P06

# 進化計算を用いた複数デブリ投棄衛星の連続除去軌道最適化

## Optimization of a Trajectory to Remove Multiple Space Debris Using Evolutionary Computation

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スペースデブリの除去効率を向上させるため，1 機の除去衛星が複数のデブリを除去する方法が検討されている．現在地球周辺には多くのデブリが存在するため，除去順序の組み合わせ数は膨大になり最適解を厳密に求めることは困難である．そのため，デブリ除去衛星の軌道を最適化する効率的なアルゴリズムが求められる．デブリ除去最適化問題は巡回セールスマン問題の応用として考えることが可能であり，進化的アルゴリズムの適用が考えられる．本研究では，除去候補のデブリから一定個数のデブリを選択し連続的に会合するミッションシナリオを想定し，進化計算を用いてこれを最適化する手法を提案する．目的関数は除去衛星の合計ΔV 最小化と除去デブリのレーダ反射断面積(RCS)最大化の 2 目的とした．最適化には NSGA-II と MOEA/D の 2 つの進化計算アルゴリズムをそれぞれ適用し，最適化性能の差を調査するとともに対象となる最適化問題に関する知見獲得を目的とする．

In order to improve space debris removal efficiency, a method of removing multiple debris by one satellite has been studied. Since there are many debris currently around the Earth, the number of combinations of removal order becomes enormous and it is difficult to strictly obtain the optimal solution. Therefore, an efficient algorithm to optimize the trajectory of the debris removal satellite is required. The active debris removal optimization problem can be thought of as an application of the traveling salesman problem, and the application of the evolutionary algorithm can be considered. In this research, we propose a method to optimize this by using evolutionary computation, assuming a mission scenario in which a certain number of debris are selected from debris to be removed and are continuously engaged. The objective function was aimed at minimizing the total ΔV of removal satellites and maximizing the Radar Cross-Section (RCS) of eliminated debris. For optimization, we apply two evolutionary computation algorithms of NSGA-II and MOEA/D, to investigate the difference in optimization performance and to acquire knowledge on the target optimization problem.

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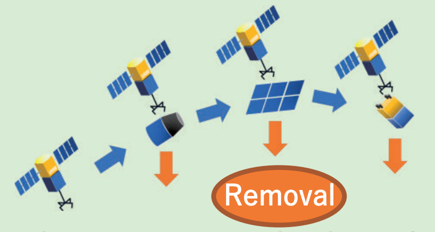
## Introduction

### Active Debris Removal

- ADR is required because of continued increase of debris.
- It is desirable to remove multiple space debris.
- We used evolutionary calculations as the combination becomes enormous.

### Purpose

- Multiobjective optimization with integer genes and real genes.
- Acquisition of knowledge on the influence of optimization scheme.

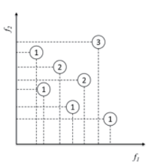



Optimizing removal order and transfer schedule

## Optimization Methods

### Pareto Approach

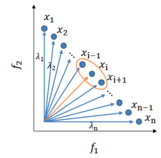
**NSGA-II**



Based on superior relationship

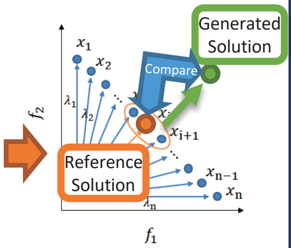
### Non-Pareto Approach

**MOEA/D**



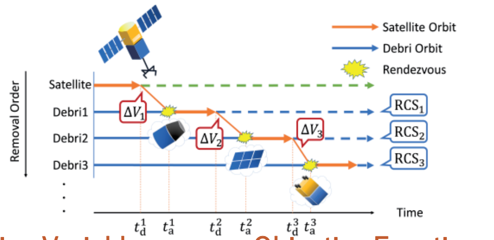
Scalar with uniform weight vector

**MOEA/D-R**




Restricted update individuals to newly generated

## Problem Definition




### Design Variables

| | |
|---|---|
| Debris Number | $j^1, \ldots, j^N$ |
| Departure Time | $t_d^1, \ldots, t_d^N$ |
| Arrival Time | $t_a^1, \ldots, t_a^N$ |

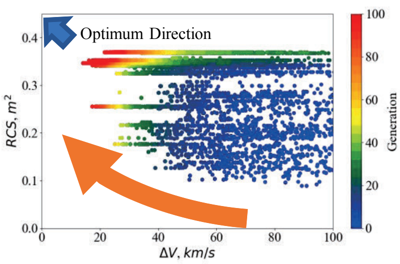
### Objective Functions

| | |
|---|---|
| Minimize | $\Delta V\ [km/s]$ |
| Maximize | RCS $[m^2]$ |

## Results

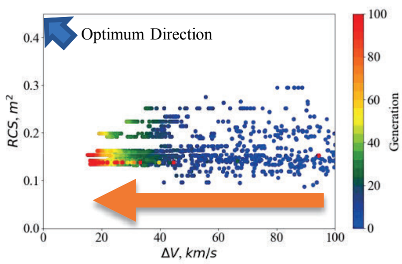
Removal number: **10 pcs.**
Taeget debris: **Fengyun 1C (100 pcs.)**

### History of Solution Groups



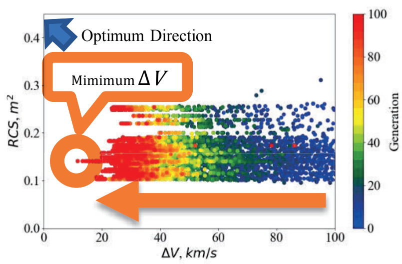

NSGA-II

- Optimization proceeds in the upper left direction
- Discover individuals with large RCS




MOEA/D

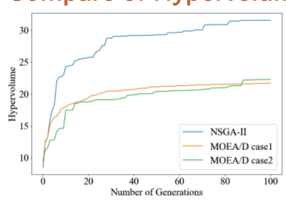
- Optimization proceeds in the left direction
- Large RCS are lost




MOEA/D-R

- Dense solution distribution
- Discover minimum Δ V in all methods

### Compare of Hypervolume




- NSGA-II searches for the widest range
- MOEA/D-R overtakes the reference method at the end of the search

## Conclusions

- Debris removal satellite orbit optimization using NSGA-II and MOEA/D.
- The solution distribution is the most widely with NSGA-II.
- MOEA/D-R gains a dense solution distribution.