which also becomes input to the inverse kinematics routine in order to get local coordinate of individual robot joint angles After some mathematical operation the position of consecutive knot points at beginning from i to end of segment $i+1$ is a function of drive transform as follow

$$D(i+1) = \begin{bmatrix} C(\theta) & 0 & S(\theta) & \delta_X \\ 0 & 1 & 0 & \delta_Y \\ -S(\theta) & 0 & C(\theta) & \delta_Z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (8)$$

Total trajectory point generated at point N is as follow

$$P_N = \prod_{i=1}^{N-1} P_i D(i+1) \quad (9)$$

The related transformation at any point *N* which become input to inverse kinematics routine is

$$T_4(N) = \prod_{i=1}^{N} C_{Workobject} P_i D(i+1)({}^{tool}T_{i+1})^{-1} \quad (10)$$

Fig.1 Fuzzy Sweeping Radius with ADEPT SCARA Robot Implementation

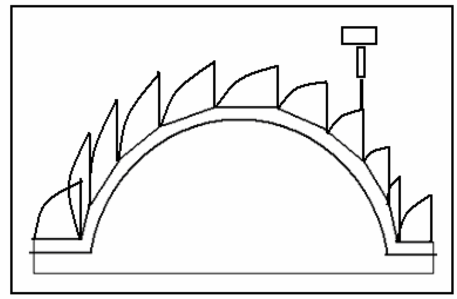

Fig.2 Fuzzy Sweeping Radius Movement

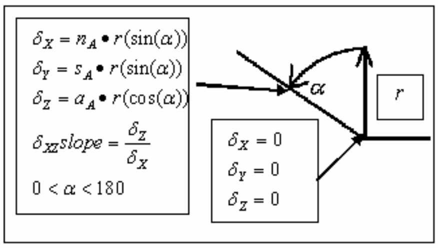

Fig.3 Important Parameter for Sweeping Radius

2·2 Sweeping Radius Contour Tracking

The objective of this research is to automate the incremental measuring motion utilizing the gross output of total positions and yaw orientation angles from task planning algorithm discussed before. Another important point is the slope gradient measurement at any knot points for correcting the optical sensor reflectance correction factor along the contour positive and negative slope gradient. The complex contour of any different gradient is being approximated by segment of chord distance r . The smaller the r value the higher the accuracy of contour shape being measured but at a higher computation cost (refers fig.1). The first pass of robot program is to measure the incremental position and slope along the contour gradient and store the positions recorded in the data base. The stored locations will be used again and again for playback purpose in subsequent passes (running a production part program).

2. Fuzzy Discriminator Development

The complexity of the curve can be represented by value of the slope differences and value of local slope. Fuzzy subprogram written in ADEPT SCARA robot V+ code will return the value of sweeping radius dr to the main program of sweeping radius method based upon curve complexities in real time(refer figure3). More sampling measurements points will be generated to complex curve and less sample on the flat simple curve. Three fuzzy sets of SMALL MEDIUM and BIG were used for each input to fire five output singletons of SMALL, MEDIUM, BIG, VERY BIG and MAXIMUM BIG giving a total of nine rules as follows;

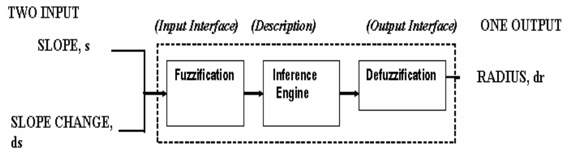

Fig.4 Two input one output Fuzzy Model

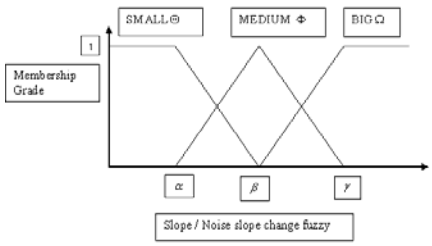

Fig.5. Input of Slope and Slope difference Fuzzy representation

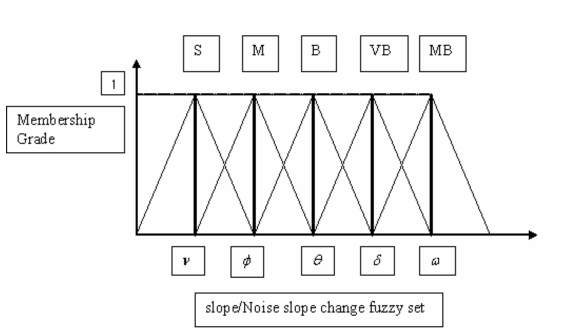

Fig.6. Singleton Output Sweeping Radius Sampler

Rule 1; IF u is B and du is S THEN dr is S

Rule 2; IF u is B and du is M THEN dr is M

Rule 3; IF u is B and du is B THEN dr is B

Rule 4; IF u is M and du is S THEN dr is M

Rule 5; IF u is M and du is M THEN dr is B

Rule 6; IF u is M and du is B THEN dr is VB

Rule 7; IF u is S and du is S THEN dr is B

Rule 8; IF u is S and du is M THEN dr is VB

Rule 9; IF u is S and du is B THEN dr is MB

Where :

$u =$ current local slope input, $du =$ slope error (noise slope changes)input, dr = radial sweeping parameter output, B: Big, M: Medium,S: Small, VB: Very big,MB: Maximum Big

The fuzzy output value then transformed to a crisp value using as defuzzification strategy the average of the impulses or average singletons. This method is considered as a special case of the average peak value (Lee, 1990), where the areas of output fuzzy set partitions by unity impulses centered at half support value of each set;

$$u = \frac{\sum_{i=1}^{n} w_i a_i \int_{w_i - \infty}^{w_i + \infty} \delta(w_i) dw}{\sum_{i=1}^{n} a_i}$$

3. Fuzzy Contour Tracking Result

The actual contour traced and the tracking error along contour, matching the semicircle geometry of radius 40 millimeter is plotted in figures 7 and 8. The safety margin of 0.1 to 2.5 millimeter is allowed at the beginning and near to the end of the semicircle object in order to avoid measuring the very high slope at those regions. The sweeping radius parameter is adjusted intelligently by this autonomous fuzzy contour tracking program dependent upon the contour slope and noise slope change. The total sample of 74 points were collected over 80 millimeter of horizontal measuring distance.

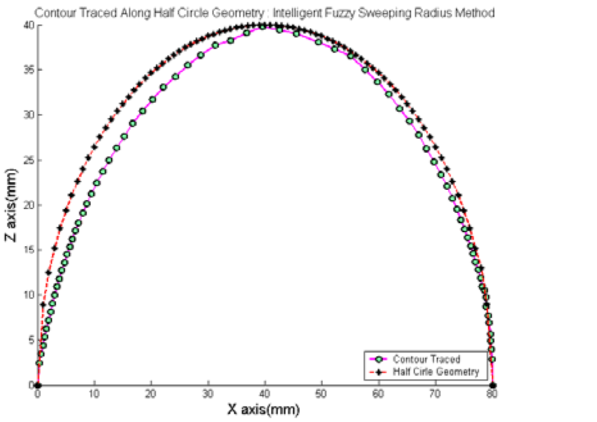

Fig.7.: Contour Traced along semicircle geometry with Intelligent Fuzzy Sweeping Radius Method.

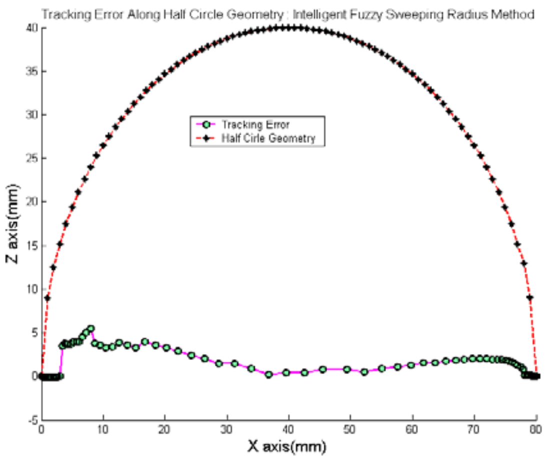

Fig 8 Tracking Error along semicircle geometry with Intelligent Fuzzy Sweeping Radius Method

4. Conclusion

This work demonstrate that :-

・The automation of tedious and time consuming robot contour tracking program is possible and feasible just by employing only one discrete optical sensor interface to ADEPT SCARA Robot.

・Fuzzy Logic can be programmed into industrial robot with the simplification on the output side by employing Sugeno Singleton output thus simplifying robot fuzzy programming.

・Using the Fuzzy Logic More samples is generated along infinity and high slope region curve and less samples approximating flat and low slope with less complexity

・Error is quite high in the high slope region especially in the positive slope portion. Negative slope portion posses less error in comparison to positive slope

・The higher the slope value the more error and more samples need to be generated in order to approximate and track a contour

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