World Academy of Science, Engineering and Technology
International Journal of Mechanical and Materials Engineering
Vol:10, No:9, 2016

Movement Optimization of Robotic Arm Movement Using Soft Computing

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International Science Index, Mechanical and Materials Engineering Vol:10, No:9, 2016 waset.org/Publication/10005652

***Abstract*—**Robots are now playing a very promising role in industries. Robots are commonly used in applications in repeated operations or where operation by human is either risky or not feasible. In most of the industrial applications, robotic arm manipulators are widely used. Robotic arm manipulator with two link or three link structures is commonly used due to their low degrees-of-freedom (DOF) movement. As the DOF of robotic arm increased, complexity increases. Instrumentation involved with robotics plays very important role in order to interact with outer environment. In this work, optimal control for movement of various DOFs of robotic arm using various soft computing techniques has been presented. We have discussed about different robotic structures having various DOF robotics arm movement. Further stress is on kinematics of the arm structures i.e. forward kinematics and inverse kinematics. Trajectory planning of robotic arms using soft computing techniques is demonstrating the flexibility of this technique. The performance is optimized for all possible input values and results in optimized movement as resultant output. In conclusion, soft computing has been playing very important role for achieving optimized movement of robotic arm. It also requires very limited knowledge of the system to implement soft computing techniques.

***Keywords*—**Artificial intelligence, kinematics, robotic arm, neural networks, fuzzy logic.

I. Introduction

TODAY, robotic is part of every industry from entrainment to any manufacturing industry. In the recent years, with the increasing use of robots in industry, it helps to reduce risk of human operator in hazardous environment and also overcome the fatigueness of the human operator due to repetitive tasks [8]. On the induction of robots in the production process of industry, it requires flexibility to modify as per the change of process and also to incorporate intelligence to adapt changes. Major parts of industrial robots are mechanical structures which are movable in nature. The mechanical structure of a robot is usually a kinematic chain which functions as a similar to the structure of the human body [1], [9]. Robots' different parts (links) act like human bones and called as links, and actuators used to provide force to the joints act like human muscles. One link is connected to another link through joints, and movement of the links is known as DOF. The complexity of the robots is normally defined in terms of DOF; as DOF increases the complexity of the robot to handle or control also increases. In most of the industrial applications, robotic arms are used which resemble human arm having different DOF as per the application. In such robotic arms, there is end effector fixed with last link of the robotic arm like human hand which is called as manipulator. In place of manipulator, some tools may be used in some cases like cutting tool, welding tool, spray painting tool etc. In order to control robot or to execute certain task, each joint, link and manipulator has to be controlled through computer program [8], [9]. Different sensors are also used to sense the environment and accordingly provide the feedback to control process. The autonomous robot structures effectively utilize the sensors so that with proper path, planning can be accomplished for assigned task with minimum involvement or without involvement of operator [5], [15]. Path planning is a very challenging issue in the case of autonomous robots [2].

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II. Robotics Arm

Robotic arms are defined in terms of different DOF and their area of operation is defined as work volume. Robotic arms can work in 2D or 3D space as per the DOF of the arm structure and accordingly defined as a work volume [1], [8]. The links of robotic arms can move in two modes, as a translational (linear) displacement or rotational (revolute) motion. Fig. 1 shows the seven DOF robotic arm structure. The total number of DOF equals to sum of the DOF of each joint, link and manipulator used in particular arm structure. Different arms of the structure are known as links and linkage of two links is known as a joint and accordingly movement of each joint is known as a DOF of a particular joint. A human arm structure has seven DOF [15].

Fig. 1 Robotic Arm with Seven Degrees of Freedom [1]

III. Robotic Arm structure

Industrial robots are available in wide range of robotic arm structures depending upon the application. These structures are available with specific work volume as per their DOF

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structure [17], [18]. The commercially available robots have following basic configurations:

a. *Cartesian Configuration*: In this configuration, there will be three linear axes movement of joints which are perpendicular to each other. Such kind of configuration is used for pick and place operation, electronic assembly operations, handling machine tools, welding etc.
b. *Cylindrical Configuration:* In this configuration, there will be two linear and one rotary axes movement and defined as a cylindrical work volume. This kind of configuration is used for assembly operations, machine tools, spot welding etc.
c. *Spherical/Polar Configuration:* In this configuration, there will be one linear and two rotary axes movement of joints and defined as a spherical work volume.
d. *Articulated Configuration:* In this configuration, there will be three rotary axes movement of joints and movement of articulate configuration arm is like a human arm. In this configuration, by connecting manipulator at the end of the last link which works like human hand and which adds more DOF to the manipulator. It is most widely used configuration in the industry.

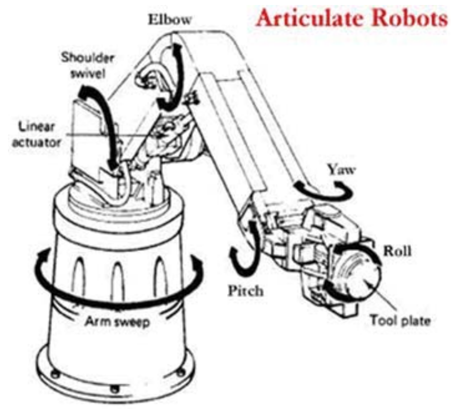

Fig. 2 Articulate robot [15]

Fig. 2 represents an articulated robot having rotary joints used in various industrial applications. In Fig. 2, articulated robot has two links and three rotary axes movement of joints. The manipulator or end effector is connected at the end of the last link shown as with three rotary axes movement. Each joint is powered by electric motors to provide the rotary axis movement. Articulate robot has more number of rotary joints to increase the capability of the robot [15].

IV. Kinematics

A robotic arm can be modeled as a chain of rigid bodies called links. The links are inter-connected to one another by joints. One end of the chain of the links is fixed to the base, while the other end is free to move [8]. At the end of robotic arm is connected with a tool or end effector. To reach particular target in three-dimensional space, movement is given to robotic arm links, joints and manipulator in such a manner to reach desired target [7]. The robotic arm can be programmed to follow a path to reach the target in the work space [17], [18]. To find the relationship between the joint variables and the position and the orientation of the robotic arm is called the kinematics transformation. Kinematics can be defined in two ways as:

a. Direct Kinematics

For direct kinematics, we must have dimensions of all the link lengths and information about joint angles of the robot arm. By using this information, calculating the position and orientation of the hand of the robot is called forward kinematics. In direct kinematics, by substituting the values of joint and link variables in the set of equations that defines the particular configuration of the robotic system, one can calculate the position and orientation of the robot.

b. Inverse Kinematics

For inverse kinematics, one has to place the robot manipulator at a desired location and orientation. Then, to achieve this desired location, calculating the values of joint and link variables of the hand of the robot is called inverse kinematics. In inverse kinematics, by substituting the position and orientation in the set of equations that defines the particular configuration of the robotic system, one can calculate the values of joint and link variables of the robot [5].

Using direct kinematics, movement is given to robotic joins and links to reach the target, whereas inverse kinematics does the opposite of it, by knowing position of target or goal accordingly finds the movement of joints and links to reach particular target or goal. In inverse kinematics, there may be many solutions to achieve the same target in some cases. In such a case, there is need of optimization to reach the target with minimum movement to save energy and time [17], [18].

2 DOF Manipulator

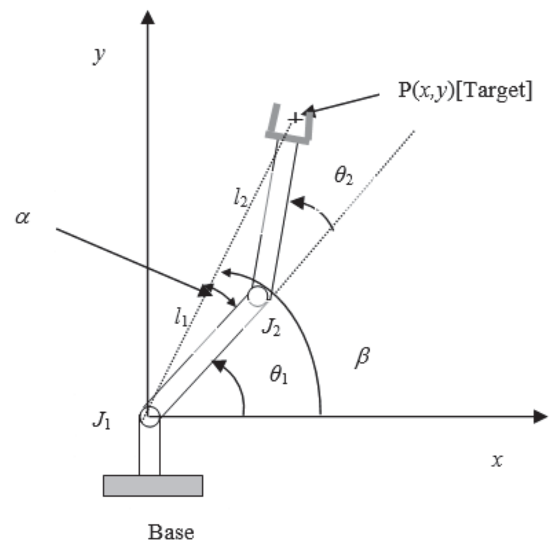

Fig. 3 2 DOF manipulator

In industrial applications, robotic arms are used for performing various activities. Two DOF robotic arm manipulator is the basic arm model with no complexity. We have considered a planar robot with 2 DOF as shown in Fig. 3. The arm moves in *xy*-plane with joint J_1 by link l_1 and joint J_2

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by link l_2. The length of link '1' and '2' are l_1 and l_2, respectively. The angles for link '1' and link '2' are θ_1 and θ_2, respectively. The end of arm position or target is at point P(x,y).

Forward Kinematics for 2 DOF Manipulator

$$x = l_1 \cos\theta_1 + l_2 \cos(\theta_1 + \theta_2) \tag{1}$$

and

$$y = l_1 \sin\theta_1 + l_2 \sin(\theta_1 + \theta_2) \tag{2}$$

Inverse Kinematics for 2 DOF Manipulator

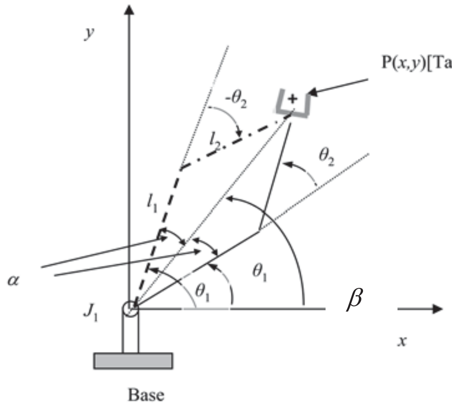

Fig. 4 2 DOF manipulator showing alternate path

In inverse kinematics, joint angle movements will be evaluated to achieve target. Rather, inverse kinematics is more important in order to drive joint angle movement for given target position for a robotic arm manipulator. For the two link manipulator, there are two possible configurations for reaching the target position defined as P (x, y) as shown in Fig. 4. Thick dashed line shows the alternate path to reach the target and respective angle θ_1 of link l_1 and -θ_2 of link l_2 (- indicates opposite direction of the angle movement)

Using inverse kinematics, the values of θ_1 and θ_2 are obtained:

$$\theta_2 = \cos^{-1}\left(\frac{(x^2 + y^2) - (l_1^2 + l_2^2)}{2 l_1 \times l_2}\right) \tag{3}$$

$$\tan\alpha = \frac{l_2 \sin\theta_2}{l_2 \cos\theta_2 + l_2}$$

$$\tan\beta = \frac{y}{x}$$

$$\theta_1 = \tan^{-1}\left(\frac{y(l_1 + l_2 \cos\theta_2) - x l_2 \sin\theta_2}{x(l_1 + l_2 \cos\theta_2) - y l_2 \sin\theta_2}\right) \tag{4}$$

3 DOF Manipulator

Three link manipulators, which are the fundamental robotic arm structure, are used in various industrial applications A vertical articulated robotic arm with 3 links is shown in Fig. 5. It is considered as an addition to one more degree to the 2 DOF manipulator. It adds to the capability of orientation as well as positioning to robotic arm by connecting an end-effector or a tool. This third DOF represents wrist joint of human arm. The length of links '1', '2' and '3' are l1, l2, and l3 respectively and are joints angles θ1, θ2, and θ3 for joints '1', '2' and '3' respectively. Also J1, J2, and J3 are the joints of links '1', '2' and '3' respectively. The target point P(x,y) is to be achieved while moving manipulator.

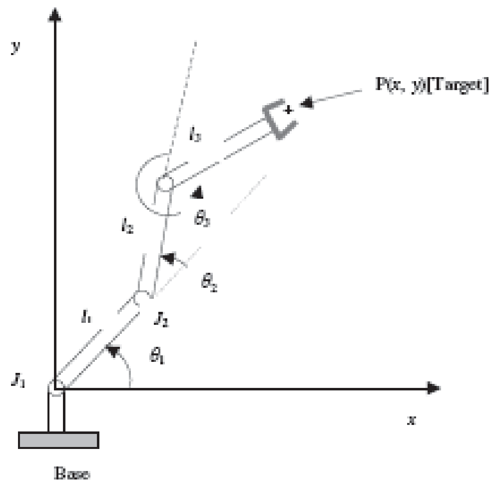

Fig. 5 3 DOF manipulator

Forward Kinematics for 3 DOF Manipulator

$$x = l_1 \cos\theta_1 + l_2 \cos(\theta_1 + \theta_2) + l_3 \cos(\theta_1 + \theta_2 + \theta_3) \tag{5}$$

$$y = l_1 \sin\theta_1 + l_2 \sin(\theta_1 + \theta_2) + l_3 \sin(\theta_1 + \theta_2 + \theta_3) \tag{6}$$

and

$$\phi = (\theta_1 + \theta_2 + \theta_3) \tag{7}$$

Inverse Kinematics for 3 DOF Manipulator

$$\theta_1 = \gamma + \sigma \cos^{-1}\left(\frac{-(x'^2 + y'^2 + l_1^2 - l_2^2)}{2 l_1 \sqrt{x'^2 + y'^2}}\right) \tag{8}$$

$$\theta_2 = \tan^{-1}\left(\frac{y' - l_1 \sin\theta_1 / l_2}{x' - l_1 \cos\theta_1 / l_2}\right) - \theta_1 \tag{9}$$

$$\theta_3 = (\phi - \theta_1 - \theta_2) \tag{10}$$

Here, we have discussed 2DOF and 3DOF robotic arm structures and manipulators. Using inverse kinematics there are multiple solutions as per the alternate paths available depending upon the DOF of robotics arm structure. As the DOFs increased, the complexity increased and it becomes very difficult to find solution using classical methods. In order to find solution of such robotic problem, there is need of optimization to find solution and optimal path from multiple path solutions.

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V. OPTIMIZATION

Nowadays, use of robotics is an essential technology in the industry. There are variety of robots are used in industry i.e. robotic arms, mobile robots, autonomous robots, military robots, entertainment robots, health-care robots, nano-robots and humanoid robots etc. As in most of the cases, inverse kinematic is widely used in industrial robots. In this case, we know the position of job or target and accordingly control the robot or robotic arm. As DOF of the robotic structure has been increased, solution of such problem becomes quite complex task. Where low DOF problems can be solved by using mathematical equations, for higher DOF structures, it is not feasible to solve with classical methods [17], [18].

Optimization plays very important role in robotics to take care of minimum path movement problems or called path planning problems. Many researchers have reported the use of fuzzy logic and genetic algorithms to the path planning problems in robotic arm movement [3]. The capabilities of artificial intelligence techniques are explored by many researchers in order to find the optimal solution for higher DOF robotic structures.

VI. SOFT COMPUTING

Soft computing (SC) is technique used for developing intelligent or autonomous system work like human brain. Such kind of developed systems can accommodate and compensate imprecision's and uncertainties of environment [10]. SC includes various techniques like fuzzy logic, Neural Networks and evolutionary computing techniques like genetic algorithms, particle swarm intelligence, Ant colony, Bee colony etc. whereas combining one or two or more SC techniques together to develop hybrid system are also reported by many researchers to solve the optimization problems.

Fuzzy Logic

Fuzzy logic is multi-valued logic which works on approximation rather than exact values. The advantage of a fuzzy model is easy to design and implement. It does not require the the complex mathematical as an input, but it is dependent on experience for design logic. Its maximum value must lie in those areas where such qualitative process knowledge is maximum and necessary for understanding [4].

Fuzzy rule base is based upon truth table of logic. Rule base is a collection of rules related to the fuzzy sets, the input variables and output variables. These rules make the system to decide what to do. These rules relate the input and output variables. Fuzzy logic is helpful in situations where the control variables are continuous. Fuzzy rules often take the place of a mathematical model. Fuzzy logic is very useful where mathematical model of the system is difficult to design [13], [16], [17].

Control of some systems cannot be easily specified in terms of an IF/THEN rule base. An example of such a system would be a robotic arm operating in the presence of an obstacle. Also, sometimes the 'experts' providing the rule base disagree among themselves. This was demonstrated at the Kawasaki Steel Corporation in Japan. A fuzzy logic control system was installed to help operators make decisions regarding control of a blast furnace. The researchers summarised, "There is a slight difference in knowledge between a multiple number of experts". Their data suggest that, in practice, the operators ignore the expert system's suggestion over 15-20% of the time [21].

Artificial Neural Networks (ANN)

ANNs are structured around different layered neuron model like human brain. In these different layers, input from one layer and sum of all values produced output for next layer as an input [19].

The inverse kinematics problem is a non-linear problem. Several iterative and neural network techniques are used in solving the inverse kinematics problems. Error is occurred due to deflection and mass load positioning. The magnitude of the error is affected by load, movement, and stiffness. Various researchers have reported successfully implementation of neural networks to solve the correction errors and compensation [4], [6], [10], [18].

Evolutionary Algorithms

Evolutionary Algorithms are metaheuristic optimization techniques which are based on the process of natural selection. A "fitness" function is used to evaluate each solution accordingly decision has been taken for the use of next generation of solutions or not. The algorithm creates a new population of solutions, like gene transfer in sexual reproduction. Machine learning techniques such as evolutionary algorithms or ANNs are used for implementation of behaviors in mobile robotics. Fuzzy controller using genetic algorithms for the implementation of behavior in a mobile robot have been discussed in [12].

Evolutionary computation is a collection of algorithms based on the evolution of a population toward a solution of a problem. These algorithms can be used successfully in various applications that require the optimization of a multi-dimensional function [14]. The population of possible solutions evolves from one generation to the next and at the end, it reaches to a satisfactory solution of the problem [11]. The three primary elements of evolutionary computation techniques are: *Evolution Algorithms (EA)*; *Genetic Programming (GP)*; *Genetic Algorithms (GA)*. This technique incarnates the processes observed in natural evolution, and provides efficient solution to search results.

Hybrid Systems

Hybrid systems incorporate two or more soft computing techniques to obtain efficient solution. To find efficient solution for non-linear problems, various researchers show superiority of SC techniques like GA, neural networks, fuzzy logic, etc. The SC based nonlinear control algorithms have been successfully applied for the control 4 DOF SCARA robot [6], [19]. GA reinforcements have been developed and various efficient new approaches in fuzzy modeling have been evolved. Intelligent robots have been developed using adaptive fuzzy hybrid position and force control capabilities [17], [18]. Particle Swarm Optimization (PSO) evolutionary technique is successfully implemented in grasp problem of robotic arm [20].

The combinations of two technologies i.e., neuro-fuzzy has been successfully combined so as to maximize their individual strengths and compensate for individual shortcomings. Robust adaptive fuzzy neural controllers for non-linearities compensation in robots have been developed and other automatic systems.

VII. Conclusion

In this work, robotics kinematics problem for different DOF structures have been analyzed and discussed the effective use soft computing techniques like neural network, fuzzy and GA etc. in solving inverse kinematics problem. In the presence of several optimization attributes in case of order manipulator, SC techniques are helpful to find the solutions of kinematics problems. SC techniques can be used as preferable methods to describe by analytical or mathematical models. For autonomous robots, knowledge about the environment is necessary and it is mostly unpredictable and incomplete. Therefore, the SC tools like neural networks, fuzzy control, and evolutionary computing etc. are of benefit to the robotic problems. Fuzzy rule based systems combined with the ANNs and evolutionary techniques like GA etc. play vital role in developing autonomous robots. SC techniques contribute fully in developing fully autonomous robots.

References

[1] Fu K.S., Gonzalez R.C., Lee C.S.G., *Robotics: Control, Sensing, Vision and Intelligence*. McGraw Hill International Editions, 1987.

[2] Lozano P. and Erez T "*A simple motion-planning algorithm for general robot manipulators*" IEEE Journal of Robotics and Automation 3(3), 224–238, 1987.

[3] Cameron S. "*Obstacle avoidance and path planning*". International Journal of Industrial Robot 21(5), 9-14,1994.

[4] Ankit Saxena and Abhinav Saxena, "*Review of Soft Computing Techinques used in Robotics Applications*" Int. journal of Information and Computation Technology, vol.3 (3), 101-106, 2013.

[5] Ahuactzin J. M., Gupta K. K, "*The kinematic roadmap: a motion planning based global approach for inverse kinematics of redundant robots*" IEEE Transactions on Robotics and Automation, 15(4), 653-669, 1999.

[6] Piero P. Bonissone, Yu-To Chen, Kai Goebel, And Pratap S. Khedkar, "*Hybrid Soft Computing Systems: Industrial and Commercial Applications"* Proc. IEEE, Vol. 87(9), Sept. 1999.

[7] Galicki M., "*Time-optimal controls of kinematically redundant manipulators with geometric constraints*". IEEE Transactions on Robotics and Automation 16(1), 89-93,2000.

[8] Deb S.R., "*Robotics Technology and Flexible Automation*" Tata McGraw Hill, 2002.

[9] Schilling R.J., "*Fundamental of Robotics: Analysis and Control"* Prentice Hall, India Pvt. Ltd., 2002.

[10] Frank Hoffmann, "*An Overview on Soft Computing in Behavior Based Robo*tics" Proc. IFSA'03 Proceedings of the 10th international fuzzy systems association World Congress conference on Fuzzy sets and systems, Berlin, Heidelberg, pp 544-551, 2003.

[11] Dongbing Gu, Huosheng Hu, Jeff Reynolds, Edward Tsang, "*GA-based Learning in Behavior Based Robotics*" Proceedings of IEEE International Symposium on Computational Intelligence in Robotics and Automation, Kobe, Japan, 16-20 July 2003.

[12] Gemeinder M. and Gerke M., *GA-based path planning for mobile robot systems employing an active search algorithm"* Elsevier Applied Soft Computing3(2), 149-158, 2003.

[13] Tang Y. and Velez-Diaz D., "*Robust fuzzy control of mechanical systems*". IEEE Transactions on Fuzzy Systems 11(3), 411- 418,2003.

[14] Dusko Katic, Miomir Vukobratovic, "*Genetic Algorithms in Robotics"* International Series on Microprocessor-Based and Intelligent Systems Engineering Vol. 25, 2003.

[15] Craig J.J., "*Introduction to Robotics: Mechanics and control"* Pearson Education Asia, 2004.

[16] O. Hachour, "*The proposed Fuzzy Logic Navigation approach of Autonomous Mobile robots in unknown environments"* International Journal of Mathematical Models and Methods in Applied Sciences, 2009.

[17] Banga V K, Kumar R, Singh Y "*Fuzzy genetic optimal control for robotics system*", International journal of Physical Sciences. 6(2), 204-212,2011.

[18] Banga V K, Kumar R, Singh Y "*Modeling and simulation of robotics arm movement using soft computing*" World academy of science, 75, 614-620 2011.

[19] Jorge Armendariz, Vicentre Parra-Vega, Rodolfo Garcia Rodrigez, Sergio Rosales, "Neuro-fuzzy self-turning of PID control for semiglobal exponential tracking of robot arms", Elsevier Applied Soft Computing, 25, 139-148, 2014.

[20] Haitham EI-Hussieny, Samy F. M. Assal, A.A Abouelsound, Said M. Megahed and tsukasa Ogasawara "Incremental learning of reach-to-grasp behavior: A PSO-based Inverse Optial control approach", Seventh Int. conference of soft Computing and Pattern Recognition (SoCPaR2015), 129-135, 2015.

[21] Zhi Liu, Ci Chen, Yun Zhang and C. L. Philip Chen, "Coordinated fuzzy control of robotic arms with actuator nonlinearities and motion constraints" Elsevier Information Sciences, 1-13, 2015.

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