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Generalized kinematic analysis of an industrial serial robot using labview

Jebaraj J
PG Manufacturing Engineering
Christian College of Engineering and Technology
Oddanchatram,India
Jebaraj505@gmail.com

Dr.S.Navaneethasanthakumar
Department of Mechanical Engineering
Christian College of Engineering and Technology
Oddanchatram,India
snscrk@rediffmail.com

Abstract— **The study of robot kinematic analysis is an interesting problem since its applications are directed to industries. In this work a generalized procedure for the forward kinematics analysis of industrial serial robot is proposed. The analysis is done by using LAB VIEW software. The generalized LAB VIEW programme is used to analyze the forward kinematics of any industrial robot and plotted the graphs of analyzing path of the robot manipulator. We are considering the SCORBOT industrial robot and its manipulator path values for validation of this proposed work.**

Keywords— Industrial robot; D-H Parameters; Forward kinematics; LAB VIEW software.

I. INTRODUCTION

Serial manipulators are the most common industrial robots. They are designed as a series of links connected by motor-actuated joints that extend from a base to an end-effecter. Often they have an anthropomorphic arm structure described as having a "shoulder", an "elbow", and a "wrist". Serial robots usually have six joints, because it requires at least six degrees of freedom to place a manipulated object in an arbitrary position and orientation within its workspace.

A popular application for serial robots in today's industry is the pick-and-place assembly robot, called a SCARA robot, and also today's educational purpose robot, called SCORBOT robot which has five degrees of freedom.

The application is based on the type of work that the robot is to do. Robot models are designed and created with specific applications or processes in mind. Different applications will have different requirements. For instance, a painting robot will require a small payload but a large movement range and be explosion proof. On the other hand, an assembly robot will have a small workspace but will be very precise and fast. Depending on the target application, the industrial robot will have a specific type of movement, linkage dimension, control law, software and accessory packages.

The workspace determination of a robot with general structural parameters is a complex problem, which cannot be solved in an explicit way. His project work aimed to characterize the free workspace of the robot and the changes that occur in the presence of obstacles.

An industrial robot commonly refers to a robot arm used in a factory environment for manufacturing applications. Traditional industrial robots can be classified according to different criteria such as **type of movement** (degrees of freedom), **application** (manufacturing process), **architecture** (serial or parallel) and **brand**. Then there is also a new qualifier for industrial robots that can be **collaborative or not**.

II. KINEMATICS ANALYSIS

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

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

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workspaces of all kinematics chains of a manipulator is determined to obtain the geometric representation of the dexterous workspace. [1]

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. MATLAB program using analytical method.[2] Khushdeep Goyal et al (2010) simulated the workspace based on 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.[3] 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.[4]Kamel Bouzgou et al (2015) propose a study of criteria for choosing the best solution among the solutions of the inverse geometric model of the 6 DOF robot arm, FANUC 200iC Lr Mate. Knowledge of these parameters can help us the control and the generation of motions without that the task will be redundant with a minimization of the execution time, the effort and energy consumed by actuators. For this, the solving of the inverse kinematics by an analytical method is necessary, and the Jacobian matrix give us the nonlinear equation for find the singular configurations. We validate our work by conducting a simulation software platform that allows us to verify the results of manipulation in a virtual reality environment based on VRML and Matlab software, integration with the CAD model.[5]S.N.Mulande et al (2015) an algorithm to calculate the 3D workspace based on Denavit-Hatenberg (D-H) parameters to indicate the number of possible target solution and orientation, have been developed and validated. The existing Robix robot is modeled in CAD software and the respective D-H parameters have been calculated. The data so found out is given as an input for the Matlab simulation in order to visualize the 3D- workspace.[6]S.Seriani et al (2015) is inspired by an industrial task, i.e., spray painting a large area by means of a robotic system consisting in a cable driven parallel robot (CDPR). In many cases, the area of the robot workspace is smaller than the area to be painted. For this reason, the base of the robot has to be shifted several times during the painting process. These robots are referred to as repetitive workspace robot (RWR). In other words, in order to accomplish the whole task, they need to be moved after they have completed a sub task locally. In this work we are evaluate the efficiency of the workspace of a 2-link CDPR. Finally we show how the index value changes in relation to some geometrical parameters of the robot, thus laying the foundation for a general design methodology.[7]Himanshu Chaudhary and Rajendra Prasad (2011), an Adaptive Neuro-Fuzzy Inference System (ANFIS) method based on the Artificial Neural Network (ANN) is applied to design an Inverse Kinematic based controller forthe inverse kinematical control of SCORBOT-ER V Plus. The proposed ANFIS controller combines the advantages of a fuzzy controller as well as the quick response and adaptability nature of an Artificial Neural Network (ANN). The ANFIS structures were trained using the generated database by the fuzzy controller of the SCORBOT-ER V Plus. The performance of the proposed system has been compared with the experimental setup prepared with SCORBOT-ER V Plus robot manipulator. Computer Simulation is conducted to demonstrate accuracy of the proposed controller to generate an appropriate joint angle for reaching desired Cartesian state, without any error. The entire system has been modeled using MATLAB 2011.[8] M.F.Aly et al (2014), an workspace (WS) determination of a robot with general structural parameters is a complex problem, which cannot be solved in an explicit way. Closed form solutions are only available in some particular cases. Otherwise, computational algorithms and numerical techniques are used. The task becomes even much more complicated by the presence of obstacles in the robot accessible region. Obstacle presence does not only exclude points from the original WS but it affects the whole robot workspace's shape and size to the extent that it sometimes divides the working space in two or more separate regions that cannot be linked by the same robot. Much research work in the literature is directed toward path planning in the presence of obstacles without having to determine the robot WS. However, a real situation in industry occurs when the knowledge of the WS is of importance in facility layout. This paper presents an approach for the estimation of a generic open-chain robot in the presence of obstacles with any desired number of prismatic and/or revolute joints of any order. Joints' axes may have any orientation relative to each other. The robot can be placed in free space or in a work cell consisting of a set of Computer Numerically Controlled (CNC) machines and some obstacles.[9]

III. METHEMATICAL MODEL PROPOSED A GENERALIZED PROCEDURE

Denavit–hartenberg parameters

The Denavit–Hartenberg parameters (also called D-H parameters) are the four parameters associated with a particular convention for attaching reference frames to the links of a spatial kinematic chain, or robot manipulator.

Jacques Denavit and Richard Hartenberg introduced this convention in 1955 in order to standardize the coordinate frames for spatial linkages.

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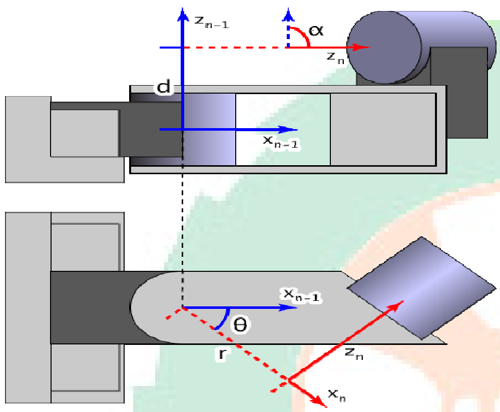
Richard Paul demonstrated its value for the kinematic analysis of robotic systems in 1981. While many conventions for attaching references frames have been developed, the Denavit-Hartenberg convention remains the standard approach.



Denavit–Hartenberg parameters

Denavit-hartenberg matrix

It is common to separate a screw displacement into the product of a pure translation along a line and a pure rotation about the line, so that

$$[Z_i] - \mathrm{Trans}_{Z_i}(d_i)\,\mathrm{Rot}_{Z_i}(\theta_i),$$

and

$$[X_i] = \mathrm{Trans}_{X_i}(r_{i,i+1})\,\mathrm{Rot}_{X_i}(\alpha_{i,i+1}).$$

Using this notation, each link can be described by a coordinate transformation from the previous coordinate system to the next coordinate system.

$$^{n-1}T_n = \mathrm{Trans}_{z_{n-1}}(d_n) \cdot \mathrm{Rot}_{z_{n-1}}(\theta_n) \cdot \mathrm{Trans}_{x_n}(r_n) \cdot \mathrm{Rot}_{x_n}(\alpha_n)$$

Note that this is the product of two screw displacements,

The matrices associated with these operations are:

$$\mathrm{Trans}_{z_{n-1}}(d_n) = \left[\begin{array}{ccc|c} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_n \\ \hline 0 & 0 & 0 & 1 \end{array}\right]$$

$$\mathrm{Rot}_{z_{n-1}}(\theta_n) = \left[\begin{array}{ccc|c} \cos\theta_n & -\sin\theta_n & 0 & 0 \\ \sin\theta_n & \cos\theta_n & 0 & 0 \\ 0 & 0 & 1 & 0 \\ \hline 0 & 0 & 0 & 1 \end{array}\right]$$

$$\mathrm{Trans}_{x_n}(r_n) = \left[\begin{array}{ccc|c} 1 & 0 & 0 & r_n \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ \hline 0 & 0 & 0 & 1 \end{array}\right]$$

$$\mathrm{Rot}_{x_n}(\alpha_n) = \left[\begin{array}{ccc|c} 1 & 0 & 0 & 0 \\ 0 & \cos\alpha_n & -\sin\alpha_n & 0 \\ 0 & \sin\alpha_n & \cos\alpha_n & 0 \\ \hline 0 & 0 & 0 & 1 \end{array}\right]$$

This gives:

$$^{n-1}T_n = \left[\begin{array}{ccc|c} \cos\theta_n & -\sin\theta_n\cos\alpha_n & \sin\theta_n\sin\alpha_n & r_n\cos\theta_n \\ \sin\theta_n & \cos\theta_n\cos\alpha_n & -\cos\theta_n\sin\alpha_n & r_n\sin\theta_n \\ 0 & \sin\alpha_n & \cos\alpha_n & d_n \\ \hline 0 & 0 & 0 & 1 \end{array}\right] = \left[\begin{array}{ccc|c} & R & & T \\ \hline 0 & 0 & 0 & 1 \end{array}\right]$$

where R is the 3×3 submatrix describing rotation and T is the 3×1 submatrix describing translation.

IV SOFTWARE USED

In this work, all the analyses namely Forward Kinematics Analysis (FKA), Reachability Analysis (RA), Path Analysis (PA), Workspace Analysis (WA), and Inverse Kinematics Analysis (IKA) are done using LabVIEW and FKM is verified using RoboCell and validated with AutoCAD. The LabVIEW is much suitable for these analyses. Various features of the software used and the reason for selecting the same are presented here as an overview.

LABVIEW

In this research FKM, Reachability analysis, path and workspace analyses, and IKM have been developed using LabVIEW. The LabVIEW is employed for the analysis of SCORBOT ER V Plus. It has many tools and they are efficiently used by many researchers. The reasons for using LabVIEW in this research work are given below:

1. Dataflow Programming
2. Graphical Programming
3. Interfacing
4. Code compilation
5. Large libraries
6. Code re-use
7. Parallel programming
8. Ecosystem

FORWARD KINEMATIC ANALYSIS

In this work, the generalized procedure of forward kinematic analysis of the industrial serial robot was proposed.the forward kinematic analysis of the serial robot is consided the following parameter of the serial robot,

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1. Base minimum
2. Shoulder minimum
3. Elbow minimum
4. Wrist minimum
5. Base maximum
6. Shoulder maximum
7. Elbow maximum
8. Wrist maximum

The above parameters of the serial robot minimum and maximum values are analysised and done by using labview software.

BASE MINIMUM & MAXIMUM

In this experiment, Base Rotation increment is set as 10. The initial value for θ_1 is -155 and final value is 155. These data are computed and interpolated data encompass a set of N=32 points stating X,Y and Z coordinates. All the joint parameters with their minimum range are assumed.
θ_2 = -35, θ_3 = -130, θ_4 =-130 and θ_5 =-570 are kept constant and θ_1 (±155) is variable..

TABLE I. BASE MINIMUM

S.NO	T1	PX	PY	PZ
1	-155	-40.6412	-18.9513	401.545
2	-145	-36.7329	-25.7207	401.545
3	-135	-31.7085	-31.7085	401.545
4	-125	-25.7207	-36.7329	401.545
5	-115	-18.9513	-40.6412	401.545
6	-105	-11.6061	-43.3147	401.545
7	-95	-3.90829	-44.672	401.545
8	-85	3.90829	-44.672	401.545
9	-75	11.6061	-43.3147	401.545
10	-65	18.9513	-40.6412	401.545
11	-55	25.7207	-36.7329	401.545
12	-45	31.7085	-31.7085	401.545
13	-35	36.7329	-25.7207	401.545
14	-25	40.6412	-18.9513	401.545
15	-15	43.3147	-11.6061	401.545
15	-5	44.672	-3.90829	401.545
17	5	44.672	3.90829	401.545
18	15	43.3147	11.6061	401.545
19	25	40.6412	18.9513	401.545
28	35	36.7329	25.7207	401.545
21	45	31.7085	31.7085	401.545
22	55	25.7207	36.7329	401.545
23	65	18.9513	40.6412	401.545
24	75	11.6061	43.3147	401.545
25	85	3.90829	44.672	401.545
26	95	-3.90829	44.672	401.545
27	104	-11.6061	43.3147	401.545
28	115	-18.9513	40.6412	401.545
29	125	-25.7207	36.7329	401.545
30	135	-31.7085	31.7085	401.545
31	145	-36.7329	25.7207	401.545
32	155	-40.6412	18.9513	401.545

BASE MAXIMUM

In this experiment, base rotation increment is set as 10. The initial value for θ 1 is -155 and final value is 155. These data are computed and interpolated data encompass a set of N=32 points stating X,Y and Z coordinates. All the joint parameters with their minimum range are assumed.
θ_2 = 130, θ_3 = 130, θ_4 =130 and θ_5 =570 are kept constant and θ_1 (±155) is variable.

TABLE II BASE MAXIMUM

S.NO	T1	PX	PY	PZ
1	-155	35.2179	16.4224	324.847
2	-145	31.8311	22.2884	324.847
3	-135	27.4772	27.4772	324.847
4	-125	22.2884	31.8311	324.847
5	-115	16.4224	35.2179	324.847
6	-105	10.0574	37.5345	324.847
7	-95	3.38675	38.7108	324.847
8	-85	-3.38675	38.7108	324.847
9	-75	-10.0574	37.5345	324.847
10	-65	-16.4224	35.2179	324.847
11	-55	-22.2884	31.8311	324.847
12	-45	-27.4772	27.4772	324.847
13	-35	-31.8311	22.2884	324.847
14	-25	-35.2179	16.4224	324.847
15	-15	-37.5345	10.0574	324.847
15	-5	-38.7108	3.38675	324.847
17	5	-38.7108	-3.38675	324.847
18	15	-37.5345	-10.0574	324.847
19	25	-35.2179	-16.4224	324.847
28	35	-31.8311	-22.2884	324.847
21	45	-27.4772	-27.4772	324.847
22	55	-22.2884	-31.8311	324.847
23	65	-16.4224	-35.2179	324.847
24	75	-10.0574	-37.5345	324.847
25	85	-3.38675	-38.7108	324.847
26	95	3.38675	-38.7108	324.847
27	104	10.0574	-37.5345	324.847
28	115	16.4224	-35.2179	324.847
29	125	22.2884	-31.8311	324.847
30	135	27.4772	-27.4772	324.847
31	145	31.8311	-22.2884	324.847
32	155	35.2179	-16.4224	324.847

CONCLUSION

In this project, based on wide study of literature review the problems in the industrial robots were identified especially in workspace. There is no such generalized procedure implemented so for in serial robots.

Suitable software (LABVIEW) for this workspace is chosen based on unique feature of the software to represent. The workspace in 3D visualization AUTOCAD is found suitable.

To do workspace analysis four rotations: 1.Base, 2.Shoulder, 3.Elbow, 4.Wrist are considered to done by developing separate LabVIEW programs, and is to be verified and validate by using Robocell software.

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