# CONTROL OF SPACECRAFT FOR RENDEZVOUS MANEUVER IN AN ELLIPTICAL ORBIT

# STEROWANIE STATKIEM KOSMICZNYM DLA ZAGADNIENIA MANEWRU SPOTKANIA NA ORBICIE ELIPTYCZNEJ

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## Abstract

Rendezvous maneuver is one of a key elements of space flight technology. Orbital rendezvous maneuver denotes the technology that two satellites attain the same position and velocity, both vectors relative to the Earth, at the same time. The present development directions of automatic control methods for rendezvous maneuver problem are focused on autonomy of spacecraft performing maneuver, assurance of safety during the maneuver and enabling of impromptu maneuvers execution.

So far, the major vast of rendezvous maneuvers was performed in circular orbits of the target satellite. Future missions will require an execution of maneuvers completed with concatenation of satellites in an elliptical orbit. This motivates a development of suitable models of relative motion dynamics as well as automatic control methods for such case.

The conducted investigation concerns a problem of spacecraft control for rendezvous maneuver with assumption that the target satellite is moving in a Keplerian elliptical orbit. A method based on model predictive control, also referred as control with receding horizon, has been proposed in order to find a quasi-optimal maneuver trajectory. The relative motion is represented by a controlled variables vector, namely vector of relative position and velocity in Cartesian reference frame. One of the basic assumptions during control algorithm design has been an extension of initial conditions set, for which exists a possibility of control objective accomplishment.

Mathematical model of relative motion dynamics plays a key role in the control algorithm. The vast majority of control methods developed so far utilizes linearized models of relative motion, such as Hill-Clohessy-Wiltshire equations for the case of circular orbit of the target satellite, or Tschauner-Hempel equations for the elliptical case. The accuracy of that class of models degrades quickly together with increasing of the separation between spacecraft and target satellite, what restricts the set of initial conditions for which the maneuver can be successfully accomplished.

Described peculiarity of linearized models was one of the reasons for which the proposed control method utilizes full, nonlinear and time-variant model of relative motion. It was applied as an internal model for the predictive controller, enabling process output prediction and state estimation. The model directly considers the dependency of the process dynamics on propellant mass expelled by spacecraft thrusters.

Another assumption for the controller design was an ability of utilization of quadratic programming procedure for solving of the optimal control problem. This assumption was motivated by peculiarities of nonlinear optimization procedures, which do not guarantee predictable time required for finding of solution, or the result found by them is only a local solution. Reduction of the optimization procedure to a quadratic optimization problem was obtained using a method proposed by author, involving the generation of local linear models distributed within prediction horizon. The proposed algorithm considers variance of the model parameters within a prediction horizon, what enables for more accurate prediction of the process output. Consideration of system dynamics variance was implemented owing to mechanism of prediction of model parameters, which are dependent on time and trajectories of state and control. The dependency of model parameters on control trajectory enforced application of heuristic method for preliminary estimation of future control trajectory. This

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allowed for avoidance of direct consideration of model parameters dependency on control trajectory in optimization procedure, what would lead to a nonlinear optimization problem.

Conducted numerical experiments denote that the proposed predictive control algorithm enables for satisfying of requirements for rendezvous maneuver in an elliptical orbit. The proposed output prediction system with consideration of model parameters variance over prediction horizon allowed for improvement of control process quality. Significant improvement was achieved in terms of the set of feasible initial conditions. The algorithm proposed by author enables for maneuver control with initial separation between satellites more than 36 000 km, what far exceeds the range of reliable operation of the present algorithms for orbital relative motion control.

The main problems belonging to the original author's contribution include: an output prediction method with consideration of model parameters variance over prediction horizon, a method for estimation of future model parameters, formulation of predictive control algorithm utilizing the mentioned methods and simulations of the control loop involving the proposed algorithm.

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