Robotic Arm Kinematics and Soft Computing

Gurjeet Singh, Dr. V. K. Banga, Jasjit Kaur

***Abstract*—T**oday robots are used in every walk of human life. All over the world, robots are on the move. In order to co-operate with a human, a robot should have a human-like behavior when moving. To achieve this, is necessary to give the robot human like configuration and human like kinematics. In this paper, we provide a brief review of robotics and its kinematics type. The inverse kinematics of two and three links arm of robotic system have been discussed. Robotics requires a working knowledge of electronics, mechanics and software, and is usually accompanied by a large working knowledge of many subjects. A person working in the field computation using soft computing that learns the inverse kinematics of a robot arm played important role in the robotics.

***Keywords*—**Kinematics, Robotics arm, Neural networks, Fuzzy logic.

I. Introduction

ROBOTICS is a robotics. Although the appearance and capabilities of robots vary vastly, all robots share the features of a mechanical, movable structure under some form of autonomous control[5,6]. The structure of a robot is usually mostly mechanical and can be called a kinematic chain (its functionality being similar to the skeleton of the human body). The chain is formed of links (its bones), actuators (its muscles) and joints which can allow one or more degrees of freedom. Most contemporary robots use open serial chains in which each link connects the one before to the one after it. These robots are called serial robots and often resemble the human arm. Some robots, such as the Stewart platform, use closed parallel kinematic chains. Robots used as manipulators have an end effector mounted on the last link. This end effector can be anything from a welding device to a mechanical hand used to manipulate the environment. The mechanical structure of a robot must be controlled to perform tasks. The control of a robot involves three distinct phases - perception, processing and action (robotic paradigms). Sensors give information about the environment or the robot itself (e.g. the position of its joints or its end effector). Using strategies from the field of control theory, this information is processed to calculate the appropriate signals to the actuators (motors) which move the mechanical structure. The control of a robot involves various

Gurjeet Singh is working as a lecturer and pursuing M.Tech (Electronics and Communication Engineering) in Department of Electronics & Communication Engineering, Amritsar College of Engineering and Technology, Amritsar, Punjab, India(mann_567@yahoo.com).

Dr. Vijay Kumar Banga is working as professor and Head of the Department of Electronics & Communication Engineering, Amritsar College of Engineering and Technology, Amritsar, Punjab, India (e-mail: vijaykumar.banga@gmail.com).

Outer Space - Manipulative arms that are controlled by a human are used to unload the docking bay of space shuttles to launch satellites or to construct a space station.

The Intelligent Home - Automated systems can now monitor home security, environmental conditions and energy usage. Door and windows can be opened automatically and appliances such as lighting and air conditioning can be pre programmed to activate. This assists occupants irrespective of their state of mobility.

Exploration - Robots can visit environments that are harmful to humans. An example is monitoring the environment inside a volcano or exploring our deepest oceans. NASA has used robotic probes for planetary exploration since the early sixties.

Military Robots - Airborne robot drones are used for surveillance in today's modern army. In the future automated aircraft and vehicles could be used to carry fuel and ammunition or clear minefields.

Farms - Automated harvesters can cut and gather crops. Robotic dairies are available allowing operators to feed and milk their cows remotely.

The Car Industry - Robotic arms that are able to perform multiple tasks are used in the car manufacturing process. They perform tasks such as welding, cutting, lifting, sorting and bending. Similar applications but on a smaller scale are now being planned for the food processing industry in particular the trimming, cutting and processing of various meats such as fish, lamb, beef.

Hospitals - Under development is a robotic suit that will enable nurses to lift patients without damaging their backs. Scientists in Japan have developed a power-assisted suit which will give nurses the extra muscle they need to lift their patients and avoid back injuries.

II. Robotics Arm

A robotic arm is a robotic manipulator, usually programmable, with similar functions to a human arm. The links of such a manipulator are connected by joints allowing either rotational motion (such as in an articulated robot) or translational (linear) displacement. The links of the manipulator can be considered to form a kinematics chain [7, 11]. The business end of the kinematics chain of the manipulator is called the end effectors and it is analogous to the human hand. The end effectors can be designed to perform any desired task such as welding, gripping, spinning etc., depending on the application. For example robot arms in perform a variety of tasks such as welding and parts rotation and placement during assembly.

Fig. 1 Robotic Arm with Seven Degrees of Freedom

Robot arms are typically categorized by the number of controlled degree of freedom (DOF) they can execute. This number is equal to the sum of the DOF of each of a robot arm’s individual joints. Generally these will be either Hinge joints or Pivot joints, both of which are only capable of rotation about a sing The number of DOF that a manipulator possesses is the number of independent position variables that would have to be specified in order to locate all parts of the mechanism. In other words, it refers to the number of different ways in which a robot arm can move [6]. A normal human arm is redundant (and therefore holonomic) in that it has seven DOF. The shoulder gives pitch, yaw and roll. The elbow allows for pitch. The wrist allows for pitch and yaw. And the elbow and wrist together allow for Roll. Only three DOF are needed to move the hand to any particular point within a given three dimensional space, but having a greater the number of controlled DOF enables human beings to grasp items in that space from a variety of different angles and directions. In a Two Dimensional (2-D) space (like a table-top or the floor) there are three Degrees of Freedom. These include displacement along the X and Y axes, plus rotation. In a Three Dimensional (3-D) space there are six degrees of freedom. These consist of displacement along three perpendicular axes (X, Y and Z), and rotation about those same axes. DOF in 3D space are generally identified using the following nautical terms: Displacements

- Heave: Moving up and down
- Surge: Moving forward and backward
- Sway: Moving left and right Rotations
- Yaw: Turning left and right flight
- Roll: Tilting side to side
- Pitch: Tilting forward and backward

III. Robotic Arm Structure

Cartesian Robot / Gantry Robot: Used for pick and place work, application of sealant, assembly operations, handling machine tools and arc welding. It's a robot whose arm has three prismatic joints, whose axes are coincident with a Cartesian coordinator.

Cylindrical Robot: Used for assembly operations, handling at machine tools, spot welding, and handling at die-casting machines. It's a robot whose axes form a cylindrical coordinate system.

Spherical Robot / Polar Robot (such as the Unimate): Used for handling at machine tools, spot welding, die-casting, fettling machines, gas welding and arc welding. It's a robot whose axes form a polar coordinate system

SCARA Robot: Used for pick and place work, application of sealant, assembly operations and handling machine tools. It's a robot which has two parallel rotary joints to provide compliance in a plane.

Articulated Robot: Used for assembly operations, die-casting, fettling machines, gas welding, arc welding and spray painting. It's a robot whose arm has at least three rotary joints. It is most widely used in the industry.

An articulated robot is a robot with rotary joints (e.g. a legged robot or an industrial robot). Articulated robots can range from simple two-jointed structures to systems with 10 or more interacting joints. They are powered by a variety of means, including electric motors.

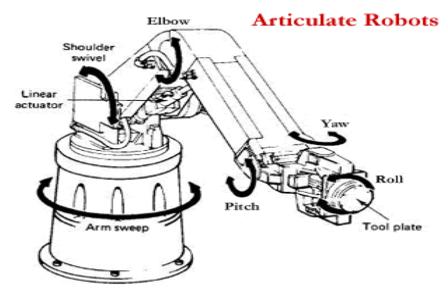

Fig. 2 Articulate robot

A rotary joint is a connection between two objects. The connection allows both objects, even though each is connected to another object, the ability to rotate or have movement up to 360 degrees. The two rigid objects that are attached by the joint are sometimes called a kinematic pair while the joint is referred to as a mechanical constraint. Most of the time these two objects that are connected together are cylindrical. The connection gives both objects increased capabilities to perform work functions. Articulated robots usually have several of these connections which gives them a great deal of flexibility in performing work duties. Each joint that a robotic has represents an increase in freedom to perform tasks. There is no limit to the number of rotary joints that articulated robots can have and a robotic may have other types of joints to increase its capability even more [3, 5].

Parallel Robot: One use is a mobile platform handling cockpit flight simulators. It's a robot whose arms have concurrent prismatic or rotary joints.

Anthropomorphic Robot: Shaped in a way that resembles a human hand, i.e. with independent fingers and thumbs.

IV. Kinematics

Use It is (from Greek κινεῖν, kinein, to move) is the branch of classical mechanics that describes the motion of bodies (objects) and systems (groups of objects) without consideration of the forces that cause the motion. Kinematics is not to be confused with another branch of classical mechanics: analytical dynamics (the study of the relationship between the motion of objects and its causes), sometimes subdivided into kinetics (the study of the relation between external forces and motion) and statics (the study of the relations in a system at equilibrium). Kinematics also differs from dynamics as used in modern-day physics to describe time-evolution of a system [1]. Kinematics is the process of calculating the position in space of the end of a linked structure, given the angles of all the joints. It is easy, and there is only one solution. Inverse Kinematics does the reverse. Given the end point of the structure, what angles do the joints need to be in the achieve that end point. It can be difficult, and there are usually many or infinitely many solutions. This process can be extremely useful in robotics. You may have a robotic arm which needs to grab an object. If the software knows where the object is in relation to the shoulder, it simply needs to calculate the angles of the joints to reach it. The simplest application of kinematics is for particle motion, translational or rotational [8]. The next level of complexity comes from the introduction of rigid bodies, which are collections of particles having time invariant distances between themselves. Rigid bodies might undergo translation and rotation or a combination of both. A more complicated case is the kinematics of a system of rigid bodies, which may be linked together by mechanical joints. It's of two types.

- Forward kinematics
- Inverse kinematics

Forward kinematics: The essential concept of forward kinematic animation is that the positions of particular parts of the model at a specified time are calculated from the position and orientation of the object, together with any information on the joints of an articulated model. So for example if the object to be animated is an arm with the shoulder remaining at a fixed location, the location of the tip of the thumb would be calculated from the angles of the shoulder, elbow wrist, thumb and knuckle joints. Three of these joints (the shoulder, wrist and the base of the thumb) have more than one degree of freedom, all of which must be taken into account. If the model were an entire human figure, then the location of the shoulder would also have to be calculated from other properties of the model [2, 4].

Inverse kinematics: It will enable us to calculate what each joint variable must be if we desire that the hand is located at particular point and have a particular position. The position and orientation of the end effector relative to the base frame compute all possible sets of joint angles and link geometries which could be used to attain the given position and orientation of the end effector [1, 4].

Forward Kinematics

$$x = l_1 \cos\theta 1 + l2 \cos(\theta 1+ \theta 2) \quad (1)$$

$$y = l_1 \sin \theta 1 + l_2 \sin (\theta 1+\theta 2) \quad (2)$$

Inverse kinematics

$$x^2 + y^2 = l_1^2 \cos^2\theta_1 + l_2^2 \cos^2(\theta_1+\theta_2) + 2 l_1 l_2 \cos\theta_1 \cos^2(\theta_1+\theta_2) + l_1^2 \sin^2\theta_1 + l_2^2 \sin^2(\theta_1+\theta_2) + 2 l_1 l_2 \sin\theta_1 \sin^2(\theta_1+\theta_2) \quad (3)$$

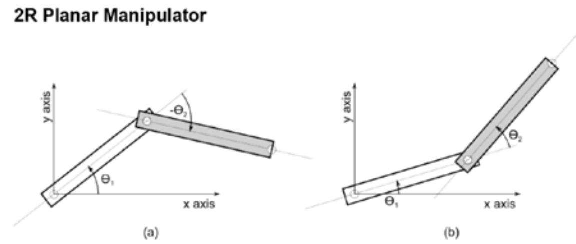

Fig. 3 Two link robotic arm

$$= l_1^2+ l_2^2 + 2l_1l_2 \cos\theta_1 \cos(\theta_1+\theta_2)+ \sin\theta_1 \sin^2(\theta_1+\theta_2) \quad (4)$$

Next we use the following equalities

$$\text{Sin}(x \pm y) = \sin x \cos y \pm \cos x \sin y \quad (5)$$

$$\text{Cos}(x\pm y)= \cos x \cos y \pm \sin x \sin y \quad (6)$$

Therefore

$$x^2 + y^2 = l_1^2 + l_2^2 + 2 l_1 l_2[\cos\theta_1 \cos\theta_2 - \sin\theta_1 \sin\theta_2 + \sin\theta_1 (\cos\theta_2 \sin\theta_1 + \cos\theta_1 \sin\theta_2)] \quad (7)$$

$$= l_1^2 + l_2^2 + 2 l_1 l_2 [\cos^2\theta_1 \cos\theta_2 + \sin^2\theta_2 \cos\theta_2]$$

$$= l_1^2 + l_2^2 + 2 l_1 l_2 \cos\theta_2 \quad (8)$$

And

$$\cos\theta_2= \frac{x^2 + y^2 - l_1^2 - l_2^2}{2l_1 l_2} \quad (9)$$

From here we could get the angle directly using the arc cosine function but this function is very inaccurate for small angle s, the typical way to avoid this accuracy is to convert further until we can use the atan2 function

$$\cos^2\theta_2 + \sin^2\theta_2 = 1 \text{ and } \sin\theta_2=\pm\sqrt{1-\cos^2\theta_2}$$

The two solutions corresponding to the 'elbow up' and 'elbow down 'configuration as shown in above figure and finally we get:

$$\theta_2=\text{atan2}(\sin\theta_2 \cos\theta_2) \quad (10)$$

$$= \text{a tan2} (\pm\sqrt{1-\cos^2\theta_2} . \cos\theta_2$$

$$=\text{atan2}\left(\pm\sqrt{1-\left(\frac{x^2 + y^2 - l_1^2 - l_2^2}{2l_1 l_2}\right)}, \frac{x^2 + y^2 - l_1^2 - l_2^2}{2l_1 l_2}\right. \quad (11)$$

For solving θ_1 we rewrite the original nonlinear equations using a change of variables as follow (figure 4)

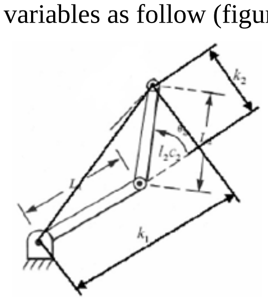

Fig. 4 Mathematical expression for two links

$$x=l_1\cos\theta_1+l_2\cos(\theta_1+\theta_2) \quad (12)$$
$$y=l_1\sin\theta_1+l_2\sin(\theta_1+\theta_2) \quad (13)$$
$$x = k_1\cos\theta_1 + k_2\sin\theta_1 \quad (14)$$
$$y=k_1\sin\theta_1+ k_2\cos\theta_1 \quad (15)$$

where

$$k_1 =l_1+ l_2\cos\theta_2 \quad (16)$$
$$k_2 = l_2\sin\theta_2 \quad (17)$$

next we change the way we write the constant k_1 k_2 (figure 5)

$$r = \sqrt{k_1^2 + k_2^2}$$

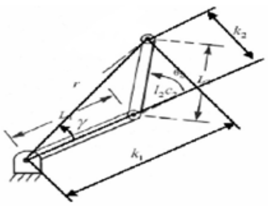

Fig. 5 Mathematical expression

$$\Upsilon= \operatorname{atan2}(k_2, k_1) \quad (18)$$

$K_1= r\cos\Upsilon$

$K_2= r\sin\Upsilon$

Inserting into previous transformations of x and y yields.

$$X= r\cos\Upsilon\cos\theta_1+r\sin\theta_1\sin\Upsilon \quad (19)$$
$$y= r\cos\Upsilon\cos\theta_1+r\sin\theta_1\sin\Upsilon \quad (20)$$

or $\frac{y}{r}= \sin(\theta_1+\Upsilon)$

$\frac{x}{r}= \cos(\theta+\Upsilon)$

Apply the atan2 function

$$\Upsilon+ \theta_1 \operatorname{atan2}\left(\frac{y}{r}, \frac{y}{r}\right)=\operatorname{atan2}(y,x) \quad (21)$$
$$\theta_1 = \operatorname{atan}(y,x)-\operatorname{atan2}(k_2, k_1) \quad (22)$$

A. Mathematical model of three degree-of-freedom (3 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. A vertical articulated robotic arm with 3 links (Figure 1) having length l1, l2 and l3 respectively, is considered which has a three degree-of- freedom [2,3]. In three degree-of-freedom robotic arm the inverse kinematics equations are as below:

$x = l1\cos\theta1 + l2\cos(\theta1 + \theta2) + l3\cos(\theta1 + \theta2 + \theta3$ (23)

$y = l1\sin\theta1 + l2\sin(\theta1 + \theta2) + l3\sin(\theta1 + \theta2 + \theta3)$ (24)

$\theta = \theta1 + \theta2 + \theta3$

Knowing the arm link lengths l1, l2 and l3 for position (x, y) we had calculated the values of joint angles θ1, θ2, θ3 [3]

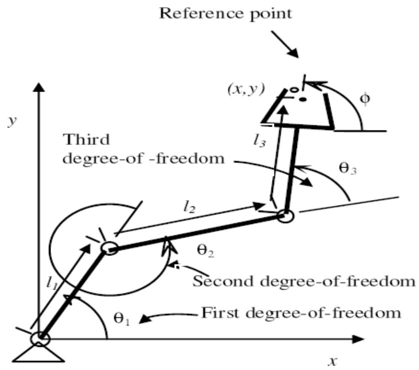

Fig. 6 Three link robotic arm

B. Modeling of robotics arm

The inverse kinematics problem is much more interesting and its solution is more useful. At the position level, the problem is stated as, "Given the desired position of the robot's hand, what must be the angles at all of the robots joints?" Humans solve this problem all the time without even thinking about it. When you are eating your cereal in the morning you just reach out and grab your spoon. You don't think, "my shoulder needs to do this, my elbow needs to do that, etc." Below we will look at how most robots have to solve the problem. We will start with a very simple example.

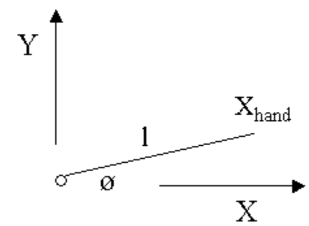

Fig. 7 Single link manipulator

The figure above is a schematic of a simple robot lying in the X-Y plane. The robot has one link of length l and one joint with angle Ø. The position of the robot's hand is Xhand. The inverse kinematics problem (at the position level) for this robotics as follows: Given Xhand what is the joint angle Ø? We'll start the solution to this problem by writing down the forward position equation, and then solve for Ø.

Xhand = lcosØ (forward position solution)

CosØ = Xhand / l

Ø = cos-1(Xhand/l)

To finish the solution let's say that this robot's link has a length of 1 foot and we want the robot's hand to be at X = .7071 feet. That gives:

Ø = cos-1(.7071) = +/- 45 degrees

Even for this simple example, there are two solutions to the inverse kinematics problem: one at plus 45 degrees and one at minus 45 degrees! The existence of multiple solutions adds to the challenge of the inverse kinematics problem. Typically we will need to know which of the solutions is correct. All programming languages that I know of supply a trigonometric function called ATan2 that will find the proper quadrant when given both the X and Y arguments: Ø = ATan2(Y/X). There is one more interesting inverse kinematics problem

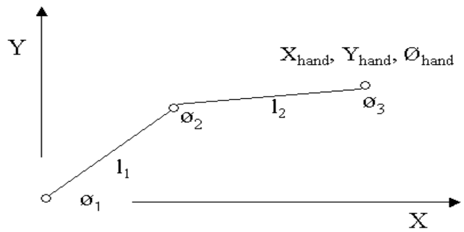

Fig. 8 Two link manipulator

You may have to use your imagination a bit, but the schematic above is the planar part of the SCARA robot we discuss in the industrial robots section. Here's the statement of the inverse kinematics problem at the position level for this robot:

Given: Xhand, Yhand, Øhand

Find:Ø1,Ø2andØ3 To aid in solving this problem, I am going to define an imaginary straight line that extends from the robot's first joint to its last joint as follows:

B: length of imaginary line

q1: angle between X-axis and imaginary line

q2: interior angle between imaginary line and link l1

Then we have:

B2 =Xhand2 + Yhand2 (22)

q1 =ATan2 (Yhand/Xhand) (23)

q2 =a cos [(l12 - l22 + B2)/2l1B] (24)

Ø1 = q1 + q2

V. SOFT COMPUTING

This problem is well addressed by neuro-fuzzy techniques because a solution is not easily found by analytical or numerical techniques. While an analytical technique is difficult, moving an arm in the presence of an obstacle can be instinctively performed b a child. Neuro-fuzzy systems excel in using sample data to determine an input-output relationship. Neural networks bring to this solution the ability to learn while fuzzy logic is based on mimicking an expert's thinking. In addition, as hardware technology progresses, more and more value will be placed on solutions that can utilize parallel processing, like neural networks. The field of neuro-fuzzy technology has gone in many directions. The neuro-fuzzy technique replaces the traditional fuzzy logic system with a multilayer back propagation neural network. This type of system is beneficial for several reasons. While it is true that a child is able to move an arm around an obstacle to reach a desired goal, that ability is intuitive. Putting the instructions for performing such a task into a neat, fuzzy logic, IF/THEN rule base is not easy [12]. Thus, there is a necessity for the neural network to learn the rules. The fuzzifiers and defuzzifiers necessary for any fuzzy system provide an interface between an expert's control of a simulated arm and the neural network.GAs are tools on probabilistic and casualty, not necessarily they will have the same type of evolution when applied to the same problem. GAs are slower because they are tools of evolution and not for specific optimizations [9]. They are simpler, easy programming, and demand less mathematics complexity to describe the process to be optimized. ANN and fuzzy logic techniques required more information regarding system and more mathematics as compare to GA. The great advantage observed in the GAs is tool of easy application and in robotics they could be thoroughly used to do several tasks, needing for that only small description of the problem.

VI. CONCLUSION

In this paper we have presented the robotics kinematics for two and three link manipulator problem and discussed the kinematics in the contest of soft computing techniques like fuzzy, neural network and genetic algorithms. It is concluded that in the presence of several optimization attributes for a physical system of higher order manipulator, soft computing techniques are alternatives to find the solutions of kinematics problem. Various soft computing techniques have their own advantages as neural networks required complete information of the system and required training where as fuzzy and genetic algorithms required less information of the system and easy to implement.

REFERENCES

[1] Ahuactzin J. M., Gupta K. K., 1999. 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.

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

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

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

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

[6] Deb S.R., Robotics Technology and Flexible Automation. Tata Mc-Graw Hill, 2002.

[7] Fu K.S., Gonzalez R.C., Lee C.S.G., Robotics: Control, Sensing, Vision and Intelligence. Mc-Graw Hill International Editions, 1987.

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

[9] Gemeinder M. and Gerke M., 2003. GA-based path planning for mobile robot systems employing an active search algorithm. Elsevier Applied Soft Computing 3(2), 149-158.

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

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

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

Gurjeet Singh is working as a lecturer in Department of Electronics & Communication Engineering in Amritsar College of Engineering and Technology, Amritsar, Punjab, India

Vijay Kumar Banga is working as professor and Head of the Department of Electronics & Communication Engineering, Amritsar College of Engineering and Technology, Amritsar, Punjab, India. He obtained his B. E (Electronics and Instrumentation Engineering) from Punjabi University, Patiala, Punjab, India, M.Tech (Electronics and Instrumentation) from Panjab University , Chandigarh, India and Ph.D. in Electronics (Artificial Intelligence) form Thapar University, Patiala., India. Presently, he has 13 years of research and UG & PG teaching experience.