International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:3, No:12, 2009

Fuzzy-Genetic Optimal Control for Four Degree of Freedom Robotic Arm Movement

V. K. Banga, R. Kumar and Y. Singh

Abstract**—**In this paper, we present optimal control for movement and trajectory planning for four degrees-of-freedom robot using Fuzzy Logic (FL) and Genetic Algorithms (GAs). We have evaluated using Fuzzy Logic (FL) and Genetic Algorithms (GAs) for four degree-of-freedom (4 DOF) robotics arm, Uncertainties like; Movement, Friction and Settling Time in robotic arm movement have been compensated using Fuzzy logic and Genetic Algorithms. The development of a fuzzy genetic optimization algorithm is presented and discussed. The result are compared only GA and Fuzzy GA. This paper describes genetic algorithms, which is designed to optimize robot movement and trajectory. Though the model represents is a general model for redundant structures and could represent any n-link structures. The result is a complete trajectory planning with Fuzzy logic and Genetic algorithms demonstrating the flexibility of this technique of artificial intelligence.

Keywords**—**Inverse kinematics, Genetic algorithms (GAs), Fuzzy logic (FL), Trajectory planning.

I. INTRODUCTION

AUTONOMOUS navigating robots have become increasingly important. Motion planning is one of the important tasks in intelligent control of an autonomous mobile Robot. Optimal movement is critical for efficient autonomous mobile robot. Many proposed approaches either used fuzzy logic or genetic algorithms [6,8,12,13]. Path conditions can be modeled using fuzzy linguistic variables so as to allow for imprecision and uncertainties of path data. Many new A basic and general framework for Robot control has been developed [4]. The obstacles have always been a source of malfunctioning of the Robot and Robotic arm. Various efforts have been made to develop efficient arm movement trajectories for eluding obstacles. Probability goes along with the real time process and their control for better performance. Olson C.F. et al. [3] have developed model and techniques for probabilistic self localization for mobile Robot. Davendra P. Garg et. al.[5] successfully implemented torque minimization for path optimization of multiple manipulators.

Fuzzy logic system is introduced to approximate the unknown robotic dynamics by using adaptive algorithm. Edward T. Lee [1] has implemented fuzzy logic to robot navigation. H. F. Ho et al. [11] have developed a stable adaptive fuzzy-based tracking control for robot systems with parameter uncertainties and external disturbance.

Genetic algorithms are often viewed as function optimizers, although the range of problems to which genetic algorithms have been applied is quite broad. A Genetic algorithm based path-planning software for mobile robot systems focusing on energy consumption. This algorithm is executed within two different phases of the optimization process [2, 7]. In the execution phase of the GA itself, the results of the preparation phase are used to find optimum paths. Industrial robots should perform complex tasks in the minimum possible cycle time in order to obtain high productivity. The problem of determining the optimum route of a manipulator's end effector using genetic algorithms have successfully implemented by Zacharia P. Th. et. al. [10].

Galantucci L. M. et al. [9] implemented the hybrid fuzzy logic-genetic algorithms (FL-GA) methodology to plan the automatic assembly and disassembly sequence of products.

The hybridization model consists of the fuzzy controller for the parameters of single link manipulator [14] and also for simultaneous localization and mapping of mobile robots[15].

In this paper, genetic optimization is employed to find optimum joint angles for four degree-of–freedom robotic systems. The cost function in genetic algorithm as implemented in this case is augmented by three attributes viz. joint movement, fiction and least settling time. At any time the values of these three attributes is found with the help of fuzzy logic. In a given case of cost function the weitages for these three attributes are determined through fuzzy reasoning. Fuzzy logic models have been developed for the above said three attributes as its input and the weitages as required for these three attributes in the cost function as three outputs.

II. ROBOTIC SYSTEMS

Robotic systems are characterized by their degree-of freedom (DOF). A very simple robotic system may have two degree-of-freedom, whereas a complex a robotic system have more degree-of-freedom. Robotic arm movement is effected by joint movement, friction and settling time.

V. K. Banga is with Department of Electronics & Communication Engineering, Amritsar College of Engineering & Technology, Amritsar, Punjab(INDIA). Ph. +919417800072, Email ID: vijaykumar.banga @gmail.com.

R. Kumar is with School of Mathematics & Computer Applications, Thapar University, Patiala, Punjab (INDIA). Email ID: rajnagdev@yahoo.co.in

Y. Singh is with Department of Electrical & Instrumentation Engineering, Thapar University, Patiala, Punjab (INDIA).Email ID: yad_pra@yahoo.com.

The robotic arm movement depends upon the angular movement of the joint. Joint movement determines the power required. The joint movement must be adjusted to stay within the power available on the robotic system to be used.

Friction must also be considered in relation to robotic arm movement. The actual angular arm movement is defined as theoretical angular movement, which is provided by the controller minus the movement lost due to friction.

Settling time is the most important factor in the case of any real time system. It refers to the transient response, which contains dam pings (vibrations) for a given change in the input (step function). High-speed robots must have least settling time thus exhibiting minimum physical vibrations in the movement of robotic arm.

III. MATHEMATICAL MODEL OF FOUR DEGREE-OF-FREEDOM (4 DOF) ROBOTIC SYSTEM

In Four degree of freedom of the robotic arm the inverse kinematics equations are as below with figure 1 as four degree-of-manipulator**.**

$$x=\cos\theta\,(L\cos\phi + L_4\cos\psi) \tag{1}$$

$$y = \sin\theta\,(L\cos\phi + L_4\cos\psi) \tag{2}$$

$$z = L_1 + L\sin\phi + L_4\sin\psi \tag{3}$$

where ψ: Pitch angle

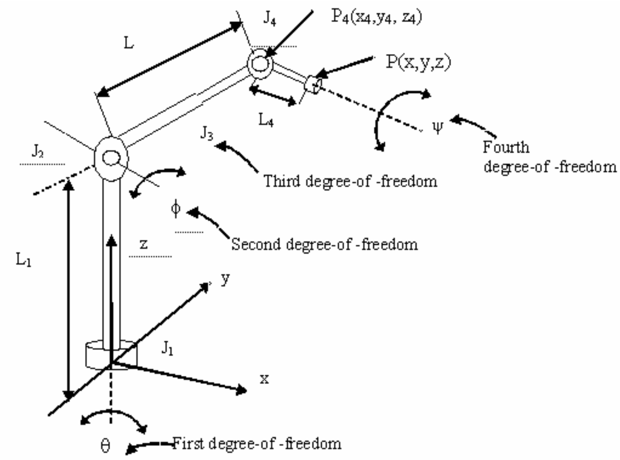

Fig. 1. Four degree-of –freedom manipulator

Let the position of fourth joint "P4" be (x_4, y_4, z_4). Also

$$x_4 = x - \cos\theta\,(L_4\cos\psi) \tag{4}$$

$$y_4 = y - \sin\theta\,(L_4\cos\psi) \tag{5}$$

$$z_4 = z - L_4\sin\psi \tag{6}$$

The manipulator has four degree-of -freedom: joint 1 (J_1) allows rotation about the z-axis; joint 2 (J_2) allows rotation about an axis that is perpendicular to the z-axis; joint 3 (J_3) is a linear joint which is capable of sliding over a certain angle; and joint 4 (J_4) which allows rotation about an axis that is parallel to the joint 2 (J_2) axis. Rotation along joint 1 (J_1) to the base rotation θ; the angle of rotation of joint 2 (J_2), elevation angle ϕ; the length of linear joint 3 (J_3), extension L (L represents a combination of link 2 and 3); and the angle that joint 4 (J_4) makes with x-y plane, pitch angle ψ. Knowing the arm link lengths L_1, L and L_4 for position (x, y, z) we had calculated the values of joint angles θ, ϕ and ψ.

IV. PROBLEM FORMULATION

In robot manipulator any mathematical modeling inaccuracy will hamper the mathematical optimization process. Also, as the configuration is changed, the optimization needs to be redefined. Here in this work, genetic algorithms are proposed to search the optimal angular displacement of robot arms as shown in flowchart figure 2.

The Genetic Algorithm for generating the population of chromosomes having optimized values.

[Start] Generate random population of *n* chromosomes (suitable solutions for the problem).

[Fitness] Evaluate the fitness *f(x)* of each chromosome *x* in the population.

[New population] Create a new population by repeating following steps until the new population is complete.

a. Selection. Select two parent chromosomes from a population according to their fitness (the better fitness, the bigger chance to be selected).

b. Crossover. With a crossover probability, cross over the parents to form new offspring (children). If no crossover was performed, offspring is the exact copy of parents.

c. Mutation. With a mutation probability, mutate new offspring at each locus (position in chromosome).

d. Accepting. Place new offspringin the new population.

[Replace] Use new generated population for a further run of the algorithm.

[Test] If the end condition is satisfied, stop, and return the best solution in current population.

[Loop] Go to [Fitness].

Solutions obtained from inverse kinematics are fed to the Genetic Algorithm for generating the population of chromosomes to be optimized.

In our case Fitness of each chromosome depends upon many factors. We will consider three mains factors on which the fitness function will be calculated by applying fuzzy Logic. These three main factors are:

- Joint Movement (A1)
- Friction (A2)
- Least Settling Time (Min. Vibration) (A3)

First we will decide the importance and value of these three attributes for the each angle separately.

The corresponding cost function (fc) is given below by equation (7).

$$fc = A1 \times \lambda 1 + A2 \times \lambda 2 + A3 \times \lambda 3 \tag{7}$$

Attributes joint movement (A1), friction (A2) and settling time (A3) are inputs and weights $\lambda 1$, $\lambda 2$ and $\lambda 3$ are outputs of fuzzy models. Table 1 and 2 show the inputs fuzzy expressions and output fuzzy expressions, respectively. The ranges of fuzzy input membership functions and output membership functions are from 0 to 1 (per unit basis).

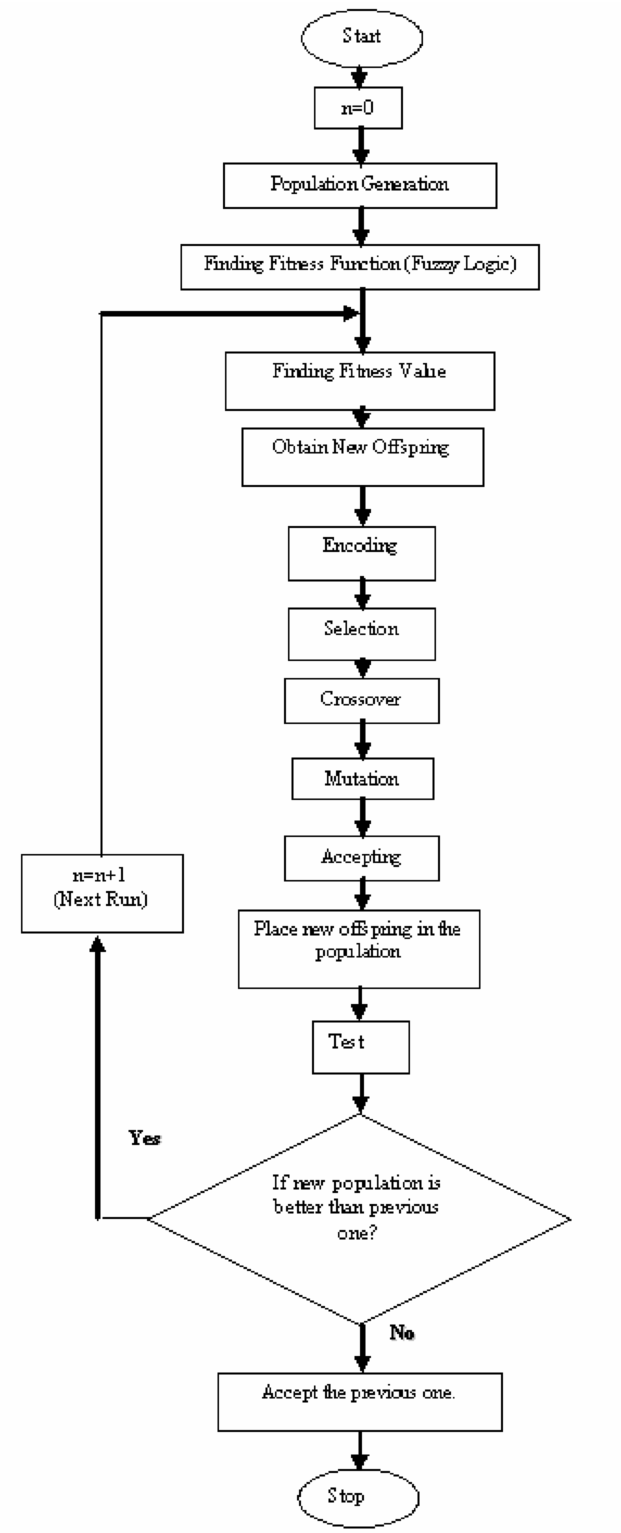

Fig. 2. Flowchart Using Genetic Algorithm

TABLE I INPUT FUZZY EXPRESSIONS

1st input (joint movement)		2nd input (friction)		3rd input (settling time)		Index representation for all three inputs
S	Small	S	Small	S	Small	0.3
M	Medium	M	Medium	M	Medium	0.7
L	Large	L	Large	L	Large	1.0

TABLE II OUTPUT FUZZY EXPRESSIONS

1st Output ($\lambda1$)		2nd Output ($\lambda2$)		3rd Output ($\lambda3$)		Index representation
VS	Very small	VS	Very small	VS	Very small	0.20
S	Small	S	Small	S	Small	0.40
M	Medium	M	Medium	M	Medium	0.60
L	Large	L	Large	L	Large	0.80
VL	Very large	VL	Very large	VL	Very large	1.00

V. SIMULATION AND TESTING

Four degree-of-freedom (4 DOF)

Maximum reach of the robot arm	: 915 mm
Length of first link (l1)	: 305 mm
Length of second link (L)	: 434 mm
Length of third link (l4)	: 51 mm
Origin or reference Point (O) coordinates	: (0, 0, 0)
Destination Point (P) coordinates	: (x, y, z)

x: 406 mm
y: 127 mm
z: 533 mm

The system has been considered for developing the software code using GA (whose flowchart is shown in fig 4),. Solving these equations we get the following values for the angles of the links:

θ =17.37°
ϕ =30.09°, 26.26°
ψ =84.69°, 5.26°

By applying the inverse kinematics initially and then from successive runs performed during the design and development for the optimization

From the above simulation, we obtained optimized result for various joints:
θ =17.36°
ϕ =20.06°, 36.29°
ψ =84.69°, 5.26°

VI. RESULTS AND DISCUSSIONS

An optimization method based on the genetic algorithms and fuzzy logic is proposed. In the developed genetic algorithms, in order to obtain the optimal angular displacements for the robotic arms in the whole workspace, elitism has been retained from the previous generation to the next. Figure. 3 illustrates percentage fitness versus generation graph for 4 DOF systems.

Figure 4 shows the convergence of best of each generation for robotic system. It can be seen that there is rapid convergence within 20 generations to an almost perfect solutions. Where as in the case of only GA there is rapid convergence within 40 generations. The performance is optimal is over all possible input values as the evolution function exhaustively test the possible input spaces.

It is concluded that GA and FL is practical and effective method for achieving optimization of robotic arm angular displacements.

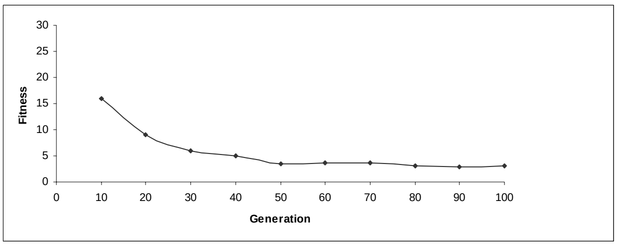

Fig. 3. Fitness versus generations graph

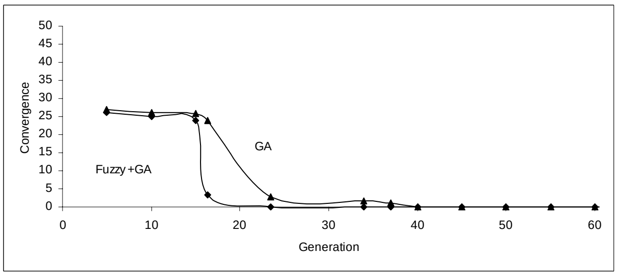

Fig. 4. Convergence versus generation graph

The method proposed in this paper is robust, optimal for robotic arm movement and adaptation to be dynamic conditions in the environment.

REFERENCES

[1] Edward T. Lee, “Applying fuzzy logic to robot navigation”, Journal of Kybernetes, 24(6), 38–43(1995).

[2] Monteiro D. C., Madrid M. K., “Planning of robot trajectories with genetic algorithms”, IEEE Proceedings of the first workshop on Robot Motion and Control, RoMoCo '99, Kiekrz, Poland, 223–228 (1999).

[3] Olson C. F., J. P. Lab., Technol. CIo, Pasadena “Probabilistic self-localization for mobile robots”, IEEE Transactions on Robotics and Automation, Vol.16, No.1, 55-66(2000).

[4] Gillespie R. B., Colgate J. E., Peshkin M. A. “A general framework for robot control”, IEEE Transactions on Robotics and Automation, Vol.17, No.4, 391-401(2001).

[5] Devendra P. Garg and Manish kumar, “Optimization Techniques applied to multiple manipulators for path planning and torque minimization”, Engineering Applications of Artificial Intelligence, Vol. 15, No. 3-4, 241-252 (2002).

[6] Nasser Sadati, Javid Taheri, “Genetic algorithm in robot path planning problem in crisp and fuzzified environments”, IEEE ICiT’02, Bangkok, Thailand, 175-180 (2002).

[7] Gemeinder M. and Gerke M., “GA-based Path Planning for Mobile Robot Systems employing an active Search Algorithm”, Journal of Applied Soft Computing, Vol. 3, No. 2, 149-158 (2003).

[8] Rosales E. M., Gan J. Q., Huosheng Hu, Oyama E., “A hybrid appproach to inverse kinematics modelling and control of pioneer 2 robotic arms”, Technical report CSM-413, University of Essex (2003).

[9] Galantucci L. M., Percoco G., Spina R., “Assembly and disassembly planning by using fuzzy logic & genetic algorithms”, International Journal of Advanced Robotic Systems, 1(2), 67–74 (2004).

[10] Zacharia P. Th. and Aspragathos N. A., “Optimal Robot task scheduling based on Genetic Algorithms”, Elsevier Robotics and Computer-Integrated Manufacturing, Vol. 21, 67–79 (2005).

[11] Ho H. F. at. el. , “Robust fuzzy tracking control for robotic manipulators” , Simulation Modelling Practice and Theory , Vol. 15, Issue 7, 801-816 (2007).

[12] Nguyen . V. B. and Morris A. S., “Genetic Algorithm Tuned Fuzzy Logic Controller for a Robot Arm with Two-link Flexibility and Two-joint Elasticity”, Springer J Intell Robot Syst, Vol. 49, 3–18(2007).

[13] M. Mucientes et.el. , “Design of a fuzzy controller in mobile robotics using genetic algorithms”, Elsevier Applied Soft Computing, Vol. 7, No. 2, 540-546 (2007).

[14] Alam M. S., Tokhi M. O., “Hybrid fuzzy logic control with genetic optimisation for a single-link flexible manipulator” Elsevier Engineering Applications of Artificial Intelligence, 21(6), 858-873 (2008).

[15] Momotaz Begum, George K. I. Mann, Raymond G. Gosai, “Integrated fuzzy logic and genetic algorithmic approach for simultaneous localization and mapping of mobile robots”, Elsevier Applied Soft Computing 8(1), 50–165 (2008).

Vijay Kumar Banga is working as Professor in the Department of Electronics and Communication Engineering, Amritsar College of Engineering and Technology, Amritsar, India. He obtained his B. E (Electronics & Instrumentation Engineering) from Punjabi University, Patiala, Punjab, India, M.Tech (Electronics and Instrumentation) from Panjab University, Chandigarh, India and pursuing Ph.D. in Electronics and Instrumentation form Thapar University, Patiala, India. Presently, he has 10 years of research and UG & PG teaching experience. He has 25 research papers to his credit in various international journals and conferences. His areas of research and interest include Robotics, Fuzzy logic and Genetic algorithms.

Dr. Rajesh Kumar is presently Associate Professor in the School of Mathematics and Computer Applications and Head Computer Centre at Thapar University, Patiala, Punjab, India. He obtained his M.Sc. (Applied Mathematics), M.Phil. (Computer Applications), and Ph. D. from University of Roorkee (Now IIT Roorkee), Roorkee, UP, India. In all, he has 18 years of research experience and is guided 03 Ph.D. students. He has more than 70 research papers to his credit in various international/national journals and conferences. He is also been teaching faculty at Panjabi University, Patiala, Punjab, India. His areas of research include pattern recognition, fracture mechanics, modeling of engineering systems and their simulations.

Dr. Yaduvir Singh is currently Associate Professor in the Department of Electrical & Instrumentation Engineering, Thapar University, Patiala, Punjab, India. He obtained his B.Tech.(Electrical Engineering) from D.E.I. Agra, UP, India, M.E. (Control & Instrumentation Engineering) from M.N.R.E.C., Allahabad, U.P., INDIA, M.B.A (Marketing Management) from New Port University U.S.A. and Ph. D. (Electrical Engineering) from TIET Patiala, Punjab, India. Presently, he has 15 years of research and UG & PG teaching experience. He has more than 125 research papers to his credit in various international/national journals and conferences. He has also been regular teaching faculty at NERIST Itanagar, GBPEC Puri Garhwal and HBTI Kanpur and is a member of various professional bodies/ societies of repute. His areas of research and interest include power electronics, automated control systems, artificial intelligence, fuzzy logic and artificial neural network system.