Orbital Robotics & Distributed Space Systems Final Project

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Dynamics Modeling of a Space Debris Removal Mission

DISCLAIMER: This is the assignment of final project for the course of *"Orbital Robotics & Distributed Space Systems"*. More details regarding some of the assignments will be delivered in the next weeks.

1 Assumptions

Consider a debris removal mission in the Earth environment, defined by the following initial conditions (see **Fig. 1**) and constraints:

- The spacecraft S/C moves on an initial circular and equatorial orbit, with altitude $h_1 = 600\,\text{km}$ and radius R_1.
- The non-cooperative target (like a space debris denoted by D) is located on a second circular and equatorial orbit, with estimated altitude of $h_2 = 350\,\text{km}$ and radius R_2.
- Consider an initial phasing angle ϕ_0 between the two orbiting objects of $10°$.

2 Assignments [8 pts + 2 bonus]

PART 1 [max 2 pt], Orbital transfer to debris position: Analytically compute the minimum change of velocity ΔV required to perform a two-impulse transfer from the satellite initial position to the debris state. Evaluate the time of flight and plot the three orbits describing the maneuver. Consider an initial phasing between the spacecraft and the debris. Propagate numerically the equations of motion and verify that the obtained solution matches the analytical one (up to a reasonable error). Plot the time evolution of the constants of motion of the Kepler problem during the all transfers.

PART 2 [max 2 pt], Relative dynamics final approach: Let us consider a realistic

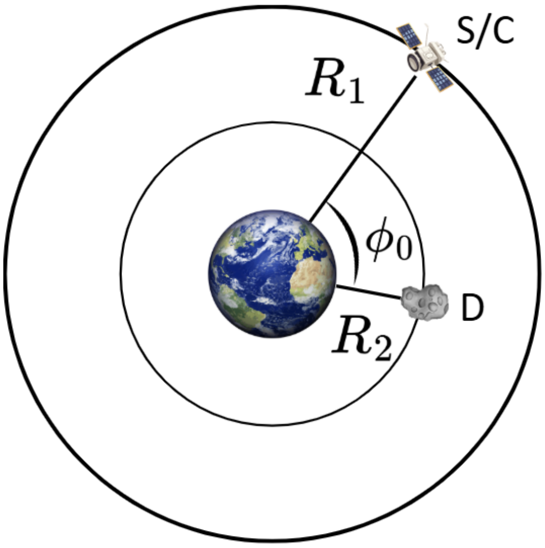

Fig. 1: Orbiting S/C and debris D around the Earth

scenario in which the artificial satellite does not perform a perfect rendezvous (i.e., the relative distance between the spacecraft and the debris is not zero). To quantify this displacement, let us assume that a random error in the final position of the satellite at the end of the transfer (performed in Part 1) is achieved. In particular, let us consider an error in the in-plane direction, both in terms of position $(500 \div 1000)$ m and velocity $(0.1 \div 1)$ m/s [use randn() Matlab function]. Perform a final approach with an analytical solution, by quantifying the required change of velocity ΔV as a function of the time of flight ΔT (assume the same initial condition for all the transfers). Assume the time of flight ranging from the initial epoch of the final approach to two orbital periods of the target and comment the results on the report. After motivating the choice, consider a specific initial condition for the approach and propagate numerically the relative linear equations of motion. Finally, through a Matlab script, verify that the trajectory obtained via the numerical integration matches the analytical one up to a reasonable error.

PART 3 [max 2 pts], Perturbations: Evaluate the effect of the atmospheric drag on the rendezvous. In particular, by applying the same analytical ΔV found in PART 2, propagate the equations of motions, adding the perturbative effect and find the final offset, in terms of both position and velocity with respect to the desired final state. Assume a drag coefficient of 2.2, a cross-sectional area of $2\,\mathrm{m}^2$ and a mass of 325 kg. Motivate the choice for the value of the atmospheric density to use in the drag formulation.

PART 4 [max 2 pts], Robotic Manipulator: Considering your spacecraft has a square body with a protruding 5 revolute DOF robotic manipulator:

- Identify and list all the mathematical quantities necessary for analysing the modelled scenario. Decide on the geometry and the numerical values. Prepare a drawing of the geometry of the scenario that illustrates the parameters involved, and verify the number of degrees of freedom with two different approaches. Define the possible modes of operation for the manipulator.

- By considering and underlining the necessary assumptions, analyse and express the kinematics equations of the system. Then, starting from an initial equilibrium state, study the propagation of a contact force at the end-effector (your spacecraft's manipulator reached contact with the debris). Simplification: you can consider the first 3 revolute fixed and rotation possible only on the last two revolutes.
- *In alternative to the two points above (or for your personal interest)*, execute and report the Deepnote exercises up to Chapter 3 from the Russ Tedrake Robotic Manipulator course (not specific for space applications).

PART 5 (Bonus and Optional) [max 1 pt each (in addition to the total 11)]:

- Identify a possible debris retrieval/de-orbiting technology and describe characteristics, main requirements, and implications on the spacecraft dynamics.
- In the same scenario of PART 2, evaluate the required ΔV that is necessary to reach the debris in presence of the aforementioned orbital disturbances.

3 Report [3 pts]

The report will be graded on a scale from 0 to 3 points. Each group must internally decide a Team Leader for the final project delivery. Specifically, a clear and informative README.txt file (with format #NumberGroup_TeamLeaderFullName.txt) is needed, explaining all MATLAB codes and working features, evaluated for a maximum of 0.5 points. This evaluation will also take into account the quality and clarity of the adopted methodology, readability and labeling of figures and plots, correct use of units of measurement and the overall organization of the document.