On space robot motion planning

© G.K. Borovin[1,2], V.V. Lapshin[2]

[1]Keldysh Institute of Applied Mathematics RAS, Moscow, 125047, Russia
[2]Bauman Moscow State Technical University, Moscow, 105005, Russia

The paper focuses on the problem of motion control of a space robot. The robot consists of a body and a telescopic manipulator, and is in state of passive flight, i.e. it does not use any propulsion that controls movement and navigation of the robot body. Only the actuators installed at the axes are used to control robot movements. Thus, the robot movement is affected only by internal forces. The movement of the manipulator has a noticeable effect on the movement of the robot body due to the conservation laws of robot momentum and its angular momentum relative to the center of mass. We assumed that the robot momentum and angular momentum are equal to zero. There are constraints both on the variation limits in the length of the manipulator arm and the angle of its rotation relative to the body. The problem is solved as a plane problem. When the manipulator arm moves from the initial position to the final one, the latter being located in the working space, the program motion includes the sequence of the following alternating actions: shortening the manipulator arm length to the minimum value, its rotation relative to the robot body, extending the manipulator arm length to the maximum value, then again the arm rotation relative to the robot body, etc. Findings of the research show that due to these cyclic motions of the manipulator arm relative to the body, the robot body can be rotated at an arbitrary angle. As a result, the working space of a passively flying space robot is significantly larger than the working space of a robot with a fixed body. The working space of the robot in absolute space is a ring bounded by two circles centered at the center of the robot mass and radii equal to the minimum and maximum distance from the center of the robot mass to the robot gripper. Moreover, when constructing the program motion, it is possible to provide not only the robot gripper taking a given final position, but also the required value of the angle between the robot body and the manipulator arm in the final position, which is more advantageous for the work.

Keywords: *space robot, motion control, construction of the program motion*

REFERENCES

[1] Dubovsky S., Papadopouls E. The Kinematics, Dynamics, and Control of Free-Flying and Free-Floating Spase Robotics Systems. *IEEE Transactions on Robotics and Automation*, 1993, vol. 9 (5), pp. 531–543.

[2] Moosavian S., Ali A., Papadopouls E. Free-Flying Robots in Space: an Overview on Dynamics Modelling, Planning and Control. *Robotica*, 2007, vol. 25 (5), pp. 537–547.

[3] *Buran* [“Molniya”. Research Industrial Corporation]. Available at: http://www.buran.ru (accessed June 24, 2017).

[4] Inaba N., Oda M. Autonomous Satellite Capture by a Space Robot — World First on Orbit Experiments on a Japanese Robot Satellite ETS-VII. *Proc. of 2000 IEEE Int. Conf. on Robotics and Automation*, 2000, pp. 1169–1174.

[5] Rutkovskiy V.Yu., Sukhanov V.M., Glumov V.M. *Avtomatika i telemekhanika — Automation and Remote Control*, 2010, no. 1, pp. 80–98.

[6] Rutkovskiy V.Yu., Sukhanov V.M., Glumov V.M. Motion Equations and Control of the Free-Flying Space Manipulator in the Reconfiguration Mode. *Automation and Remote Control*, 2010, vol. 71 (1), pp. 70-86.

[7] Rutkovskiy V.Yu., Sukhanov V.M., Glumov V.M. *Avtomatika i telemekhanika — Automation and Remote Control*, 2010, no. 11, pp. 84–99.

[8] Rutkovskiy V.Yu., Sukhanov V.M., Glumov V.M. Control of Multimode Manipulative Space Robot in Outer Space. *Automation and Remote Control,* 2010, vol. 71 (11), pp. 2345–2359.

[9] Rutkovskiy V.Yu., Sukhanov V.M., Glumov V.M. Novyi podhod k resheniyu osnovnoy zadachi upravlenya svobodnoletayushchim kosmicheskim manipulyatsionnym robotom [A new approach to solving the basic task of controlling a free-flying space manipulation robot]. *Trudy XII Vserossiyskogo simposiuma po problemam upravleniya* [Proc. of XII All-Russian symposium on the problems of control]. Moscow, 2014, pp. 3853–3865.

[10] Lapshin V.V. *Izvestia RAN. Teoriya i sistemy upravleniya — Journal of Computer and Systems Sciences International*, 2017, no. 1, pp. 161–167.

[11] Lapshin V.V. Robot Motion Control in Zero-Gravity Conditions. *Journal Computers and System Sciences International*, 2017, vol. 56 (1), pp. 157–163.

[12] Borovin G.K., Lapshin V.V. About a Motion of Free-Floating Space Robot. *Mathematica Montesnigri*, 2017, vol. XXXIX, pp. 67–78.

[13] Lapshin V.V. *Izvestia AN SSSR. Mekhanika tverdogo tela — Mechanics of Solids,* 1983, no. 5, pp. 42–51.

[14] Lapshin V.V. *Izvestia AN SSSR. Mekhanika tverdogo tela — Mechanics of Solids*, 1984, no. 1, pp. 159–165.

[15] Hemami J., Zheng Y. Dynamics and Control of Motion on the Ground and in the Air with Application to Biped Robot. *Journal of Robotics Systems*, 1984, no. 1, pp. 101–116.

[16] Raibert M.H. *Legged robots that balance.* Cambridge, Massachusetts, MIT Press, 1986, 234 p.

[17] Hodgins J., Raibert M.H. Biped Gymnastics. *Robotics Research: The Fourth Int. Symp.*, Cambridge, Massachusetts, MIT Press, 1987, pp. 5–14.

[18] Lapshin V.V. Motion Control of a Legged Machine in the Supportless Phase of Hopping. *The International Journal of Robotics Research*, 1991, vol. 10 (4), pp. 327–337.

[19] Okhotsimsky D., Platonov A., Kirilchenko A., Lapshin V., Tolstousova V. Walking Machines. *Advances in Mechanics*, 1992, vol. 15 (1–2), pp. 39–70.

[20] Lapshin V.V., Kolesnikova G.P. *Vestnik MGTU im. N.E. Baumana. Ser. Estestvennye nauki — Herald of the Bauman Moscow State Technical University. Series Natural Sciences*, 2007, no. 4, pp. 20–28.

[21] Lapshin V.V., Chashnikov S.P. *Vestnik MGTU im. N.E. Baumana. Ser. Estestvennye nauki — Herald of the Bauman Moscow State Technical University. Series Natural Sciences,* 2011, no. 1, pp. 55–67.

[22] Lapshin V.V. *Mekhanika i upravlenie dvizheniem shagayuschikh mashin* [Mechanics and motion control of walking machines.]. Moscow, BMSTU Publ., 2012, 199 p.

[23] Borovin G.K., Lapshin V.V. *Izvestiya RAN. Teoriya i sistemy upravleniya — Journal of Computer and Systems Sciences International*, 2014, no. 4, pp. 148–160.

[24] Borovin G.K., Lapshin V.V. Optimal Attitude Control of Two Pivotally Connected Bodies in the Supportless Phase of Motion. *Journal Computers and System Sciences International*, 2014, vol. 53 (4), pp. 610–622.

Borovin G.K., Dr. Sc. (Phys.-Math.), Professor, Chief Research Fellow, Keldysh Institute of Applied Mathematics, RAS. e-mail: borovin@keldysh.ru
SPIN-code of RISC 6604-4668

Lapshin V.V., Dr. Sc. (Phys.-Math.), Professor, Department of Theoretical Mechanics, Bauman Moscow State Technical University.
e-mail: lapshin032@bmstu.ru
SPIN-code of RISC 2292-7446