Review on Motion Planning of Space Robots

P. N. Dal and S. V. Shah

Department of Mechanical Engineering
Indian Institute of Technology
Jodhpur 342 037, India
dal.1@iitj.ac.in, surilshah@iitj.ac.in

Abstract

Everything does not always go as planned in space,e.g., the first space station, Skylab had experienced a problem during launch. After launching the satellite, many tasks have to be performed like refuelling, servicing, docking, transporting, berthing, and debris removing[3]. Robot manipulator mounted on the satellite base can perform these tasks very effectively and efficiently. Shuttle remote manipulator system (SRMS)[19] was used for first time to manipulation on second Space Shuttle Mission (STS-2). It has been used for berthing and cooperating human extravehicular activities. Servicing and maintenance of Hubble space telescope and establishment of International Space Station have been done with human manipulator collaboration[19]. Many motion planning techniques have been developed in the last two decades and have been implemented successfully. In motion planning, path planning for autonomous obstacle removal with minimum disturbances to the base and energy consumption imposes a new challenge in the field of space robotics[7,9]. Challenges in this field are identified and solutions are overviewed. Many algorithms such as genetic, artificial intelligence, ant colony, fuzzy control, Rapidly-exploring random trees (RRT)[2] are researched for manipulator path planning application. Every method has their own limitations and characteristics according to the environmental constraints. Hence, path planning by environment-based modeling with grid approach can be efficient and convenient[16] . Capturing the obstacle or debris with the reactionless energy optimum path, the cooperation of robots, the multi-arm space robot (closed kinematic chains), and the dynamic singularity avoidance is previously described in many works of literature[5,17,18,19]. However, the laws of conservation of linear and angular momenta create disturbance in the position and orientation of the satellite base[12]. Moment reaction transfer to the base should be zero to achieve accurate positioning in order to capture the object and move it to desired position. But nonholonomic nature of zero reaction moment constraints increases the path planning complexity. Task space and joint space control generates singularity in the obtained path. Hence, holonomic distribution and task-space control were used to capture the object smoothly and accurately[12]. Sometime due to effect of reactionless manipulation constraints on motion of the end effector, singularity occurs and is known as algorithmic singularities which are different from dynamic singularities. To eliminate algorithmic singularity generic path planning algorithm with non holonomic constraints were derived in[6].Holonomic distribution for nonholonomic constraints, eliminating algorithmic singularities, reaction null space approach were used for reactionless manipulation[3,6,8,10,12,15]. These methods allow us to find a different reactionless path. To track the trajectory from initial to grapple point in order to capture the in-orbit object, the task level constraints in terms of end effector velocity were derived. However, the planned trajectory contains some singular points hence, three point-to-point path planning strategies were developed, which improve the reactionless operation of the dual-arm robot[14]. The dynamic nature of constraints required for reactionless manipulation creates difficulty while finding minimum energy consumed path by optimization method[13]. Hence to minimizing the energy over specific interval time, the optimal control method was implemented. Experimental set up for reduction of vibrations to flexible base by controlling joint angle through radial basis function networks(RBFNs) was constructed in[1]. Trajectory obtained by RBFNs is itself having minimum energy consumption. Methods observed above give the reactionless and the minimum energy consumed path and pose the challenge of removing the obstacles in path autonomously. Navigation, configuration estimation and potential to environmental awareness allow the autonomous robot to monitor the proper functioning of the own state and the state of surrounding environment[4]. Autonomous path planning obtained in three stages. Firstly, the target features were evaluated by eye-

in-hand camera which gives the motion in real time. Secondly, the manipulator motion was obtained through numerically feasible approach to eliminate dynamic singularities. Lastly, the disturbances created by manipulators were minimized and reactions transfer to the base was evaluated. For example, the Sojourner for planetary surface exploration performed the task as commanded by human and found the path autonomously by avoiding the obstacles in the path[11]. For motivating research and development in the autonomous reactionless and minimum energy consumed path tracking while removing the obstacle, various methods are reviewed in this paper.

References

1.Abe, A.: Minimum energy trajectory planning method for robot manipulator mounted on flexible base. In9th Asian Control Conference (ASCC), pp. 1-7. IEEE 2013.
2. Benevides, J. R.; Grassi, V.: Autonomous path planning of free-floating manipulators using RRT-based algorithms. 12thLatin American Robotics Symposium and 3rd Brazilian Symposium on Robotics (LARS-SBR), pp. 139-144, IEEE 2015.
3. Flores-Abad, A.; Ma, O.; Pham, K.; Ulrich, S.: A review of space robotics technologies for on-orbit servicing. Progress in Aerospace Sciences, Vol. 1, No. 68, pp. 1-26, 2014.
4. Gao, Y., Chien, S.: Review on space robotics: Toward top-level science through space exploration. Science Robotics, Vol. 2, No. 7, pp. eaan5074, 2017.
5. Gattupalli, A.; Shah, S. V.; Krishna, K. M. and Misra, A. K.: Control Strategies for Reactionless Capture of an Orbiting Object using a Satellite Mounted Robot. In P. Conference on Advances In Robotics, ACM, 2013.
6. James, F.; Shah, S. V.; Kumar, A.; Krishna, K. M.; Misra A. K.: Reactionless Maneuvering of a Space Robot in Precapture Phase. AIAA Journal of Guidance, Control, and Dynamics, Vol. 39, No. 10, pp. 2419-2425, 2016.
7. Li, C.; Liang, B.; Xu, W.: Autonomous trajectory planning of free-floating robot for capturing space target. In IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 1008-1013, IEEE 2006.
8. Meng, D.; Lu, W.; Xu, W.; She, Y.; Wang, X.; Liang, B.; Yuan, B.: Vibration suppression control of free-floating space robots with flexible appendages for autonomous target capturing. Acta Astronautica, Vol. 151, pp. 904-18, 2018.
9. National Aeronautics and Space Administration Goddard Space Flight Center: On-Orbit Satellite Servicing Study; Project Report,URL:http://ssco.gsfc.nasa.gov/servicing_study.html, 2010.
10. Naveen, B.; Shah, S. V.; Misra, A. K.: Momentum Model-based Minimal Parameter Identification of a Space Robot. AIAA Journal of Guidance, Control, and Dynamics, Vol. 42, No. 3, pp. 508-523, 2019.
11. Pedersen, L., Kortenkamp, D., Wettergreen, D., Nourbakhsh, I. and Korsmeyer, D.: A survey of space robotics, 2003.
12. Rybus, T.: Obstacle avoidance in space robotics: Review of major challenges and proposed solutions. Progress in Aerospace Sciences, Vol. 101, pp. 31-48, 2018.
13. Shah, S. V.; Gattupalli, A.; and Misra, A. K.: Energy Optimum Reactionless Path Planning for Capture of Tumbling Orbiting Objects using a Dual-Arm Robot. In 1st International and 16th Nat. Conf. on Machines and Mechanisms (iNaCoMM), IIT Roorkee, India, 2013.
14. Shah, S. V.; Sharf, I.; and Misra, A. K.: Reactionless Path Planning Strategies for Capture of Tumbling Objects in Space Using a Dual-Arm Robotic System. AIAA Guidance, Navigation, and Control Conference (AIAA GNC), USA, 2013.
15. Li, T.; Li, Q.; Li, W.; Xia, J.; Tang, W.; Wang, W.: A Path Planning Algorithm for Space Manipulator Based on Q-Learning. In 8th Joint International Information Technology and Artificial Intelligence Conference (ITAIC),pp. 1566-1571, IEEE 2019.
16. Xu, R.; Luo, J.; Wang, M.: Kinematic and dynamic manipulability analysis for free-floating space robots with closed chain constraints. Robotics and Autonomous Systems, pp. 103548, 2020.
17. Xu, W.; Liu, Y.; Liang, B.; Xu, Y.; Qiang, W.: Autonomous path planning and experiment study of free-floating space robot for target capturing. Journal of Intelligent and Robotic Systems, Vol. 51, No. 3, pp. 303-31, 2008.
18. Yan, L.; Xu, W.;, Hu, Z.; Liang, B.: Multi-objective configuration optimization for coordinated capture of dual-arm space robot. Acta Astronautica, Vol. 167, pp. 189-200, 2020.
19. Yoshida, K.; Wilcox, B.: Space Robots and Systems. In: Siciliano, B.; Khatib, O.: Handbook of Robotics, Berlin, Heidelberg, Springer 2008.