Satellite Model Refinement for Approaching Disabled Satellites using Modified Least Square Method

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ABSTRACT

The removal of disabled satellites requires the chaser satellite to perform approach tasks. The uncertainties of chaser inertial parameters and thruster output force affect the control accuracy, which may lead to a collision. In this paper, a modified least square method is proposed to refine the model of the chaser satellite, and then the identified parameters are then applied to the controller to reduce control error. Firstly, an optimal trajectory is planned and then performed in space, after which the state sequences are transmitted to the ground. Next, in order to refine the satellite model, a modified least square method is carried out to identify the modification ratio of thrusters, in which two extra limits are introduced to enhance convergence. One is the maximum fix value per step, the other is the total fix upper limit. Finally, the chaser controller is integrated with the modification value. Simulation results indicate that the proposed method enhances the process of convergence and significantly reduces the remaining error.

INTRODUCTION

The removal of disabled satellites can reduce the collision risk to other satellites and release precious orbit resources. One common removal approach is sending a chaser to approach the target satellite. Generally, to maintain control accuracy and avoid collisions, the controller is designed considering external disturbances, such as using robust control laws or adjusting itself through satellite parameter identification. Moreover, parameter identification can also contribute to the performance improvement of the control laws.

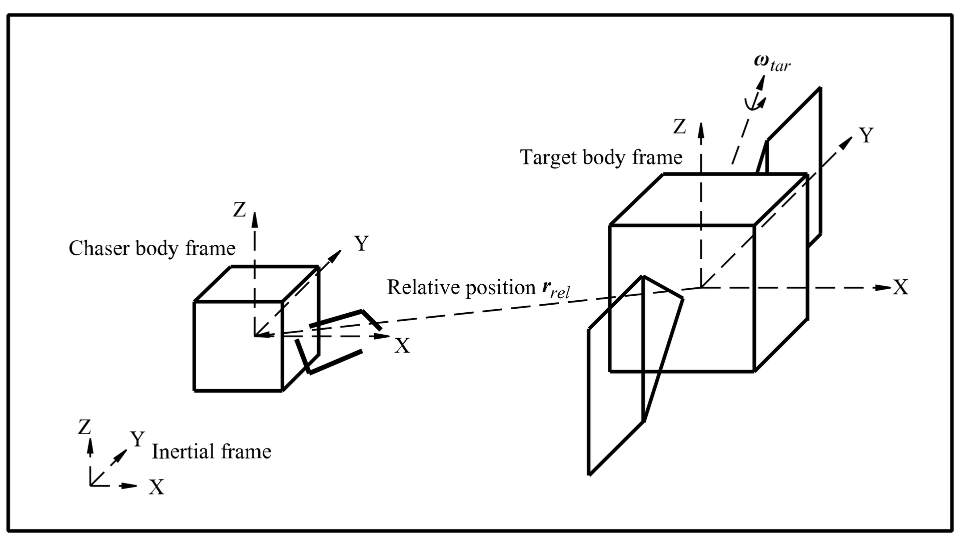
The approach to the target satellite is an orbit-attitude coupled process, in which the two kinds of control error affect each other. Although the errors of the satellite body and thrusters can be identified through a series of separate experiments, if the experiment is carried out with only one approach trajectory, the refinement effect could be intuitively observed and guaranteed, and the time for the experiment could also be reduced.

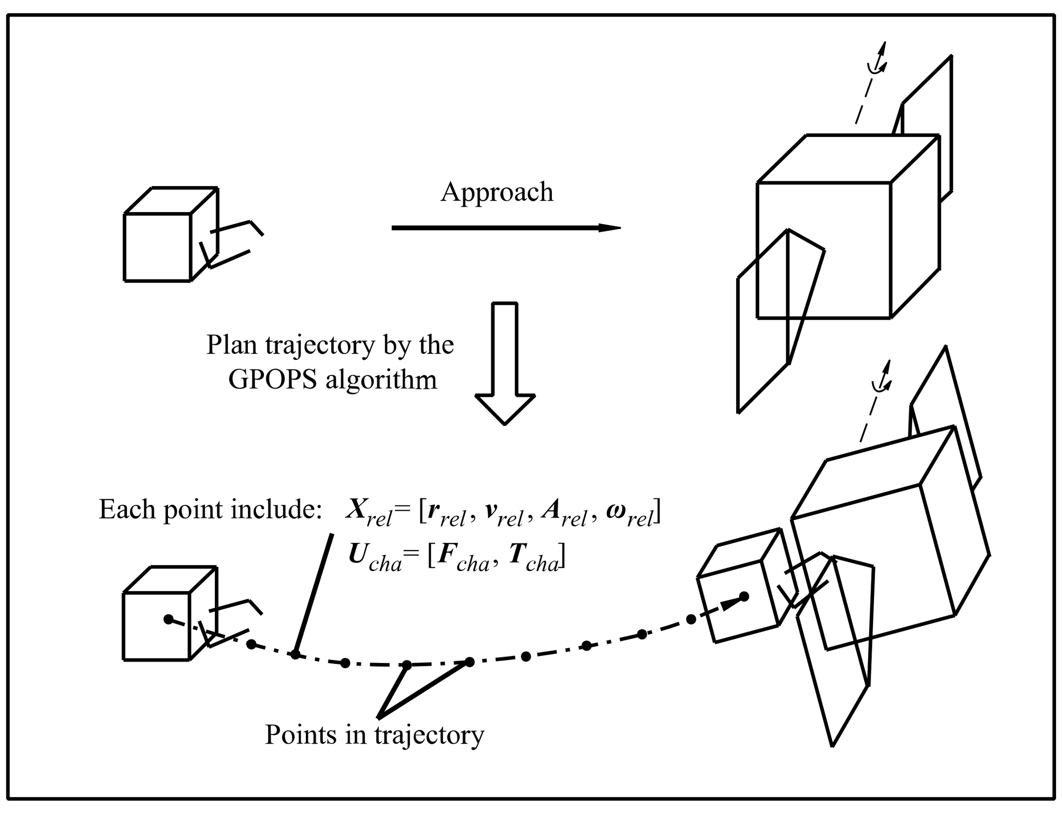
METHODOLOGY

Parameters for Identification

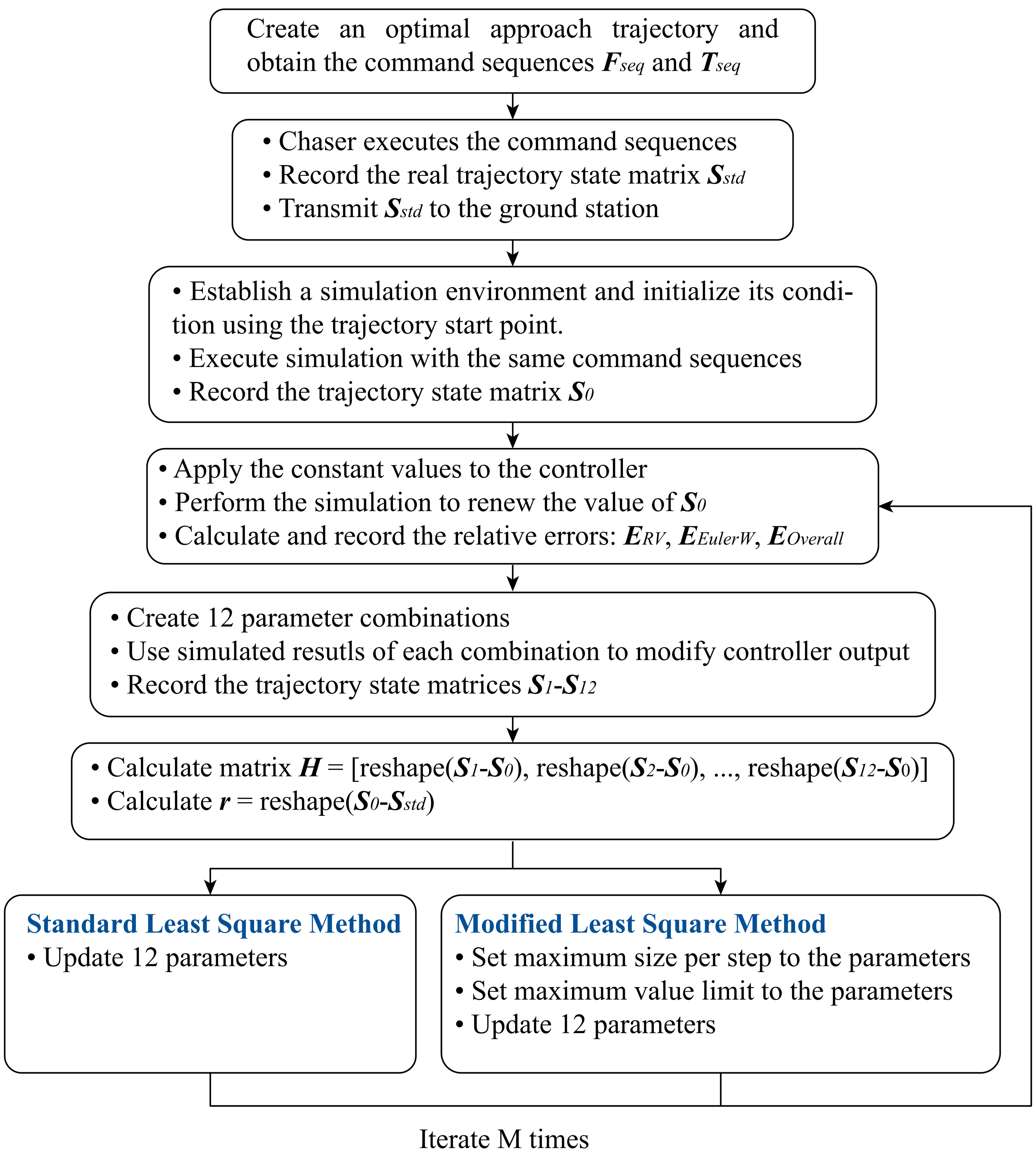
12 parameters are designed for the controller to fix the output amplitude.

Parameter	Definition
$\Delta F_{+xRatio}$, $\Delta F_{-xRatio}$, $\Delta F_{+yRatio}$, $\Delta F_{-yRatio}$, $\Delta F_{+zRatio}$, $\Delta F_{-zRatio}$	Orbit control command amplitude modification ratios of the +x axis ~ -z axis thrusters. Only one thruster is installed in each direction, and the thrusters do not generate extra torque.
$\Delta T_{+xRatio}$, $\Delta T_{-xRatio}$, $\Delta T_{+yRatio}$, $\Delta T_{-yRatio}$, $\Delta T_{+zRatio}$, $\Delta T_{-zRatio}$	Attitude control command amplitude modification ratios of the +x axis ~ -z axis thrusters. Two thrusters are installed in each torque direction symmetrically and they do not generate extra force.





Satellite Model Refinement Strategy

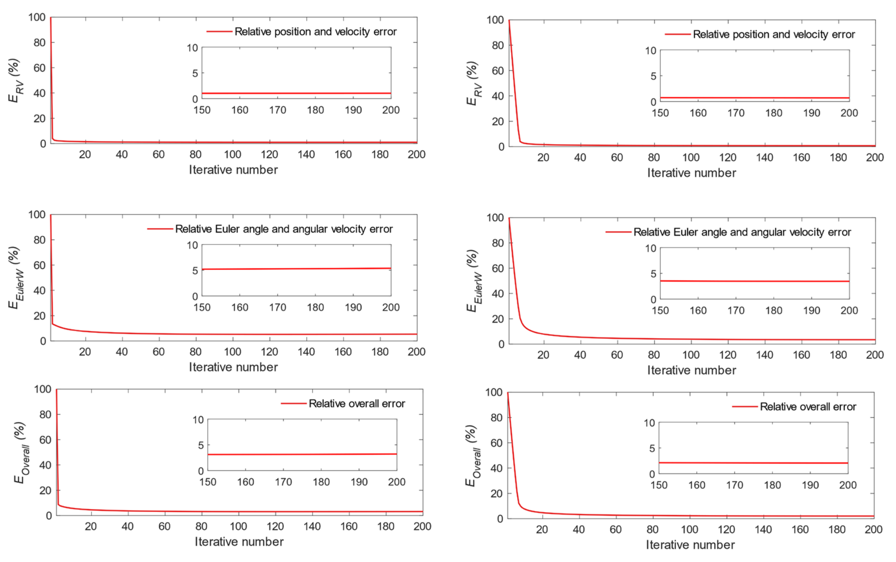


SIMULATION RESULTS

Simulation Condition Formulation

- At the initial simulation time, the position of the target is set to [42164000, 0, 0] m in the inertia frame.
- The initial relative velocities, chaser Euler angles, target Euler angles, and the chaser angular velocities of the trajectories are all set to zero.
- The original final relative position is [-2.75, 0, 0] m. However, it is set to [-4, 0, 0] m to avoid collision.
- During the trajectory planning, the maximum chaser control force is [5, 2, 2] N for each direction of the axis, and the maximum control torque is [0.3, 0.5, 0.2] Nm.

Effectiveness Verification



The E_{RV}, E_{EulerW}, and $E_{Overall}$ of the two methods under trajectory 1.

Relative error	Standard method	Modified method
E_{RV}	1.02%	0.696%
E_{EulerW}	5.18%	3.45%
$E_{Overall}$	3.10%	2.07%

The $E_{Overall}$ of the two methods under other trajectories.

Trajectory ID	$E_{Overall}$ of the standard method	$E_{Overall}$ of the modified method	Error reduction ratio
1	3.10%	2.07%	-33.2%
2	2.35%	1.87%	-20.4%
3	3.16%	2.15%	-32.0%
4	3.37%	2.43%	-27.9%
5	2.66%	1.97%	-25.9%

- The standard least square method and the proposed modified least square method are tested and compared on the five trajectories.
- The figures above present the performance comparison between the standard least square method (left) and the proposed modified least square method (right) carried out according to trajectory 1.
- The upper table shows the relative errors of the standard method and the modified method, while the lower table lists the overall relative errors of both methods under five different trajectories.

∴The remaining error of the proposed modified least square method is at least 27.9% lesser than the standard method.

CONCLUSION

In this paper, a modified least square method is proposed to improve the accuracy of satellite model refinement for approaching disabled satellites. Since this model refinement problem has non-linear characteristics, the standard method shows a disadvantage in the final convergence process. To suppress the overshooting and utilize the prior human knowledge, we introduce two limits on parameter identification, which are the maximum step size and the maximum total fix value. The direction of the standard method is reserved while improper step sizes are avoided. To depict the practical usefulness efficiency, simulation results are presented for different trajectories. The results reveal that the proposed method generates a lower remaining error than the standard method, with an average decrement of 27.9%.

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