An Effective Prediction of Position Analysis of Industrial Robot Using Fuzzy Logic Approach

P. Kesaba, B.B. Choudhury and M.K. Muni

Abstract Industrial robots have been extensively used by many industries as well as organizations for different applications. This paper introduces some qualitative parameters to find out the best predictive value as per the comparison to experimental value. In the fuzzy-based method, the weight of each criterion and the rating of each alternative are described by using different membership functions and linguistic terms. By using four techniques triangular, trapezoidal, Gaussian and Hybrid membership functions, the effective prediction of robot angle with their position is determined in accordance to space of Robot. This paper compares four techniques and found that the Hybrid membership function is the effective one for determination of effective prediction measurement as it shows a good agreement with the experimental result. By taking help of this paper the user can easily access to any point of the workspace locations. It is very effective one by the fuzzy logic systems to analyze the work space.

Keywords Six axis industrial robot · Fuzzy logic · Triangular · Trapezoidal · Gaussian · Hybrid membership function

1 Introduction

Due to high labor costs and precision in repetitive works many industries have to rely on production automation to keep their competitive advantage. One of the most flexible and powerful automation technologies available today is industrial robotics. The selection of an industrial robot is a significant problem to the design engineer

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and depends on the task to be performed. Equipped with the right tool and operated in optimum path, standardized Industrial robots can perform numerous production tasks. Application of industrial robots are motivated by various technical and economical reasons like increase the quality of finished products, reduce the waste, increase degree of uniformity of quality, increase degree of operating safety etc. The control of a robot is very difficult in varying operational conditions like manufacturing environment. For these industrial applications the best alternative approach would be fuzzy logic. Fuzzy set theory provides a systematic calculus linguistically, and it performs numerical computation by using linguistic labels based on membership functions. Fuzzy logic controller gives better results and can be used where conventional controller is not suitable. It is evident that no detail mathematical description is required for fuzzy logic algorithm. Fuzzy logic algorithms can be best suited for non-accurate, subjective and uncertain source of information. It translates qualitative and imprecise linguistic statements into precise computer statements.

2 Literature Review

A fast path planning method by optimization of a path graph for both efficiency and accuracy is given by Hwang et al. [1]. The authors had proposed a path graph optimization technique employing a compact mesh representation. Gasparetto et al. [2] described a new method for smooth trajectory planning of robot manipulators. Bhalerao et al. [3] proposed an efficient parallel dynamics algorithm for simulation of large articulated robotic systems. The method presented in this paper relies on the Divide-and-Conquer-Algorithm (DCA) and the Articulated Body Algorithm (ABA). Srikanth et al. [4] addresses kinematic analysis of 3 D.O.F of serial robot for industrial applications. The study of motion is divided into kinematics and dynamics. A multi-agent approach based on fuzzy logic for a robot manipulator is given by Kazar et al. [5] proposed the method of modeling and control of a manipulator arm using fuzzy logic that can help the robot to join a well defined goal. The simulation results show the effectiveness of the approach. Abd et al. [6] presented a paper to solve a multi-objective problem in robotic flexible assembly cells. The methodology proposed by the authors is based on three main steps: (1) scheduling of the RFACs using different common rules, (2) normalization of the scheduling outcomes, and (3) selection of the optimal scheduling rules, using a fuzzy inference system. Ahmad et al. [7] presents a paper on investigations into the development of hybrid intelligent control schemes for the trajectory tracking and vibration control of a flexible joint manipulator using composite fuzzy logic control. The results are presented in time and frequency domains. The performances like input tracking capability, level of vibration reduction and time response specifications examined and a comparative assessment of the control techniques is presented and discussed. The simulation results show the effectiveness of the approach. Das and Parhi [8] have developed an methodical study on fuzzy system using some input parameters to the fuzzy membership functions for forecast of crack and relative crack depth.

3 Methods of Solution

3.1 Forward Kinematics Equation for Six Axis Industrial Robot

The Aristo robot has six DOF with all rotary type joints. The first three DOF are located in the arm which allows determining the robot position and the following three DOF are located in the end effectors to provide orientation. The present work deals with forward kinematics analysis of the robot where the position and orientation of the end effector are derived from the given joint angles and link parameters. The homogeneous transformation matrix for the 6R robot is as follows:

$$T = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

where

$p_x \quad C_1\left[d_6(C_{23}C_4S_5 + S_{23}C_5) + S_{23}d_4 + a_3C_{23} + a_2C_2\right] - S_1(d_6S_4S_5 + d_2)$

$p_y \quad S_1\left[d_6(C_{23}C_4S_5 + S_{23}C_5) + C_{23}d_4 + a_3C_{23} + a_2C_2\right] - C_1(d_6S_4S_5 + d_2)$

$p_z \quad d_6\left(C_{23}C_5 - S_{23}C_4S_5\right) + C_{23}d_4 - a_3S_{23} - a_2S_2)$

where $C_i = \cos\theta_i, S_i = \sin\theta_i$ and $C_{iJ} = \cos(\theta_i + \theta_J), S_{iJ} = \sin(\theta_i + \theta_J)\theta_i$ = Joint angle, d_i = Link Length

The input variables are six joint angles (A1–A6) within the given specified limits and outputs are the position of the end-effector (world coordinates X, Y and Z). The software used for the simulation of the robot is Aristo Version 1.4 presented in Fig. 1. Fifty seven numbers of input variables in terms of joint angles are taken experimentally and the output in terms of locations “X, Y and Z” are also obtained experimentally using forward Kinematics.

3.2 Fuzzy Logic System

Fuzzy logic is an extension of classical logic and uses fuzzy sets instead of classical sets. Fuzzy logic is a logic approximate reasoning which may be viewed as a simplification and addition of multi valued logic. Like classical set theory is used to develop classical logic, similarly fuzzy set theory is required to create fuzzy logic. Figure 2 outlines a simple architecture for a fuzzy logic controller.

The fuzzy controller has been developed where there are 6 inputs and 3 outputs parameter. The natural linguistic representation for the inputs is as follows

Industrial robot input capacity = “Input angle is θ_1 is A1”, “Input angle is θ_2 is A2”, “Input angle is θ_3 is A3”, “Input angle is θ_4 is A4”, “Input angle is θ_5 is A5” and “Input angle is θ_6 is A6”,

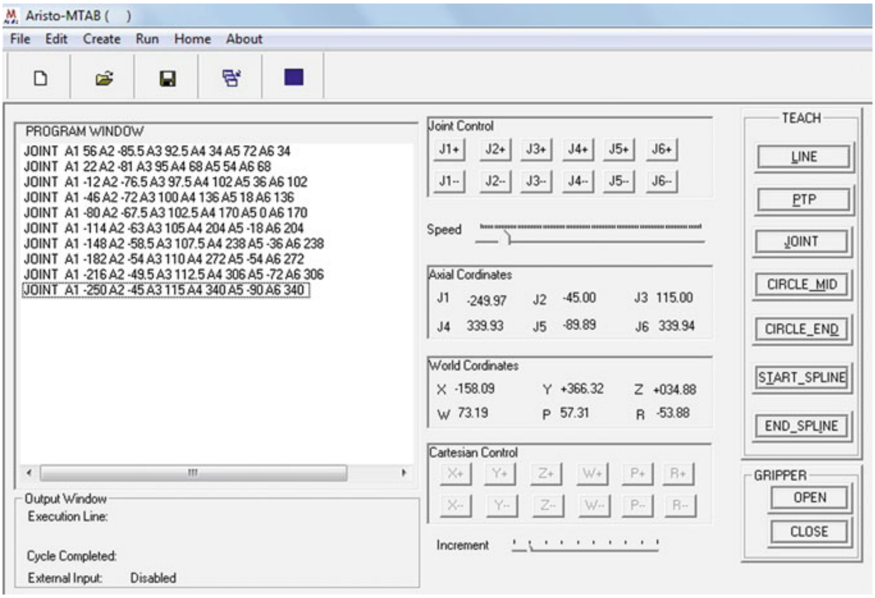


Fig. 1 Coordinates of robots using aristo simulation

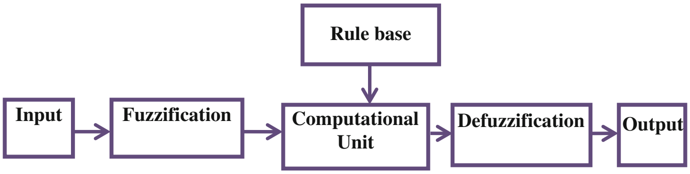


Fig. 2 Fuzzy controller architecture

Industrial robot output capacity = "Output Location is X is O1", "Output Location is Y is O2" and "Output Location is Z is O3",

The natural linguistic term used for the output is

Industrial robot Location = "OutputX= O1" and "OutputY= O2" and "OutputZ= O3" Based on the above fuzzy subset the fuzzy rules are defined in a general form as follows:

If A1 is $(A1)_i$ and A2 is $(A2)_j$ and A3 is $(A3)_k$ and A4 is $(A4)_l$ and A5 is $(A5)_m$ and A6 is $(A6)_n$ then O1 is $(O1)_{ijklmn}$ and O2 is $(O2)_{ijklmn}$ and O3 is $(O3)_{ijklmn}$

where i = 1 to 9; Because of "Input angles A1 to A6" are having nine membership functions. From the above expression, one set of rules are written as:

If A1 is (A1)i then Output (O1) is (O1)i. The Linguistic Terms Used for Fuzzy Membership Functions for angle A1 is given in Table 1. Similarly for other angles the linguistic terms are used accordingly.

The capacity of Robots is expressed in terms of four membership functions like triangular, trapezoidal, Gaussian and Hybrid as input to the fuzzy controller.

Table 1 Linguistic terms used for fuzzy membership functions

Membership functions	Terms	Linguistic term descriptions
A1VL	$A1_1$	Very low value of angle for input angle "A1"
A1L	$A1_2$	Low value of angle for input angle "A1"
A1M	$A1_3$	Medium value of angle for input angle "A1"
A1G	$A1_4$	Good value of angle for input angle "A1"
A1VG	$A1_5$	Very Good value of angle for input angle "A1"
A1VVG	$A1_6$	Very very good value of angle for input angle "A1"
A1H	$A1_7$	High value of angle for input angle "A1"
A1VH	$A1_8$	Very high value of angle for input angle "A1"
A1VVH	$A1_9$	Very very high value of angle for input angle "A1"

The triangular membership function is collection of three points forming a triangle. These membership functions are simple and fast when compared to other membership functions. Gaussian membership functions are popular methods for specifying fuzzy sets and have the advantage of being smooth. The trapezoidal membership function has a flat top and the advantage of simplicity. Hybrid membership function is combination of triangular, Trapezoidal as well as Gaussian membership function. The outputs obtained from fuzzy controllers are analyzed and compared to obtain the best effective technique for Robot selection. There are fifty seven fuzzy rules developed to acquire the outputs and some of the fuzzy rules are given in Table 2. The output of hybrid membership functions consists of four triangles, three Gaussians and two trapezoidal functions. It is a combination of all the membership functions.

Table 2 Fuzzy rules used for fuzzy inference system

Sl. no.	Some of rules used in fuzzy controller
1	If (ANGLE1 is AIVL) and (ANGLE2 is A2VL) and (ANGLE3 is A3VL) and (ANGLE4 is A4VL) and (ANGLE5 is A5VL) and (ANGLE6 is A6VL) then (OUTPUTX is O1VG)(OUTPUTY is O2VVH)(OUTPUTZ is O3VVH) (1)
2	If (ANGLE1 is AIVL) and (ANGLE2 is A2VL) and (ANGLE3 is A3VL) and (ANGLE4 is A4VL) and (ANGLE5 is A5VL) and (ANGLE6 is A6VL) then (OUTPUTX is O1H)(OUTPUTY is O2VVH)(OUTPUTZ is O3VH) (1)
3	If (ANGLE1 is AIL) and (ANGLE2 is A2L) and (ANGLE3 is A3L) and (ANGLE4 is A4L) and (ANGLE5 is A5L) and (ANGLE6 is A6L) then (OUTPUTX is O1VVH) (OUTPUTY is O2VH)(OUTPUTZ is O3VH) (1)
4	If (ANGLE1 is AIM) and (ANGLE2 is A2 M) and (ANGLE3 is A3 M) and (ANGLE4 is A4 M) and (ANGLE5 is A5 M) and (ANGLE6 is A6 M) then (OUTPUTX is O1VVH)(OUTPUTY is O2G)(OUTPUTZ is O3H) (1)
5	If (ANGLE1 is AIG) and (ANGLE2 is A2G) and (ANGLE3 is A3G) and (ANGLE4 is A4G) and (ANGLE5 is A5G) and (ANGLE6 is A6G) then (OUTPUTX is O1VH) (OUTPUTY is O2L)(OUTPUTZ is O3VVG) (1)

4 Results and Discussions

With the help of experimental setup fifty seven nos. of results are taken as given in Table 3 and in Fig. 1 and also fifty seven nos. of Fuzzy rules are developed. The different closeness values are calculated from the different fuzzy membership functions presented in Table 2. The six input variables and three outputs with Hybrid Membership Function are given in Table 4 and also in Fig. 3. The fuzzy controllers developed here for prediction of closeness with the experimental value. The predicted result from fuzzy controllers for closeness of Robots is compared with the experimental results and shows a very good agreement. It has been observed that the result of Fuzzy controller using Hybrid membership function shows more accurate result in comparison to other three controllers. So from this it can be presumed that the developed fuzzy controller along with the technique can be used as a robust tool for selection of Robots. Figure 4 shows the graphical representation of Input variables ("A1–A6") and Output (Location "O1–O3") with Hybrid Membership Function for Capacity of the Robot. All the results of four membership functions are developed and output values X, Y and Z of these membership functions are compared and presented in Figs. 5, 6 and 7 respectively.

Table 3 Experimental results taken from six axis industrial robot

	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	X	Y	Z
1	81.50	−88.88	90.63	8.50	85.50	8.50	83.70	298.10	350.00
2	64.50	−86.63	91.88	25.50	76.50	25.50	98.20	301.40	369.30
3	56.00	−85.50	92.50	34.00	72.00	34.00	97.65	300.12	357.98
4	47.50	−84.38	93.13	42.50	67.50	42.50	159.50	311.04	350.08
5	39.00	−83.25	93.75	51.00	63.00	51.00	210.70	280.90	340.60
6	30.50	−82.13	94.38	59.50	58.50	59.50	383.05	241.60	340.40
7	13.50	−79.88	95.63	76.50	49.50	76.50	389.10	152.60	328.70
8	5.00	−78.75	96.25	85.00	45.00	85.00	390.50	101.05	321.70
9	−54.50	−70.88	100.63	144.50	13.50	144.50	290.40	−351.23	233.39
10	−63.00	−69.75	101.25	153.00	9.00	153.00	224.89	−430.14	216.37
11	−71.50	−68.63	101.88	161.50	4.50	161.50	155.10	−456.45	198.95
12	−80.00	−67.50	102.50	170.00	0.00	170.00	130.00	−360.00	190.00

Table 4 Results from hybrid method

	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	X			Y			Z		
							EXP	HYB	% ERR	EXP	HYB	% ERR	EXP	HYB	% ERR
1	81.50	−88.88	90.63	8.50	85.50	8.50	83.70	83.30	0.48	298.10	295.00	1.04	350.00	340.00	2.86
2	64.50	−86.63	91.88	25.50	76.50	25.50	98.20	91.40	6.92	301.40	295.00	2.12	369.30	340.00	7.93
3	56.00	−85.50	92.50	34.00	72.00	34.00	97.65	96.90	0.77	300.12	295.00	1.71	357.98	340.00	5.02
4	47.50	−84.38	93.13	42.50	67.50	42.50	159.50	154.00	3.45	311.04	290.00	6.76	350.08	340.00	2.88
5	39.00	−83.25	93.75	51.00	63.00	51.00	210.70	202.00	4.13	280.90	252.00	10.29	340.60	340.00	0.18
6	30.50	−82.13	94.38	59.50	58.50	59.50	383.05	355.00	7.32	241.60	234.00	3.15	340.40	332.00	2.47
7	13.50	−79.88	95.63	76.50	49.50	76.50	389.10	383.00	1.57	152.60	141.00	7.60	328.70	340.00	−3.44
8	5.00	−78.75	96.25	85.00	45.00	85.00	390.50	383.00	1.92	101.05	110.00	−8.86	321.70	297.00	7.68
9	−54.50	−70.88	100.63	144.50	13.50	144.50	290.40	276.00	4.96	−351.23	−310.00	11.74	233.39	240.00	−2.83
10	−63.00	−69.75	101.25	153.00	9.00	153.00	224.89	219.00	2.62	−430.14	−404.00	6.08	216.37	214.00	1.10
11	−71.50	−68.63	101.88	161.50	4.50	161.50	155.10	144.00	7.16	−456.45	−449.00	1.63	198.95	188.00	5.50
12	−80.00	−67.50	102.50	170.00	0.00	170.00	130.00	116.00	10.77	−360.00	−386.00	−7.22	190.00	178.00	6.32

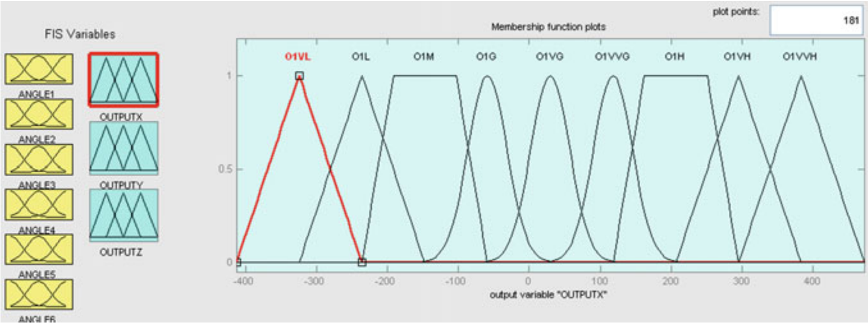


Fig. 3 Output (location "O1") with hybrid membership function for capacity of the robot

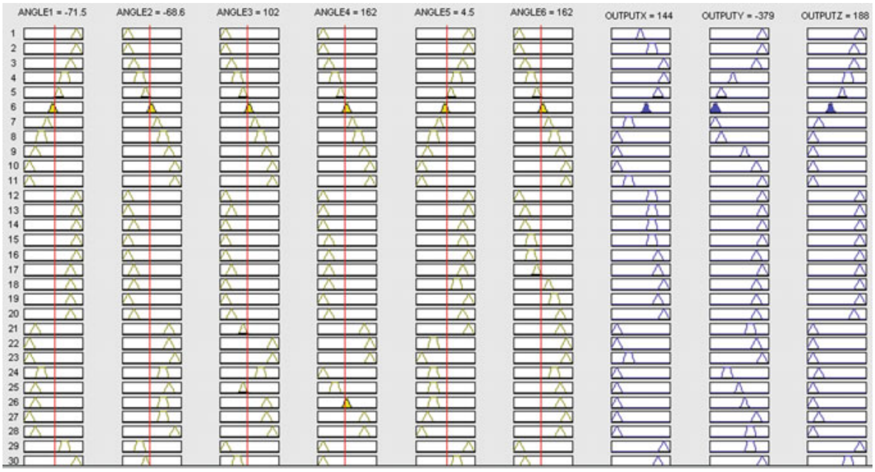
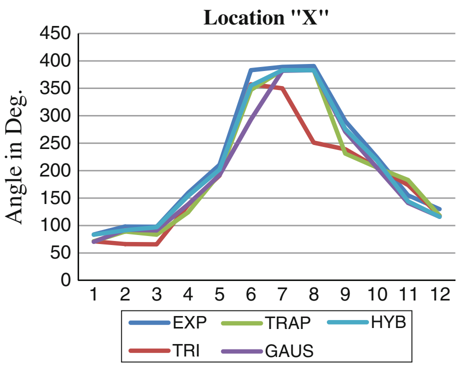


Fig. 4 Graphical representation of Input variables ("A1–A6") and output (location "O1–O3") with hybrid membership function for capacity of the robot

Fig. 5 Comparison of output value (location "X") of all four membership function with experimental value



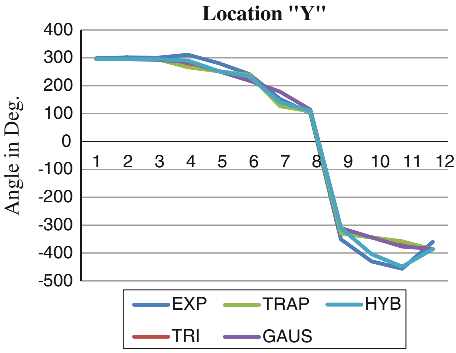


Fig. 6 Comparison of output value (location "Y") of all four membership function with experimental value

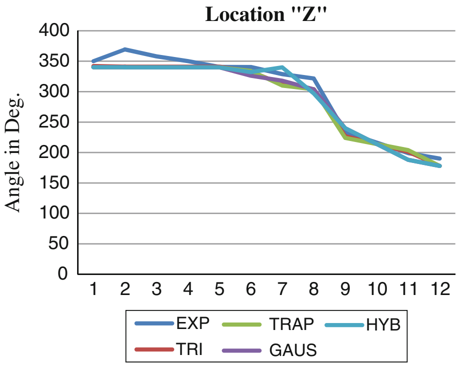


Fig. 7 Comparison of output value (Location "Z") of all four membership function with experimental value)

5 Conclusion

The results obtained from all four membership function viz. triangular, Gaussian, trapezoidal and hybrid of the fuzzy logic controller (FLC) are validated with experimental results of six axis industrial robot. From the above results it is concluded that the result obtained from hybrid membership function is very close to the experimental results. So within a specified capacity of the robot it is easy to predict the required position of the end-effector by using Fuzzy logic method. For future works the authors suggest that the technique can be applied for more DOF using Fuzzy logic and other soft computing techniques like GA, ACO etc.

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