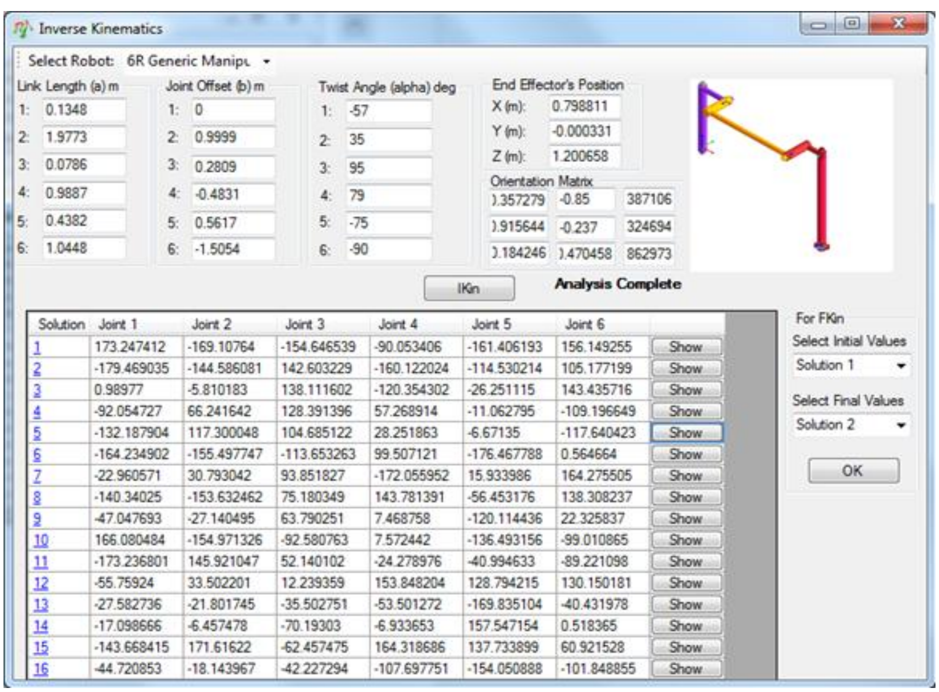
Inverse Kinematics for General 6R Manipulators in RoboAnalyzer

Sasanka Sekhar Sinha[1], C. G. Rajeevlochana[2] and Subir Kumar Saha[3]

[1]*Mechanical Engineering Department, Indian Institute of Technology Delhi, mez168275@mech.iitd.ac.in*
[2]*Mechanical Engineering Department, Indian Institute of Technology Delhi, rajeevlochan.iitd@gmail.com*
[3]*Mechanical Engineering Department, Indian Institute of Technology Delhi, saha@mech.iitd.ac.in*

Robotics has incessantly pervaded the world of industrial automation. As a subject, it has become indispensable in the academic and research curriculum. The various concepts relating to robot kinematics, dynamics, motion planning, etc., are often incomprehensible to beginners due to the abstruse underlying mathematics. Several robotics learning software have sprung up to reduce the learning curve. RoboAnalyzer is one such 3D model based robotics learning software primarily focussed on serial robot analysis based on DH description of robot geometry. A comprehensive description of the software functionalities and features is available in [1] and [2]. This paper reports a further development of RoboAnalyzer in the form of addition of inverse kinematics of a generic 6R serial manipulator to the existing Inverse Kinematics module.

Prior to the addition, RoboAnalyzer was able to solve for the inverse kinematics of a 6R wrist-partition robot using the methodology described in [3]. Precisely, the robot architecture permitted a decoupling solution strategy- positioning with the articulated arm (first 3 revolute joints) and orientation using the wrist (last 3 intersecting revolute joints) or the spherical joint. However in the presence of wrist offsets, this method fails. Most industrial 6R manipulators have this structure. However, errors in manufacturing and assembly necessitate kinematic identification followed by calibration and compensation. A general 6R inverse kinematic solution procedure will definitely eliminate the need for compensation. It was shown in [4] that the inverse kinematic solution of a general 6 DOF (degree-of-freedom) serial manipulator admitted a maximum of 16 solutions. Raghavan and Roth [4] used dialytic elimination and properties of the ideal generated by the multivariate equations to derive a 16 degree polynomial in the half-tangent of a joint variable. Later, Manocha and Canny [5] expressed this polynomial as a matrix determinant and computed its roots by reducing to an eigenvalue problem.



Solution	Joint 1	Joint 2	Joint 3	Joint 4	Joint 5	Joint 6	
1	173.247412	-169.10764	-154.646539	-90.053406	-161.406193	156.149255	Show
2	-179.469035	-144.586081	142.603229	-160.122024	-114.530214	105.177199	Show
3	0.98977	-5.810183	138.111602	-120.354302	-26.251115	143.435716	Show
4	-92.054727	66.241642	128.391396	57.268914	-11.062795	-109.196649	Show
5	-132.187904	117.300048	104.685122	28.251863	-6.67135	-117.640423	Show
6	-164.234902	-155.497747	-113.653263	99.507121	-176.467788	0.564664	Show
7	-22.960571	30.793042	93.851827	-172.055952	15.933986	164.275505	Show
8	-140.34025	-153.632462	75.180349	143.781391	-56.453176	138.308237	Show
9	-47.047693	-27.140495	63.790251	7.468758	-120.114436	22.325837	Show
10	166.080484	-154.971326	-92.580763	7.572442	-136.493156	-99.010865	Show
11	-173.236801	145.921047	52.140102	-24.278976	-40.994633	-89.221098	Show
12	-55.75924	33.502201	12.239359	153.848204	128.794215	130.150181	Show
13	-27.582736	-21.801745	-35.502751	-53.501272	-169.835104	-40.431978	Show
14	-17.098666	-6.457478	-70.19303	-6.933653	157.547154	0.518365	Show
15	-143.668415	171.61622	-62.457475	164.318686	137.733899	60.921528	Show
16	-44.720853	-18.143967	-42.227294	-107.697751	-154.050888	-101.848855	Show

Fig. 1: Inverse Kinematics module in RoboAnalyzer for general 6R manipulator

Manocha's code was real-time and met industrial level of performance. It was available open-source in Linux environment. To incorporate in RoboAnalyzer, it had to be ported to MS-Windows. MinGW (Minimalist GNU for Windows) was used to get rid of dependencies. MinGW provides a complete open source programming tool set-a port of the GNU Compiler Collection (GCC), including C, C++, ADA and Fortran compilers; GNU Binutils for Windows (assembler, linker, archive manager)- which is suitable for the development of native MS-Windows applications, and does not depend on any 3rd-party C-Runtime DLLs. It does depend on a number of DLLs provided by Microsoft themselves, as components of the operating system [6]. The Inverse kinematics module of RoboAnalyzer with 16 possible solutions is shown in Fig 1, thus providing an easy and effective way to visualize the multiple solutions of a generic inverse kinematics methodology. Figure 2 depicts how the 16 solutions would look like in a 3D environment.

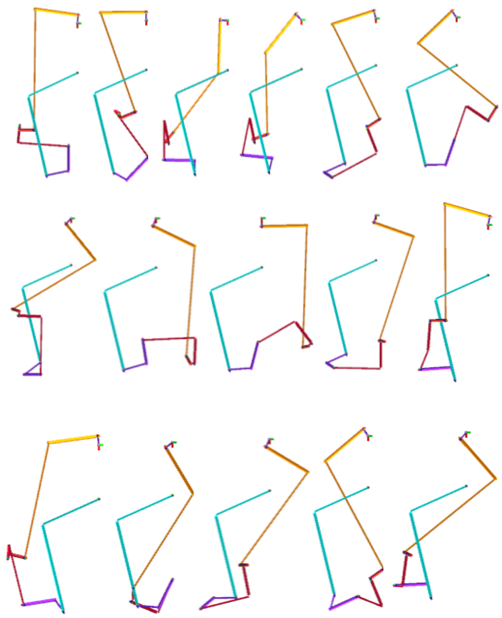


Fig. 2: 3D representation of the 16 distinct inverse kinematic solutions

An attempt was made to enhance the capabilities of RoboAnalyzer. RoboAnalyzer is available free through the website http://www.roboanalyzer.com .

References

[1] C. G. Rajeevlochana and S. K. Saha, "RoboAnalyzer: 3D Model Based Robotic Learning Software," *Proceedings of International Conference on Multi Body Dynamics*, pp. 3-13, 2011.

[2] R. S. Othayoth, R. G. Chittawadigi, R. P. Joshi and S. K. Saha, "Robot kinematics made easy using RoboAnalyzer software," *Computer Application in Engineering Education*, 2017 (pre-print: https://doi.org/10.1002/cae.21828).

[3] S. K. Saha,*Introduction to Robotics*, Tata McGraw Hill, New Delhi, 2008.

[4] M. Raghavan and B. Roth, "Inverse Kinematics of the General 6R Manipulator and Related Linkages," *ASME J. Mech. Des.*, vol. 115(3), pp. 502–508, 1993.

[5] D. Manocha and J. F. Canny, "Efficient Inverse Kinematics for General 6R Manipulators," *IEEE Trans. Rob. Autom.*, vol. 10(5), pp. 648–657, 1994.

[6] http://www.mingw.org/