Numerical Solution Approach for the ROBOTIS OP2 Humanoid Hand Inverse Kinematics

Zagidullin Linar
Intelligent Robotics Department, Kazan Federal University, 35 Kremlyovskaya street, Kazan, 420111, Russian Federation

Tatyana Tsoy
Intelligent Robotics Department, Kazan Federal University, 35 Kremlyovskaya street, Kazan, 420111, Russian Federation

Roman Meshcheryakov
Cyber-physical Lab, V. A. Trapeznikov Institute of Control Sciences of Russian Academy of Sciences, 65 Profsoyuznaya street, Moscow, 117997, Russian Federation

Kuo-Hsien Hsia
Department of Electrical Engineering, National Yunlin University of Science and Technology, 123 University Road, Section 3, Douliou, Yunlin, 64002, Taiwan, R.O.C

Evgeni Magid
Intelligent Robotics Department, Kazan Federal University, 35 Kremlyovskaya street, Kazan, 420111, Russian Federation
E-mail: lfzagidullin@stud.kpfu.ru, tt@it.kfu.ru, mrv@ipu.ru, khhsia@yuntech.edu.tw, magid@it.kfu.ru
http://robot.kpfu.ru/eng

Abstract

Small-size humanoids are widely used in human-robot interaction (HRI) projects and activities. To operate robot limbs in HRI and pick-and-place tasks it is required to solve an inverse kinematics problem. Classical approaches are closed-form solutions with algebraic or geometric approaches or a numerical solution. While a typical numerical solution is supposed to search for joint variables using an iterative optimization, in this paper we suggest an off-line solution for a ROBOTIS OP2 humanoid upper limb via a forward kinematics approach that allows to calculate in advance all possible solutions for an end effector pose within a robot workspace with several levels of the workspace discretization. The solution was obtained in a simulation and successfully validated with a real ROBOTIS OP2 humanoid.

Keywords: Humanoid, Inverse Kinematics, Control, Manipulator.

1. Introduction

Robots target to replace humans in dangerous locations or monotonous activities[1]. All activities that require object manipulation, e.g., manufacturing tasks[2], object grasping by a humanoid hand[3], door opening[4] etc., involve inverse kinematics calculations[5]. To solve inverse kinematics, algebraic, geometric or numerical methods are employed[6]. While industrial manipulators are initially designed to allow closed form solutions, design of many humanoid robots might make it difficult to find a consistent solution with algebraic or geometric approaches[7]. This is one of the reasons that makes numerical methods popular in humanoid robots[8].

This work demonstrates a simple brute-force approach for obtaining required values of joint angles for a given end effector (EE) pose of the ROBOTIS OP2 humanoid upper limb with 3 degrees of freedom (DoF). The approach employs kinematics analysis of the robot[9] and forward kinematics to generate data tables and matrices of angle values of a predefined precision in the off-line mode. The computational feasibility of the method was evaluated on a PC and the proper performance was confirmed with real ROBOTIS OP2 humanoid.

2. System Setup

Robotis OP2 (Fig. 1) is a humanoid robot developed by Korean company Robotis[10]. For today it is one of the most popular platform in research, education and competitions that involve applications in human-robot interaction, mobility, and manipulation[11].

It has 20 DoFs (6 per each leg, 3 per each arm and 2 in the neck), which are operated with 20 MX-28T servos. The robot is equipped with onboard Intel Atom Processor N2600 (dual core, 1.6 GHz) CPU, 4GB RAM and 32 GB SSD mSATA storage.

This work studies the operation of the 3DoF upper limb of the robot. Table 1 demonstrates the DH-table for the upper limb[2]. The DH-table generates the following forward kinematics equations:

$$\begin{cases} x = 60s_1s_2 + 60s_1 - 16c_1 - 129(c_1s_3 - c_3s_1s_2) \\ y = 60c_2 + 129c_2c_3 \\ z = -16s_1 - 16c_1 - 60c_1s_2 - 129(s_1s_3 + c_1c_3s_2) \end{cases} \quad (1)$$

where $c_i = \cos(\theta_i)$, $s_i = \sin(\theta_i)$ and $\theta_1, \theta_2, \theta_3$ are angles of the corresponding joints (Fig. 1). These lead to the following inverse kinematics equations:

$$\begin{cases} xc_1s_2 + ys_1s_2 + zc_2 - 16s_2 - 60 = 16s_3 + 129c_3 \\ xc_1c_2 + ys_1c_2 - zs_2 - 16c_2 = 0 \\ -xs_1 + yc_1 - 76 = -16c_3 + 129s_3 \end{cases} \quad (2)$$

Table 1. DH parameters for Robotis Darwin OP2 robot hand.

i	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	0	θ_1
2	-90	16.0	16.0	$\theta_2 - 90$
3	90	60.0	0	θ_3

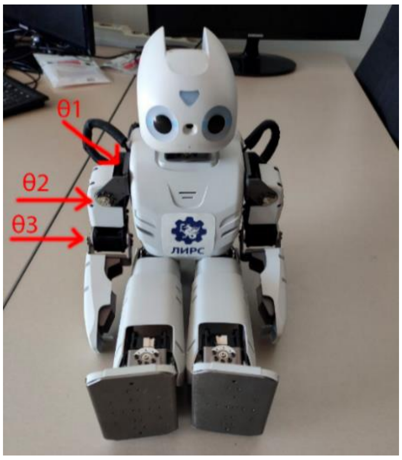


Fig. 1. Robotis Darwin OP2.

3. Brute Force Approach

The basic solution uses a prepared in advance text file, which is populated with data as follows:

(i) A value of an angle step discretization α is selected in advance by a user. We selected several values empirically, between 2 and 6 degrees. This value determines the step of each joint angle increment.

(ii) Based on the robot construction, for each joint angle minimal θ_i (*Min*) and maximal θ_i (*Max*) possible values are set, where *i=1,2,3*.

(iii) The three variables of joint angles $\theta_1, \theta_2, \theta_3$ are iteratively incremented with step α in three nested loops in order to provide all possible combinations within θ_i(*Min*) and maximal θ_i(*Max*), *i=1,2,3* joint variables. The resulting θ_i angles are used with forward kinematics equations (1) to provide *x,y,z* are coordinates of the EE, which are rounded to the closest real number with two digits after the decimal point. At this point, each line of the file contains $x, y, z, \theta_1, \theta_2, \theta_3$ values that correlate joint angles in the Joint space and an EE position in the Cartesian space. Note that the lines of the file are not ordered with regard to *x,y,z* coordinates and therefore a brute force search of the corresponding joint angles requires O(n) time, where n is the number of lines in the file.

4. Structured Brute Force Approach

This method uses the same brute force idea but structures the resulting data, which allows to greatly reduce the number of join angles calculations (actually, search in the file) on the robot at execution time. The data file is constructed in the off-line mode as follows:

(i) A matrix step value h is empirically selected in advance; it reflects the discretization level of the workspace and corresponds to the required precision of manipulation. An empty matrix M of reachable 3D Cartesian workspace is constructed with its dimensions corresponding to [X_{max}/h, Y_{max}/h, Z_{max}/h], where K_{max} are maximal possible coordinates of reachable workspace with regard to the appropriate axis K={X,Y,Z} of the global coordinate frame F_G, whose origin is placed in the center of the first joint between the robot body and the shoulder. All measurements are performed in this coordinate frame F_G.

(ii) Robot reachable workspace is divided into cubes with edges of length h. For each cube the brute force approach (Section 3) is used to calculate the joint angles' values that bring the EE into the cube's center.

(iii) Finally, the triples of $\theta_1, \theta_2, \theta_3$ angles are stored within a 3D matrix in the appropriate cell. The matrix stored as a file is uploaded to the robot.

Note that unreachable poses of the EE (that were not discovered at matrix construction time) did not produce joint variables and thus their cells within the matrix remain empty. The [0,0,0] cell corresponds to the origin of F_G that is used to descried the reachable workspace.

Next, at the execution time, to obtain the necessary joint angles, desired coordinates (X_{EE},Y_{EE},Z_{EE}) of the EE are transformed into matrix coordinates of (X_{EE}/h, Y_{EE}/h, Z_{EE}/h) with each value being rounded to the nearest integer index of the matrix.

5. Testing

A PC with 6C/12T Ryzen 5600H CPU, 16 GB DDR4 RAM and SSD NVME m.2 storage was employed for testing. To determine optimal tradeoff between the accuracy (the joint step value s) and the computation of pseudo inverse kinematics on the PC using brute force approach (Section 3) experiments were run with s=2 to s=6 degrees with a step of 0.5 degrees. Computation time was calculated as an average time to provide $\theta_1, \theta_2, \theta_3$ angles given (X_{EE},Y_{EE},Z_{EE}) coordinates.

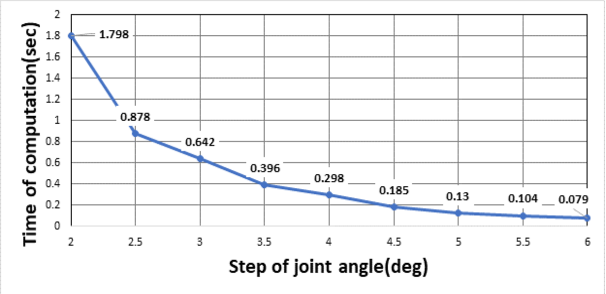


Fig. 2. Time consumption of pseudo inverse kinematics execution on the PC using brute force approach.

6. Conlcusions

The paper presents a simple off-line solution for a ROBOTIS OP2 humanoid upper limb via a forward kinematics approach that allows to calculate in advance all possible solutions for an end effector pose within a robot workspace with several levels of the workspace discretization. The solution was obtained in a simulation and successfully validated with a real ROBOTIS OP2 humanoid. The results allow determining an optimal tradeoff between the required accuracy (the joint angles' step) and the computation of joint angles using brute force approach.

Acknowledgements

This paper has been supported by the Kazan Federal University Strategic Academic Leadership Program ("PRIORITY-2030").

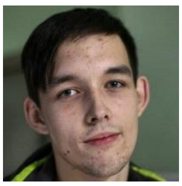
References

1. I. Ha, Y. Tamura, H. Asama, "Development of Open Platform Humanoid Robot DARwIn-OP", Advanced Robotics, Vol. 27, No. 3, pp. 223-232, 2013.
2. A. Kheddar, S. Caron, P. Gergondet, A. Comport, A. Tanguy, C. Ott, B. Henze, G. Mesesan, J. Englsberger, M. A. Roa, P.B. Wieber, "Humanoid Robots in Aircraft Manufacturing: The Airbus Use Cases", IEEE Robotics & Automation Magazine, Vol. 26, No. 4, pp. 30-45, 2019.
3. K. Khusnutdinov, A. Sagitov, A. Yakupov, R. Meshcheryakov, K.-H. Hsia, E. A. Martinez-Garcia, E.

Magid, “Development and Implementation of Grasp Algorithm for Humanoid Robot AR-601M”, 16th International Conference on Informatics in Control, Automation and Robotics, Vol. 2, pp. 379-386, 2019.
4. K. Otani, K. Bouyarmane, “Adaptive Whole-Body Manipulation in Human-to-Humanoid Multi-Contact Motion Retargeting”, IEEE-RAS 17th International Conference on Humanoid Robotics (Humanoids), pp. 446-453, 2017.
5. A. Dobrokvashina, R. Safin, Y. Bai, R. Lavrenov, “Improved Graphical User Interface for Crawler Robot Servosila Engineer”, International Siberian Conference on Control and Communications (SIBCON), pp. 1-5, 2021.
6. J.J. Craig, “Introduction to Robotics: Mechanisms and Controls”, Third Edition, Addison-Wesley, 2005.
7. M. A. Ali, H. A. Park, and C. S. G. Lee, “Closed-form Inverse Kinematic Joint Solution for Humanoid Robots”, 2010 IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 704-709, 2010.
8. M. Mistry, J. Nakanishi, G. Cheng, S. Schaal, “Inverse kinematics with floating base and constraints for full body humanoid robot control”, Proceedings of the International Conference on Humanoid Robots, pp. 22-27, 2008.
9. R.L. Williams II, “DARWIN-OP Humanoid Robot Kinematics”, International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, Vol. 4: 36th Mechanisms and Robotics Conference, pp. 1187-1196, 2012.
10. “Robotis Company”, http://en.robotis.com/
11. T. Tsoy, L. Sabirova, R. Lavrenov, E. Magid, “Master Program Students Experiences in Robot Operating System Course”, 11th International Conference on Developments in eSystems Engineering (DeSE), pp. 186-191, 2018.

Authors Introduction

Mr. Linar Zagidullin



Undergraduate student of the fourth-year of the Laboratory of Intelligent Robotic Systems (LIRS), Institute of Information Technology and Intelligent Systems (ITIS), Kazan Federal University.

Ms. Tatyana Tsoy

She graduated from International Area Studies Master's Degree Program at Tsukuba University. Since 2018 she has been a Ph.D. student in Robotics at the Institute of Information Technology and Intelligent Systems (ITIS) of Kazan Federal University. She works as a research assistant at the Laboratory of Intelligent Robotic Systems (LIRS) at KFU.

Professor Roman Meshcheryakov

In 2014 he received his degree of Professor in the specialty "System analysis, management and information processing". Since July 2018, he has been the Chief Researcher at the V. A. Trapeznikov Institute of Control Sciences of Russian Academy of Sciences and Head of the Laboratory of Cyberphysical Systems.

Associate Professor Kuo-Hsien Hsia

Received a Ph.D. degree in Electrical Engineering at the National Sun Yat-Sen University, Kaohsiung, Taiwan. He works at the National Yunlin University of Science and Technology.

Professor Evgeni Magid

A Head of Intelligent Robotics Department and a Head of Laboratory of Intelligent Robotic Systems (LIRS) at Kazan Federal University, Russia. Senior IEEE member. He earned his Ph.D. degree from the University of Tsukuba, Japan. He authors over 200 publications in English, Russian and Japanese languages.