Nonlinear Model Predictive Control of Space Redundant Manipulators

Mingming Wang[1], Roberto Lampariello[2], Ulrich Walter[1]

[1] Institute of Astronautics, TU Muenchen, {M.Wang,U.Walter@lrt.mw.tum.de}
[2] Institute of Robotics and Mechatronics, DLR, {Roberto.Lampariello@dlr.de}

Abstract

One of the main reasons for the development of space manipulators is to replace astronauts to perform tasks that involving long, repetitive operations and unhealthy, hazardous environment. Due to the particular harsh environment of space and the increasing demands of satellite maintenance, on-orbit refueling and assembly etc., the application of space robot has received significant attention. Some research has been done in the area of satellite capturing task, such as “Robot Technology Experiment (ROTEX)”, “Engineering Test Satellite VII (ETS-VII)” project, and “Orbital Express (OE)” program etc.

Conventional linear controllers (PID) are not really suitable for the control of space manipulators due to the highly nonlinear behavior of the space robot model. Model predictive control (MPC) has been used in the chemical process control industry with great success; however, the application of predictive control in the aerospace industry appears relatively new. Popularity of the model predictive control approach lies in its relatively simple idea as well as in its practical advantages. In principle, MPC is a feedback control scheme, for which in each sampling period, a finite horizon optimization problem is solved. An illustration of MPC schematic diagram is shown in Figure 1. One of the main benefits of predictive control is that the constraints on the inputs and outputs of the system can be explicitly considered in the control problem formulation.

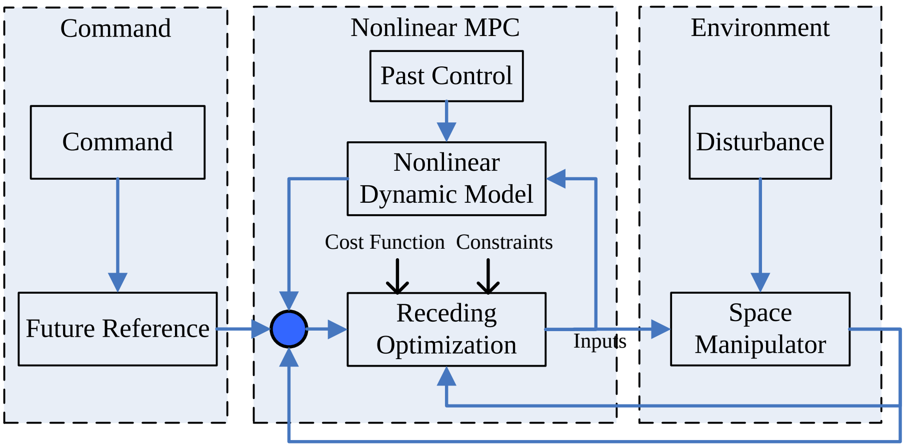

Figure 1. Schematic Diagram of Nonlinear Model Predictive Control

This study investigates the use of nonlinear model predictive control (NMPC) for space redundant manipulators to approach an un-cooperative target satellite in space environment. The objective is to evaluate the performance of the predictive controller for the approaching task and to investigate the need and feasibility of incorporating constraints into the controller. The nonlinear dynamic model of an n-link manipulator is first recalled, which is then linearized and decoupled by feedback, secondly a nonlinear model predictive control scheme, implemented with an optimized dynamic model and running within small sampling period, is exhibited. The derived nonlinear predictive control law uses a quadratic performance index of the predicted tracking error and the predicted control effort. The constrained predictive controller solved a quadratic programming problem at every sampling interval as receding horizon.

The real-time implementation is based on Simulink with the predictive controller and computed torque controller. Major simulation results performed by using a 7DOF redundant manipulator mounted on a 6DOF spacecraft prove the effectiveness of the proposed control method. The NMPC and the widely used computed torque control are compared. Tracking performance and robustness with respect to external disturbance or errors in the model are enlightened. Asymptotic error tracking and constraint handling results particularly demonstrate the effectiveness and potential of the nonlinear model predictive controller for the space redundant manipulators.

References

[1] M. W. Spong and M. Vidyasagar. *Robot Dynamics and Control.* John Wiley & Sons, New York, 1989.

[2] K. W. Lilly and C. S. Bonaventura. A generalized formulation for simulation of space robot constrained motion. *Proceedings of 1995 IEEE International Conference on Robotics and Automation*, 2835–2840, Nagoya, Aichi, Japan, 1995.

[3] E. Papadopoulos and S. Ali A. Moosavian. Dynamics and control of space free-flyers with multiple arms. *Journal Advanced Robotics*, 9(6): 603–624, 1995.

[4] Y. Umetani and K. Yoshida. Resolved motion rate control of space manipulators with generalized Jacobian matrix. *IEEE Trans. Robot. Automat.*, 5(3): 303–314, 1989.

[5] Z. Vafa and S. Dubowsky. The Kinematics and Dynamics of Space Manipulators: The Virtual Manipulator Approach. *International Journal of Robotics Research*, 9(4): 3–21, 1990.

[6] Y. Xu and T. Kanade. *Space Robotics: Dynamics and Control*. Kluwer, Boston, 1993.

[7] R. A. McCourt and C. W. de Silva. Autonomous Robotic Capture of a Satellite Using Constrained Predictive Control. *IEEE/ASME Transactions on Mechatronics*, 11(6): 699–708, 2006.

[8] S. Torres, J. A. Mendez, L. Acosta, M. Sigut, G. N. Marichal and L. Moreno. A Predictive Control Algorithm with Interpolation for a Robot Manipulator with Constraints. *Proceedings of the 2001 IEEE International Conference on Control Applications*, 536–541, Mexico City, Mexico, 2001.

[9] C. Lin and Y. Liu. Precision Tracking Control and Constraint Handling of Mechatronic Servo Systems Using Model Predictive Control. *IEEE/ASME Transactions on Mechatronics*, 17(4): 593–605, 2012.

[10] V. M. Becerra, S. Cook and J. Deng. Predictive Computed-Torque Control of a PUMA 560 Manipulator Robot. *Presented at 16th IFAC World Congress*, Prague, Czech Republic, 2005.

[11] A. Vivas and V. Mosquera. Predictive Functional Control of a PUMA Robot. *ACSE 05 Conference, CICC*, Cairo, Egypt, 2005.

[12] A. Vivas and P. Poignet. Predictive Functional Control of a Parallel Robot. *Control Engineering Practice*, 13: 863–874, 2005.

[13] V. Duchaine, S. Bouchard and C. M. Gosselin. Computationally Efficient Predictive Robot Control. *IEEE/ASME Transactions on Mechatronics*, 12(5): 570–578, 2007.

[14] D. Q Mayne, J. B. Rawlings, C. V. Rao and P. O. M. Scokaert. Constrained Model Predictive Control: Stability and Optimality. *Automatic*, 36: 789–814, 2000.

[15] A. M. Jasour and M. Farrokhi. Path Tracking and Obstacle Avoidance for Redundant Robotic Arms Using Fuzzy NMPC. *American Control Conference*, 1353-1358. St. Louis, USA, 2009.