

CONTROL ALGORITHMS FOR *SPACE TUG* RENDEZVOUS

Statement of Project

16.621

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1. Introduction

The *Space Tug* project is an ongoing MIT/Darpa research project that aims at developing a satellite – the Tug – to carry out rendezvous and docking with a target satellite. The mission of the Tug will be to capture its target, change its position and orbital elements by a predefined amount and release it without damage to the target satellite or itself. The capabilities of the Tug must include the following: rescue satellites from unusable orbits, orbital debris removal, tactical operations, and other emergent uses. The control system of the Tug used to find and dock with the target is a major aspect of this project.

The search for the target satellite is a complex procedure. Although approximate coordinates for its location would be provided, the Tug would still have to search a finite space to find it, since current tracking does not give precision below a magnitude of the order of kilometers. As a result, the Tug has to have intelligent identification and sensing strategies implemented in its control system to approach the target.

A major technology risk in the *Space Tug* project is the target identification and docking. Showing that such a process is feasible would remove this risk and would provide a possible solution to the problem. In addition, given that the control system of the Tug has thus far been modeled as a black box, the results of this research project could give clues as to what the architecture of the control system of the vehicle should be. Furthermore, successful search and rendezvous strategies could be used in other aeronautical applications, such as autonomous and formation flight.

Search strategies and algorithms for robots have been studied quite a lot in the past years. As a result, the design part of this project will be influenced by previous work

done on search algorithm, notably by the MIT department of electrical engineering and computer science. The basic strategies will be enhanced to fit the purpose of the Space Tug.

2. Hypothesis

The use of a semi-autonomous search system with human in the loop is the algorithm that will be the most effective for rendezvous and docking strategies in terms of time and energy consumption.

3. Objectives

The project is divided into two distinct parts that will achieve two different but closely related goals. The preliminary objective is to develop, implement, and test three different strategies for two-dimensional, non-cooperative target search and precise docking. This goal is the first step in achieving the primary objective.

The primary objective of the experiment is to compare these three strategies based on the trade-off costs between time and energy. The search strategies will be evaluated using predefined criteria, developed into a cost function, to examine the performance of each.

4. Overview of strategies

First of all, a model has to be developed in order to simulate the space environment. The position of the Tug in space is defined using four dimensions: three spherical coordinates and time. As a result, assumptions will have to be made in order to build a two-dimensional model that will fit the situation. One possibility is to assume that the Tug will be in the same orbital plane, relative to Earth, as the target. Furthermore, this model will also need to take care of the relative sizes of the Tug, the target and the search area. According to these parameters, the area of the test-bed environment will be chosen

to fit the model. The development of the simulation model will be completed by the end of the 16.621 semester.

During the second phase of the project, three different search and rendezvous strategies will be developed and implemented, using LEGO[®] Mindstorms robots. One strategy will be a blind search. The Tug simulator will have no sensors to find the target and will search space until it “bumps” into the target. The second strategy will be a semi-autonomous search with a human in the loop. In this case, the robot’s sensor will take data about the searched space and send it to a human controller that will interpret the data to maneuver the robot accordingly. Finally, the third search strategy will be a human-out-of-the-loop algorithm where the robot will be completely autonomous. This part of the project will be done during the 16.622 phase.

Finally, a test-bed environment will be created for the robots. It will include a non-cooperative, passive target. The different search strategies will be tested in this environment, and the time and energy consumption will be recorded in order to develop the proper cost function. This final step – which will take place during the second semester of 16.62X – will enable the comparison between the search strategies.

5. Success criteria

Linked to the above objectives, this project has two main success criteria. The first criterion is the design and development of the search algorithms in the test-bed environment. The successful implementation of the rendezvous strategies in the vehicle simulating the Tug will provide the necessary data to test the relative effectiveness of each strategy.

The second success criterion is the development of a cost function, based on the performance of each search strategy. The trade-off between time and energy has to be represented by the cost function of the form $C = \alpha \cdot \text{time} + \beta \cdot \text{energy}$. The relative effectiveness of each strategy will be calculated using this cost function and the results will be compared in order to assess the validity of the hypothesis.

6. Conclusion

This project will provide answers to the rendezvous and docking problem that could then be implemented in the broader MIT/Darpa *Space Tug* project. The results will help to point out potential solutions and algorithms for the control system of the future Tug. Time and energy consumption, as well as the successful implementations of the three searching strategies, will be the focus of the research project. It will provide a first look at the cheapest rendezvous strategy that could potentially be used in the *Space Tug* project. Ultimately, the goal of this project is to show that the semi-autonomous with a human in the loop search will satisfy this important requirement.