CHAPTER 2

LITERATURE REVIEW

Kinematics analysis (Latombe 1991, Hwang and Ahuja 1992) is one of the basic modules, needed to increase robot's intelligence and usability. It deals the relations between the variable joint coordinates of the desired robot mechanism and the positions and orientations of the end effector. Kinematic analysis can significantly increase robotic system efficiency by raising the level of abstraction in human-robot interactions. It relieves human operators of the continual burden of detailed pick and place operational plan and allows them to accomplish tasks with a fewer higher level commands.

With reduced fatigue and programming errors, human operators can increase the efficiency of the robotic system dramatically by concentrating more on accomplishing robotic tasks at supervisory level.

Development of a fast and efficient procedure for kinematics analysis is a key step in the research field on autonomous robots. Given the goal position and orientation of an object to pick up and place in a specified place using an autonomous robot in its working space, the kinematics analysis must be able to find the joint coordinates to complete the task. The methods that are currently used in practice to tackle these instances have some notable drawbacks. They fail to find inverse kinematics solutions exactly and efficiently, and have limited capabilities when handling cases in which the configuration of robot varies.

Inverse kinematics is one of the fundamental issues in the kinematics analysis and development of pick and place manipulators. Inverse kinematics normally determines the joint coordinates to satisfy position and orientation of the manipulator that coincides with desired goal optimally. Optimal performance means different things to different people - in terms of generating the required models in minimum time, obtaining a generalized model in minimum time, considering position and orientation etc.

Researchers have solved various forward and inverse kinematics problems and analysed reachability of the end effectors and workspace of various robots which are found in open literature.

The kinematics analysis can be categorized as given below:

1. Forward kinematics analysis
2. Reachability analysis
3. Path and workspace analysis
4. Inverse kinematics analysis

2.1 FORWARD KINEMATICS ANALYSIS

In order to define the position and orientation of the end effector which is a function of joint values, it is necessary to create a database for robot joints. Rotary joints provide the path of an industrial robot's TCP and its workspace. The problem of forward kinematics analysis has been investigated as found in many literatures. Various approaches have been used for the analysis.

Ambuj Kumar Mitra (2012) explained an alternative formulation for the development of homogeneous matrix method on the basis of motion at the joints of serial mechanism through the numerical study of a 5 DOF serial robot and verified the end-results of the formulation of Uicker et al (2004) for serial manipulator robot. Uicker et al (2004) presented some formulation for velocity analysis and acceleration analysis for serial robots.

Han Ming Cai et al (2011) established the coordinates of robot kinematics mathematical model and the target matrix using D-H coordinate transformation method. PRO/E is used to model the robot and MATLAB functions are used for the analysis.

Ch Ravi Kumar et al (2012) controlled the robot manipulator arm of Lynx-6 robot by traditional PID controller, Neuro Fuzzy logic controller and compared the results obtained by those methods.

These are the limitations of the above works:

1. It is evident from the available literature that the concepts are not well developed for the Reachability analysis, path and workspace analysis of general serial mechanism. Reason being, the mathematical formulations for these matrices are not much helpful for the numerical computation for kinematics analysis of multi-body mechanism.

2. The end results are not validated using geometric methods.

Zhihua Sha et al (2012) presented the analysis of a simplified model of radial lines stretching motion, the condition for radial linear motion of the end actuator of wafer-handling robot. The dynamic simulation of polar coordinates was realized based on Microsoft Visual Studio 2008 and

Pro/toolkit. Mostafa Ghayour et al (2012) analysed the direct kinematics of position of non contact legs of a Hexapod Spider-like Mobile Robot. Jun Xie et al (2012) established the kinematics model of practical series mechanical arm to act the manipulations with parallel executive mechanism, and solved the problem using D-H transformation.

The 3D model of the arm was created by Pro/E. Movement analysis upon series mechanical arm confirmed its correctness and feasibility, and also offered a theoretical basis to follow-up structural design. Anurag Verma et al (2011) investigated the forward kinematics analysis of SCORBOT ER V Plus robot as found in literature.

But this work has the following major limitations:

1. The experimental and theoretical results are not accurate.
2. For the home position and all the other set of parameters, it gave only approximate results.

2.2 REACHABILITY ANALYSIS

Reachability analysis is used to analyze the possible TCP extreme co ordinates in its workspace. Reachability analysis has been detailed as found in many literatures. Various approaches have been used.

Jingzhou (James) Yang et al (2008) addressed some criteria for implementing the placement of robot manipulators with the objective of reaching specified target points. Placement of an open-loop robotic manipulator in a working environment is characterized by defining the position and orientation of the manipulator’s base with respect to a fixed reference frame.

The approach used in this work is based on characterizing the placement, forcing a cost function to impel the workspace envelope in terms of surface patches towards the target points and subject to functionality constraints, but not requiring the computation of inverse kinematics. The numerical formulation and experimental code are demonstrated using a number of examples.

Roland Geraerts et al (2007) gave a reachability based analysis for sampling based planners which leads to a better understanding of the success of the approach in solving complex motion planning problems. This analysis compares the techniques based on coverage and connectivity of the free configuration space. The experiments show, contrary to general belief, that the main challenge is not getting the free space covered but getting the nodes connected, especially when the problems get more complicated, e.g. when a narrow passage is present. By using this knowledge, one can tackle the narrow passage problem by incorporating a refined neighbor selection strategy, a hybrid sampling strategy, and a more powerful local planner, leading to a considerable speed-up.

The limitations of the above works are:

1. The X, Y and Z values are not analysed individually. For the translational movement and one directional movement it is necessary to analyse the change in the movement.

2. The relative movement of the coordinates is not expressed in the above research. But it is considered in the model of this research.

3. The graphical representations of the reachable points are not shown as indicated clearly.

2.3 PATH AND WORKSPACE ANALYSES

Path and workspace analyses are used to analyze the possible path of travel of TCP and to develop inverse kinematics solution. The path and workspace analysis has been detailed as found in many literatures. Various approaches have been used.

Abdel-Malek et al (1999) presented a perturbation method to determine the workspace, envelope volume, bifurcation analysis, and cross sectional views of the workspace of general 5 DOF manipulator. They considered singularity avoidance as main criteria for design.

Ceccarelli and Lanni (2004) formed a multi objective optimization problem for 3R serial link manipulators by taking workspace volume and robot dimensions as objective functions, and given work space limits as constraints. They considered variables in the form of manipulator length and solved the problem using sequential programming method.

Mazen Zein et al (2006) as a preliminary step in the design of new manipulators proposed a classification based on the topology of the workspace of three-revolute orthogonal manipulators that have at least one of their D-H parameters equal to zero.

The workspace is characterized in a half cross-section by the singular curves. The workspace topology is defined by the number of cusps and nodes that appear on these singular curves.

The manipulators are classified into different types with similar kinematics properties. Each type is evaluated according to interesting kinematics properties such as, whether the workspace is fully reachable with four inverse kinematics solutions or not, the existence of voids, and the feasibility of continuous trajectories in the workspace. It is found that several orthogonal manipulators have a ‘‘well-connected’’ workspace, that is, their workspace is fully accessible with four inverse kinematics solutions and any continuous trajectory is feasible.

Andre Gallant et al (2012) presented a geometric method to determine the dexterous workspace of two architectures of kinematically redundant planar parallel manipulators. In this work, a geometric method is presented to determine the dexterous workspace of two architectures of kinematically redundant planar parallel manipulators. The architectures studied are the n-RRRR and the n-RRPR. These architectures are characterized by having a revolute actuator as the kinematically redundant actuator added to the base of each kinematics chain. First, the dexterous workspace of the non-redundant sub-chain (RRR or RPR) of each kinematics chain is studied. Then the effect of the redundant actuator is considered to yield a geometric representation of the dexterous workspace of each kinematics chain. The intersection of the dexterous workspaces of all kinematics chains of a manipulator is determined to obtain the geometric representation of the dexterous workspace. The Gauss Divergence Theorem is applied to compute the area of the dexterous workspace. An example is given to demonstrate an application of the method. Finally, some design considerations are given to maximize the size of the workspace.

Khushdeep Goyal et al (2010) simulated the workspace based on MATLAB program using analytical method. Hanming Cai et al (2012) used Monte Carlo method to analyze the workspace of an industrial robot and modeled the robot with PRO/E. The relationship between the robot position and joint variables was analyzed. But to verify the correctness of kinematics equations, simulations were not performed. Yu Jie Cui (2012) deduced a formulation of modular robot based on D-H and presented the kinematics simulation based on MATLAB. But the workspace was not simulated in this work.

A path tracking algorithm was proposed to compensate for path deviation due to torque limits by Kwang Sik Eoma et al (2000) which used a disturbance observer to obtain a SERD (Simple Equivalent Robot Dynamic) model in order to modify the desired acceleration of the nominal trajectory in Cartesian space.

A technique based on CGA (Continuous Genetic Algorithms) to solve the path generation problem for robot manipulators was presented in Zaer S. Abo-Hammoura et al (2002).

Two user defined algorithms were developed using MATLAB for Joint space and Cartesian space tracking Himanshu Chaudhary et al (2012).

The limitations of the above works are:

1. Here straight line movement of the end effector was only considered. In this only 5 parameters in Cartesian space are considered (x, y, z, roll and pitch) without considering position and orientation vectors while analyzing forward and inverse kinematics.

2. The 3D representation of the path and workspace are not shown in the presentable form.

2.4 INVERSE KINEMATICS ANALYSIS

In order to obtain the inverse kinematics solution of industrial robots, various approaches have been used.

The problem of inverse kinematics analysis had been investigated by researchers as reported in many literatures. Sariyildiz.E et al (2009,2011), Gan,J.Q (2005), Karpinska et al (2012), Nunes et al (2012), Feng.Y et al (2012). The design of controller had been investigated by researchers as reported in some literature. Han S.I et al (2011), Chaudhary.H et al (2012), Cai.H.M et al (2012), Xu.C.K et al (2011). Various approaches had been used for inverse kinematics analysis.

The analytical procedure for solving an inverse kinematics problem and to determine the joint coordinates of each joint using MATLAB program, was already available in literature Deshpande.V.A et al (2012) and Chaudhary H et al (2011).

Some researchers have addressed the inverse kinematics problem of serial robot manipulators using conventional techniques like geometric, algebraic and iterative methods. Srinivas Neppalli et al (2008), Deshpande.V.A. et al (2012) and Chris T. Freeman (2012) and some others have solved using widely published methodologies like ANN (Artificial Neural Network), ANFIS (Adaptive Neuro-Fuzzy Inference System), RNN (Random Neural Network), Biomimetic approach. Chaudhary H et al (2012), Chaudhary H et al (2012), Guang Wu et al (1994), Panagiotis K. Artemiadis et al (2010).

Algebraic methods cannot guarantee closed form solutions. Geometric methods must have closed form solutions for the first three joints of the manipulator geometrically. Because of the above reasons, serial robots have received increased attention during the last decades, along with their associated problem of complex kinematics. The proposed methods yield multiple and approximate solutions and also not suitable for real-time applications.

Alba Perez et al (2005) formulates and solves the design equations for three DOF spatial serial chains constructed with two revolute (R) joints and one prismatic (P) joint. The chain has a spherical workspace and is often used as the shoulder joint of a robot.

Iterative solutions for finding the inverse kinematics solution of industrial robots have been proposed by Uicker et al (2004). Samer Yahya et al (2011) proposed a method to compute the inverse kinematics for the specified points and carried out geometrically. In this method, the angles between the adjacent links are set to be the same, which makes lining up of two or more joint axes impossible; therefore, avoiding singularities.

Antonio Benitez et al (2012) modeled and solved kinematics chains with 6 DOF PUMA robot. The simulation environment for kinematic problems on PUMA was developed under C++ language with Open GL (Graphics Library). Sandra Di Rocco et al (2010) presented a new solution to the inverse kinematics problem of a general six-revolute serial-link manipulator based on a homotopy method. These methods provide a means of constructing a homotopy function and a finite set of start points such that the paths emanating from the start points end in a finite set of endpoints that contain all isolated solutions of the equations. They provided a new algorithm that gives a required solution to the inverse kinematics problem of a general 6R manipulator.

Tae-Jeong Jang et al (1995) proposed an iterative learning control method to achieve precise tracking control of a class of nonlinear systems over a finite time interval. The learning is done in a feedback configuration and the learning law updates the feed forward input from the plant input of the previous trial. The proposed learning control process is applied to the tracking control of a two link robot manipulator, and good tracking performance is obtained in the simulation.

Gary M. Bone (1995) developed a novel iterative learning control formulation of the long-range predictive control method GPC (Generalized Predictive Control) termed GPCL (Generalized Predictive Control with learning). According to a simulation study, for six plants of varying control difficulty, GPCL outperformed GPC after two trials, and reduced the final value of the output variance by 48% on average for a 50% repeatable disturbance. In robotic edge-following experiments with a 47% repeatable disturbance, GPCL reduced the average output variance by 32% relative to GPC after three trials. After ten trials, the reduction was 43%.

Gopinath S et al (2004) verified the iterative learning control algorithms including actuator dynamics for a two DOF industrial robot manipulators through detailed simulation results.

Chiang-Ju Chien et al (2008) presented an iterative learning controller with a projection-free adaptive algorithm for repetitive control of uncertain robot manipulators. Simulation results are also provided to illustrate the effectiveness of the learning controller.

Abdelhamid Tayebi et al (2004) proposed some adaptive ILC (Iterative Learning Control) schemes for trajectory tracking of rigid robot manipulators, with unknown parameters, performing repetitive tasks. A five DOF robot manipulator “CATALYST5” was tested experimentally. Furthermore, in contrast with classical ILC schemes where the number of iterative variables is generally equal to the number of control inputs, the adaptive control schemes tested in this paper involve just one or two iterative variables. Chris T. Freeman (2012) applied iterative learning control methodology to the point-to-point motion control problem in which the output is only specified at a subset of time instants also derived conditions for convergence to zero PTP tracking error.

It is shown how the extra design freedom the PTP set-up brings and allows additional input, output and state constraints to be simultaneously addressed, hence providing a powerful design framework of wide practical utility. Experimental results confirm the performance and accuracy that can be achieved, and the improvements gained over the standard ILC framework.

Pashkevich. A (1997) proposed two reliable iterative algorithms to solve the problem in real time. The algorithms have been implemented in commercial robot controllers and software packages for the computer-aided design of welding robotic cells. The paper deals with the inverse transformation of coordinates for robotic manipulators with high payload capacity, which is widely used in welding applications. Such manipulators are usually equipped with 3 DOF, offset wrists or 2 DOF reduced wrists that do not satisfy the Pieper condition that ensures the existence of a closed-form solution of the inverse kinematics.

A genetic algorithm based strategy for the determination of optimum joint angles in a given search space for 3 armed planar manipulator system is formulated and applied to contribute to a productive material handling and processing by Albert, F.Y.C et al (2011). Further, to optimize the movement of end effector, all the orientation vectors of the goal are not completely described. A controller based on Inverse Kinematics is designed. This serves the purpose by applying Artificial Neural Network (ANN) and an Adaptive Neuro-Fuzzy Inference System (ANFIS) method.

Liu.Z.Z et al (2012) illustrated, a 5 DOF serial robot manipulator with prismatic arm joint and offset wrist with the pre-given uncertain orientation vectors is solved by virtual joint method. Inverse kinematics calculation of arc welding robot is achieved by RBF (Radial Basis Function) of six-input and single output. The forward and inverse kinematics is seen as a nonlinear mapping between the joint space and the operation space of the robot. Song.D.Z et al (2012) obtained results of the final end-effector trajectory errors of the proposed neural network model of the inverse kinematics problem and they are verified by applying proper direct kinematics virtual LabVIEW instrumentation by Olaru.A et al (2012). But inverse kinematics in LabVIEW is not done in their work.

Song J (2012) adopted the D-H method to do the kinematics analysis of 4 DOF articulated egg plant-picking robot and inverse kinematics is solved by using the simplified inverse transformation method. It is shown by tests that the error of the forward kinematics solution is ±1.5mm, while the error of the inverse kinematics solution is ±1.31°.

The limitations of the above works are:

1. Time consumption and expensive in implementation.

2. The problems solved in the above works are only suitable for fixed parameters. LabVIEW is not used to solve the problems.

3. The proposed novel techniques namely CIIKM (Complete Iterative Inverse Kinematics Method), and PIIKM (Partial Iterative Inverse Kinematics Method) reported in this research work has not been applied in the previous work.

In order to address the above said limitations, a novel iterative procedure considering all the position and orientation vectors of the goal has been used for solving the inverse kinematics problem in this research. The iterative methods converge only to a single solution and this solution depends on the goal point.

There is no generalized model developed to analyse all the analyses in a single platform. And also the design stage needs a model to analyse kinematics issues within the specified workspace. At present there is no such method which consideres all the above stated requirements. So this research work is concerned with the development of a novel method that includes all the above and obtaining solutions by stage-by-stage approach.