Modeling and Simulation of Robotic Arm Movement using Soft Computing

V. K. Banga, Jasjit Kaur, R. Kumar, Y. Singh

Abstract—In this research paper we have presented control architecture for robotic arm movement and trajectory planning using Fuzzy Logic (FL) and Genetic Algorithms (GAs). This architecture is used to compensate the uncertainties like; movement, friction and settling time in robotic arm movement. The genetic algorithms and fuzzy logic is used to meet the objective of optimal control movement of robotic arm. This proposed technique represents a general model for redundant structures and may extend to other structures. Results show optimal angular movement of joints as result of evolutionary process. This technique has edge over the other techniques as minimum mathematics complexity used.

Keywords—Kinematics, Genetic algorithms (GAs), Fuzzy logic (FL), Optimal control.

I. INTRODUCTION

IN the recent years automation has become an extremely fast growing phenomenon whose impact have been observed in all engineering applications. Robotics have been playing vital role in automation. Motion planning is one of the important tasks in intelligent control of autonomous robots. Optimal movement is critical for efficient autonomous robots. Many researchers have proposed approaches using fuzzy logic or genetic algorithms or neural networks for robotic systems. Many new methods have been proposed that are appropriate for dynamic environment or provide response in real-time.

The obstacles have always been a source of malfunctioning of the robot and robotic arms. 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. [1] have developed model and techniques for probabilistic self-localization for mobile robot. A basic and general framework for robot control has been developed [2].

In the path planning problem, without obstacles for closed kinematics chains with n links connected by spherical joints in space or revolute joints in the plane. The configuration space of such systems is a real algebraic variety whose structure is fully determined using techniques from algebraic geometry and differential topology [3, 4].

Uncertainties in robotic arm movement have been compensated using GAs, the nature of these parameters is not to be deterministic in nature. Optimal control is concerned

with control policies that can be deduced using optimization algorithms. It deals with the problem of finding a control law for a given system such that a certain optimality criterion is achieved. A GAs based path-planning software for mobile robot systems focusing on energy consumption. This algorithm is executed within two different phases of the optimization process. For each obstacle within the environment regarded a path circumventing it is computed in a preparation phase. In the execution phase of the GA, the results of the preparation phase are used to find optimum paths. Genetic algorithms are often viewed as function optimizers, although the range of problems to which genetic algorithms have been applied is quite broad [5, 7].

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 reaching a number of task points is similar [6]. The difficulty in a robotic system is that the desired features, i.e. the speed, energy efficiency and accuracy are often contradictory. Machine learning techniques, such as evolutionary algorithms or artificial neural networks for the learning of fuzzy controllers to incorporate behaviors in mobile robots are widely used [8]. Many recent contributions on robotic arms to solve path tracking and vibration damping problems are reported. To improve the system performance by applying GAs to tune the membership function parameters of a FL controller for the robotic manipulator.

In order to solve the simultaneous localization and mapping (SLAM) problem of mobile robots, using fuzzy logic (FL) and genetic algorithms (GAs). The core of the proposed SLAM algorithm is based on an island model GA (IGA) that searches for the most probable map(s), which provide robot with the best localization information. Prior knowledge about the problem domain is transferred to GA in order to speed up the convergence. Fuzzy logic is employed to serve this purpose and allows the IGA to conduct the search starting from a potential region of the pose space [9].

Fuzzy logic and genetic algorithms have been successfully implemented on mobile robots navigation. In the genetic algorithms, selection of the fitness function parameters are task specified and the results dependent on fitness function [10]. Fuzzy logic was also implemented on robot manipulator actuated by pneumatic artificial muscles to address the position and velocity control problem.

In this paper, genetic optimization is employed to find optimum joint angles for four degree-of-freedom robotic systems. The genetic optimization replaces the tedious process

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of trial and error for a better combination of joint angles, which is valid as per inverse kinematics for robotic arm movement. 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 (laboratory scale), whereas a complex a robotic system may have more than two degree-of-freedom (DOF) (in industry scale). Robotic arm movement is effected by parameters like joint movement, friction and settling time etc.

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 damping's (vibrations) for a given change in the input (step function). High-speed robots must have least settling time thus exhibiting minimum vibrations in the movement of robotic arm.

A. Mathematical model of four degree-of-freedom (4 DOF) robotic system

To calculate movements in dynamic systems made up of several parts, the main approach is to calculate possible movements with the aid of mathematical models. At the same time it is necessary to understand both the mechanics and the physical aspects.

In Four degree-of-freedom of the robotic arm the inverse kinematics equations are as below (Figure 1):

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.
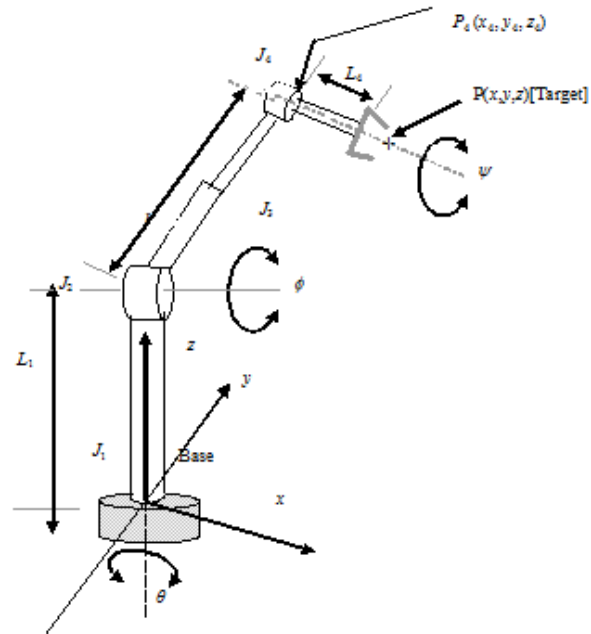

Fig. 1 Four Degree-of-freedom manipulator

B. Forward kinematics

In forward kinematics, the arm manipulator tries to achieve the target. Let it be given as P(x, y, z). The end-effector coordinates x, y and z are expressed in terms of the input joint angles θ, ϕ and ψ and link lengths L_1, L and L_4 as

$$x = \cos\theta(L\cos\phi + L_4\cos\psi) \quad (1)$$
$$y = \sin\theta(L\cos\phi + L_4\cos\psi) \quad (2)$$
$$\text{and} \quad z = L_1 + L\sin\phi + L_4\sin\psi) \quad (3)$$

where $P_4(x_4, y_4, z_4)$, coordinates of joint J_4 are

$$x_4 = L_4(\cos\psi\cos\theta) \quad (4)$$
$$y_4 = L_4(\cos\psi\sin\theta) \quad (5)$$
$$\text{and} \quad z_4 = L_4\sin\psi \quad (6)$$

C. Inverse Kinematics

For the four link manipulator, there are multiple possible configurations for reaching the target position defined as P(x, y, z). It results in multiple solutions for joint angles.

Using inverse kinematics, the values of θ, ϕ and ψ are obtained.

By shifting the frame of reference to the joint J_2. The axis of new frame becomes parallel to respective axis of other frame as such, we have

$$x = x_1 \quad (7)$$
$$y = y_1 \quad (8)$$

$$\text{and} \quad z = z_1 + L_1 \quad (9)$$

Where (x_1, y_1, z_1) are associated with next frame attached to joint J_2.

Length of link 'L', with joint J_4 are spherically polar with respect to frame attached to J_2. Hence $(x, y\ z)$ are coordinates of the frame attached with the joint J_2, thus we have

$$x_1 = L \cos \phi \cos \theta \quad (10)$$
$$y_1 = L \cos \phi \sin \theta \quad (11)$$
$$\text{and} \quad z_1 = L \sin \phi \quad (12)$$

Shifting the frame of reference from J_2 to J_4, we get

$$x_1 = x_4 + L \cos \phi \cos \theta \quad (13)$$
$$y_1 = y_4 + L \cos \phi \sin \theta \quad (14)$$
$$\text{and} \quad z_1 = z_4 + L \sin \phi \quad (15)$$

Hence, the coordinates of Joint J_4 with respect to Joint J_1 can be written as

$$x_4 = x - \cos \theta (L_4 \cos \psi) \quad (16)$$
$$y_4 = y - \sin \theta (L_4 \cos \psi) \quad (17)$$
$$\text{and} \quad z_4 = z - L_4 \sin \psi \quad (18)$$

We get

$$x_4 = \cos \theta (L \cos \phi + L_4 \cos \psi) - \cos \theta (L_4 \cos \psi)$$
$$y_4 = \sin \theta (L \cos \phi + L_4 \cos \psi) - \sin \theta (L_4 \cos \psi)$$
$$\text{and} \quad z_4 = L_1 + L \sin \phi + L_4 \sin \psi - L_4 \sin \psi$$

Which implies

$$x_4 = L \cos \phi \cos \theta \quad (19)$$
$$y_4 = L \sin \theta \cos \phi \quad (20)$$
$$\text{and} \quad z_4 = L_1 + L \sin \phi \quad (21)$$

From above Eqs., we get

$$x_4^2 + y_4^2 + (z_4 - L_1)^2$$
$$= L^2 \cos^2 \phi [\cos^2 \theta + \sin^2 \theta] + L^2 \sin^2 \phi$$
$$= L^2 \cos^2 \phi + L^2 \sin^2 \phi$$
$$x_4^2 + y_4^2 + (z_4 - L_1)^2 = L^2 \quad (22)$$

From Eqs. (13) and Eq. (14), we get

$$\frac{y}{x} = \frac{\sin \theta (L_4 \cos \psi + L \cos \phi)}{\cos \theta (L_4 \cos \psi + L \cos \phi)}$$

therefore

$$\theta = \tan^{-1}\left(\frac{y}{x}\right) \quad (23)$$

From Eqs. (16) and (17), we get

$$\frac{y_4}{x_4} = \frac{L \sin \theta \cos \phi}{L \cos \theta \cos \phi}$$

$$\frac{y_4}{x_4} = \tan \theta$$

therefore

$$\theta = \tan^{-1}\left(\frac{y_4}{x_4}\right) \quad (24)$$

Using Eq. (16) and Eq. (17), we find value of $(x_4^2 + y_4^2)$ as

$$(x_4^2 + y_4^2) = L^2 \cos^2 \phi \cos^2 \theta + L^2 \sin^2 \theta \cos^2 \phi$$
$$= L^2 \cos^2 \phi (\cos^2 \theta + \sin^2 \theta)$$

Therefore,

$$(x_4^2 + y_4^2) = L^2 \cos^2 \phi \quad (25)$$

Substituting the value of $(x_4^2 + y_4^2)$ from Eq. (19) in Eq. (20), we get

$$L^2 - (z_4 - L_1)^2 = L^2 \cos^2 \phi$$
$$L^2 - L^2 \cos^2 \phi = (z_4 - L_1)^2$$
$$L^2(1 - \cos^2 \phi) = (z_4 - L_1)^2$$
$$L^2 \sin^2 \phi = (z_4 - L_1)^2$$
$$\sin^2 \phi = \frac{(Z_4 - L_1)^2}{L^2}$$

Hence, there are two possible values of ϕ, viz.,

$$\phi = \sin^{-1}\left(\pm \frac{Z_4 - L_1}{L}\right) \quad (26)$$

Squaring x_4, y_4 and then adding using Eqs. (19) and (20), we get

$$x_4^2 + y_4^2 = \ = L_4^2 \cos^2 \psi (\cos^2 \theta + \sin^2 \theta)$$
$$= L_4^2 \cos^2 \psi$$

therefore,

$$\cos^2 \psi = \frac{x_4^2 + y_4^2}{L_4^2}$$

$$\psi = \cos^{-1} \pm \left(\frac{x_4^2 + y_4^2}{L_4^2}\right)^{1/2}$$

Or from Eq.(22)

$$\psi = \cos^{-1} \pm \left(\frac{L^2 - (z_4 - L_1)^2}{L_4^2}\right)^{1/2} \quad (27)$$

From Eqs. (23), (24), (26) and (27), we can calculate the values of joint angles θ, ϕ and ψ.

III. Simulation and Testing

A case study has been considered with the following specifications for 4 DOF manipulator.

Maximum reach of the robot arm: 915mm
Length of first link (l_1): 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: 390 mm
  y: 115 mm
  z: 512 mm

The system has been considered for developing the software code using GA and fuzzy logic. Solving these equations we get the following values for the angles of the links:

$\theta = 16.42^0$
$\phi = 32.87^0, 21.06^0$
$\psi = 67.44^0, -22.51^0$

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

the optimization process, we obtain the following population as illustrated in tables I, II and III.

A. From Inverse Kinematics

TABLE I
POPULATION FROM INVERSE KINEMATICS

No.	(1) Chromosomes	Fitness value
1.	$\{16.42^0, 32.87^0, 67.44^0\}$	348.74
2.	$\{16.42^0, 32.87^0, 22.51^0\}$	79.74
3.	$\{16.42^0, 21.06^0, 67.44^0\}$	313.52
4.	$\{16.42^0, 21.06^0, 22.51^0\}$	44.53

B. From First Run

TABLE II
POPULATION FROM FIRST RUN

No.	Chromosomes	Fitness value
5	$\{16.42^0, 31.07^0, 67.44^0\}$	343.62
6	$\{16.42^0, 31.07^0, 22.51^0\}$	209.28
7	$\{16.42^0, 22.86^0, 67.44^0\}$	319.08
8	$\{16.42^0, 22.86^0, 22.51^0\}$	184.74

C. From Second Run

TABLE III
POPULATION FROM THIRD RUN

No.	*A. Chromosomes*	Fitness value
9	$\{16.42^0, 21.06^0, 67.44^0\}$	313.52
10	$\{16.42^0, 21.06^0, 22.51^0\}$	44.53
11	$\{16.42^0, 32.87^0, 67.44^0\}$	348.74
12	$\{16.42^0, 32.87^0, 22.51^0\}$	79.74

From the above simulation, we obtained optimized result for various joints having lowest fitness value.

$\theta = 16.42^0$

$\phi = 21.06^0, 32.87^0$

$\psi = 67.44^0, 22.51^0$

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IV. RESULTS AND DISCUSSIONS

In this paper, the optimal movement of 4 DOF robotic arm using inverse kinematics have been presented. An optimization method based on the genetic algorithms and fuzzy logic is evaluated. 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. GA does not need complete knowledge of system. Genetic algorithms and fuzzy logic is practical and effective method for achieving optimization of robotic arm movement. Proposed technique can be extended to more degree-of-freedom robotic arm systems.

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