ROSSONERO: NEW FEATURES IN THE SIMULATION TOOL FOR REALISTIC RENDEZVOUS MISSION DESIGN IN THE RESTRICTED THREE-BODY PROBLEM

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ABSTRACT

ROSSONERO (Rendezvous Operations Simulation Software on Near Rectilinear Orbit) is a simulation tool for design of phasing and rendezvous maneuvers between an active chaser spacecraft and a passive target spacecraft in highly non-Keplerian orbits in which the third body perturbation can not be neglected. It is developed with particular focus for rendezvous and proximity operations in the Earth-Moon L2 Near Rectilinear Halo Orbit (NRHO) of the upcoming Lunar Orbital Platform Gateway(LOP-G). However, the tool is structured so that it can handle different orbit types, different spacecraft architectures and different three-body problem scenarios. The software simulates the full 6-DOF relative dynamics and control. Sensors and actuators models, and control allocation methods are included in the simulation tool, to assess realistic performances of the guidance and control loops. The tool also allows to perform passive safety analysis of the rendezvous sequence, in terms of different types of failure, such as missed and partially performed firings, and random unintended firings. ROSSONERO is an effective and user-friendly simulation tool for development and validation of rendezvous guidance and control under the restricted three-body problem dynamics.

1 INTRODUCTION

Future missions targeting human and robotic exploration of the Moon include utilization of a permanent orbiting outpost, the Lunar Orbital Platform-Gateway (LOPG), located in a Near Rectilinear Halo Orbit (NRHO) of Earth-Moon L2 Lagrangian point. Manned and unmanned Rendezvous and Docking/Berthing maneuvers with this space infrastructure will be extensively exploited. Therefore, analysis and design of Guidance, Navigation and Control (GNC) algorithms to successfully accomplish these complex operations is a key aspect in the international cooperation scenario aimed at establishing a sustainable and long-term human return to the lunar surface.

ROSSONERO (Rendezvous Operations Simulation Software on Near Rectilinear Orbit) is intended to simulate phasing and rendezvous trajectories in a restricted three-body problem scenario, in which the presence of a non-negligible third body influence requires accurate guidance and control design to make the chaser autonomously perform the initial and final approaches to the target station. The tool is developed in MATLAB/Simulink environment and its first version included a complete 6-DOF dynamic motion analysis and open-loop guidance for rendezvous phase only, as reported in [1].

Relative translational dynamics is based on the equations of motion given in [2] whereas relative attitude is modelled as in [3]. The equations of motion describe chaser dynamics under the Elliptic Restricted Three-Body Problem (ER3BP) with respect to a target-centered Local-Vertical Local-Horizontal (LVLH) frame in order to easily inspect relative trajectories.

Quaternions model is exploited to describe relative orientation and angular velocity, with the purpose of avoiding singularities. Target attitude instead is modelled with a saw tooth profile around the LVLH frame.
New functionalities have been added to the simulator, among which the capability of computing phasing trajectories from a Low Lunar Orbit (LLO) to a specified location in the target NRHO, sensors and actuators models as well as control allocation techniques, target pointing, closed loop guidance for the final approach which precedes either docking or robotic capture by the station, and passive safety analysis.
Phasing manoeuvre is designed exploiting Circular Restricted Three-Body Problem (CR3BP) dynamics and a numerical optimization based on ΔV consumption and position error. The user can select the number of impulsive maneuvers the chaser must execute in order to reach the target orbit in a specified location where the actual rendezvous phase may be initiated.
The rendezvous manoeuvre is simulated by defining a series of Hold Points gradually closer to the target. Each Hold Point consists of the desired relative position and velocity in the LVLH frame and the relative attitude and angular velocity, as well as the TOF from the previous Hold Point in the sequence. When relative distance is larger than 2 km, relative motion is controlled in an open loop fashion through either impulsive or continuous thrust maneuvers. The ΔV required by each transfer is evaluated by exploiting adjoint method with either ER3BP or CR3BP equations depending on user's choice.
Port-to-port motion is also computed by specifying the spacecraft docking/berthing ports position with respect to spacecraft centers of mass. A kinematic coupling between the relative rotational and translational dynamics occurs because the docking ports are not located in the spacecraft centers of mass. Chaser attitude motion and control with respect to the LVLH frame are implemented with the possibility of choosing if the chaser must keep the target in its camera field of view or it must follow a user-defined attitude profile.
Sensors and actuators models as well as control allocation techniques are included in the tool to assess realistic performances of the rendezvous guidance, expecially in the final approach regarding relative distances less than 2 km. Indeed, during this phase, closed loop guidance based on State-Dependent Riccati Equation (SDRE) technique is used to precisely control relative position and attitude.
Sensitivity to initial conditions and stochastic disturbances can also be analyzed through extensive MonteCarlo simulations to assess performances in off-nominal conditions
ROSSONERO provides the possibility of analyzing passive safety of the user-specified Hold Points, with respect to different types of failure, such as: failure to perform any planned maneuver, partially performed maneuvers, and random unintended maneuvers. If the input sequence is not safe, a new Hold Points sequence can be generated by exploiting CR3BP manifolds theory.

The paper is organized as follows: Section 2 describes the translational and attitude motion equations implemented in the tool, Section 3 and 4 describe the software structure and its functionalities, Section 5 provides a complete mission simulation whereas the conclusions are drawn in Section 6.

2 RELATIVE MOTION EQUATIONS AND CONTROL

Translational and attitude motion equations and control algorithms used in ROSSONERO are here breafly presented. Further details about relative dynamics in the three-body problem can be found in [4] whereas the reader can refer to [5] for a throughout description of guidance and control loops, as well as sensors and actuators models.

2.1 Relative Dynamics Equations of Motion

Figure 1 schematically shows how relative dynamics is simulated.

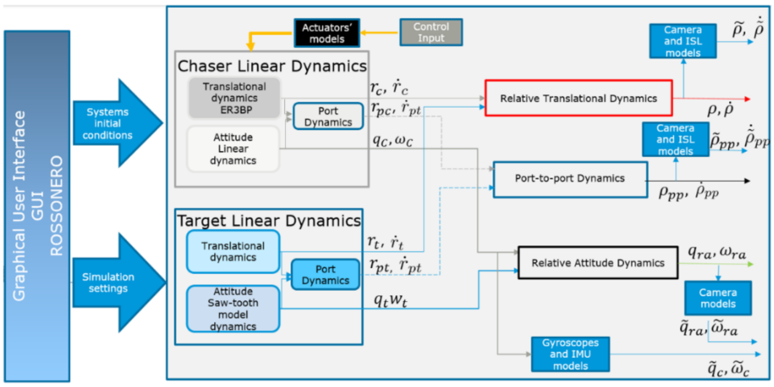
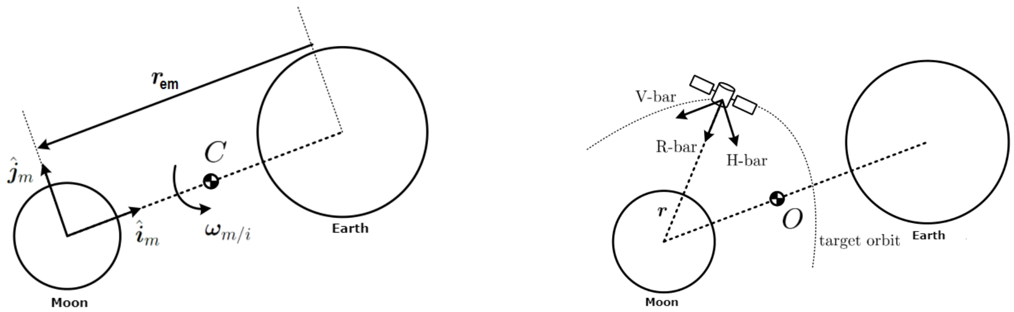


Figure 1: Translational and attitude dynamics

The absolute translational motion of chaser and target spacecraft are modelled through ER3BP equations with respect to a Moon-centered rotating frame (Figure 2a), and are then used to compute relative position and velocity in a target-centered LVLH frame (Figure 2b).



(a) Moon-centered rotating frame (b) Target-centered LVLH frame

Figure 2: Reference frames

The equations of relative motion in the LVLH frame are given in Eq. 1 [4]:

$$
\begin{aligned}
\ddot{\boldsymbol{\rho}}\big|_{\mathcal{L}} = &-\mu\frac{\boldsymbol{r}+\boldsymbol{\rho}}{\|\boldsymbol{r}+\boldsymbol{\rho}\|^3} - (1-\mu)\left(\frac{\boldsymbol{r}+\boldsymbol{\rho}+\boldsymbol{r}_{em}}{\|\boldsymbol{r}+\boldsymbol{\rho}+\boldsymbol{r}_{em}\|^3}\right) \\
&+\mu\frac{\boldsymbol{r}}{\|\boldsymbol{r}\|^3} + (1-\mu)\left(\frac{\boldsymbol{r}+\boldsymbol{r}_{em}}{\|\boldsymbol{r}+\boldsymbol{r}_{em}\|^3}\right) \\
&-2\boldsymbol{\omega}_{l/i}\times\dot{\boldsymbol{\rho}}\big|_{\mathcal{L}} - \dot{\boldsymbol{\omega}}_{l/i}\big|_{\mathcal{L}}\times\boldsymbol{\rho} - \boldsymbol{\omega}_{l/i}\times(\boldsymbol{\omega}_{l/i}\times\boldsymbol{\rho})
\end{aligned} \tag{1}
$$

where μ is the Earth-Moon mass parameter, $\boldsymbol{\rho}$, $\dot{\boldsymbol{\rho}}$, and $\ddot{\boldsymbol{\rho}}$ denote the relative position, velocity and acceleration of the chaser as seen in the LVLH frame, $\boldsymbol{r}$ is the target position in the Moon-centered rotating frame, $\boldsymbol{r}_{em}$ is the Moon position vector relative to Earth, $\boldsymbol{\omega}_{l/i}$ and $\dot{\boldsymbol{\omega}}_{l/i}$ are the angular velocity and acceleration of LVLH frame as seen in an inertial reference frame. The latter can be obtained as shown in Eq. 2:

$$
\begin{aligned}
\boldsymbol{\omega}_{l/i} &= \boldsymbol{\omega}_{l/m} + \boldsymbol{\omega}_{m/i} \\
\left[\dot{\boldsymbol{\omega}}_{l/i}\right]_{\mathcal{L}} &= \left[\dot{\boldsymbol{\omega}}_{l/m}\right]_{\mathcal{L}} + \left[\dot{\boldsymbol{\omega}}_{m/i}\right]_{\mathcal{M}} - \boldsymbol{\omega}_{l/m} \times \boldsymbol{\omega}_{m/i}
\end{aligned}
\tag{2}
$$

with $\boldsymbol{\omega}_{l/m}$ and $\left[\dot{\boldsymbol{\omega}}_{l/m}\right]_{\mathcal{L}}$ denoting the angular velocity and acceleration of the LVLH frame with respect to the Moon, whereas $\boldsymbol{\omega}_{m/i}$ and $\left[\dot{\boldsymbol{\omega}}_{m/i}\right]_{\mathcal{M}}$ are the angular velocity and acceleration of the Moon-centered rotating frame with respect to inertial frame.
Port-to-port position can then be evaluated with Eq. 3 :

$$
\boldsymbol{\rho}_{\boldsymbol{pp}} = \boldsymbol{\rho} + \boldsymbol{r}_{\boldsymbol{pc}} - \boldsymbol{r}_{\boldsymbol{pt}} \tag{3}
$$

where $\boldsymbol{r}_{\boldsymbol{pc}}$ and $\boldsymbol{r}_{\boldsymbol{pt}}$ are the positions of chaser and target docking/berthing ports with respect to their respective centers of mass (Figure 3). These positions can be set by the user.

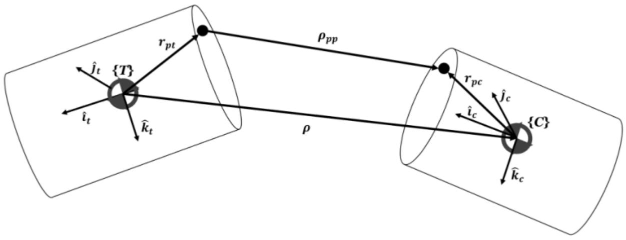


Figure 3: Port-to-port vector

Chaser attitude kinematics and dynamics with respect to the LVLH frame are given in Eq. 4:

$$
\begin{gathered}
\dot{\boldsymbol{q}}_{\boldsymbol{c/l}} = \frac{1}{2}\begin{bmatrix} 0 & -\boldsymbol{\omega}_{\boldsymbol{c/l}}^{T} \\ \boldsymbol{\omega}_{\boldsymbol{c/l}} & -\left[\boldsymbol{\omega}_{\boldsymbol{c/l}}\right]^{\times} \end{bmatrix} \boldsymbol{q}_{\boldsymbol{c/l}} \\
\mathbb{I}_c \dot{\boldsymbol{\omega}}_{\boldsymbol{c/i}} + \boldsymbol{\omega}_{\boldsymbol{c/i}} \times \mathbb{I}_c \boldsymbol{\omega}_{\boldsymbol{c/i}} = \boldsymbol{N}
\end{gathered}
\tag{4}
$$

where the superscript $\times$ denotes the skew symmetric matrix, $\boldsymbol{q}_{\boldsymbol{c/l}}$ and $\boldsymbol{\omega}_{\boldsymbol{c/l}}$ are the quaternion describing the chaser attitude and its angular velocity with respect to the LVLH frame, $\boldsymbol{\omega}_{\boldsymbol{c/i}}$ is the chaser angular velocity with respect to inertial frame, $\mathbb{I}_c$ is the chaser's inertia matrix whereas $\boldsymbol{N}$ is the acting torque. The relative attitude $\boldsymbol{q}_{\boldsymbol{t/c}}$ and angular velocity $\boldsymbol{\omega}_{\boldsymbol{t/c}}$ of the target with respect to the chaser can be computed as in Eq. 5 [6]:

$$
\boldsymbol{q}_{\boldsymbol{t/c}} = \boldsymbol{q}^{*}_{\boldsymbol{c/l}} \otimes \boldsymbol{q}_{\boldsymbol{t/l}}, \quad \boldsymbol{\omega}_{\boldsymbol{t/c}} = \boldsymbol{\omega}_{\boldsymbol{c/l}} - \boldsymbol{R}_{\boldsymbol{cl}}(\boldsymbol{q}_{\boldsymbol{c/l}})\boldsymbol{\omega}_{\boldsymbol{t/l}} \tag{5}
$$

where the operator $\otimes$ and the superscript $*$ denote the quaternions product and the conjugate operation, respectively, $\boldsymbol{q}_{\boldsymbol{t/l}}$ and $\boldsymbol{\omega}_{\boldsymbol{t/l}}$ are the target attitude and angular veocity with respect to the LVLH frame, and $\boldsymbol{R}_{\boldsymbol{cl}}(\boldsymbol{q}_{\boldsymbol{c/l}})$ represents the rotation matrix from the LVLH frame to the chaser body frame.

2.2 Sensors and Actuators Models

Due to the characteristics of a rendezvous mission, the set of sensors used by the guidance and control depends on the relative distance between chaser and target, which defines which suite is active at any particular moment. Therefore, as the relative range decreases during the approach, different chaser sensors are considered and modelled. In particular, the relative range is measured through an Inter Satellite Link (ISL) until a distance of 10 km. The relative azimuth and elevation angles between the two spacecraft are measured with a Narrow Angle Camera (NAC), which also replaces the ISL in measuring the relative range below 10 km and until 2 km when the target is within the camera field of view (FOV). For shorter distances the sensor used to measure the relative position is a Wide Angle Camera (WAC), which also measures the relative attitude. The user can define the distances at which each sensor suite is picked out as well as sensors positions with respect to chaser center of mass.
All sensors are modelled as in Eq. 6:

$$\boldsymbol{x}_m(t) = \boldsymbol{T}_x(\boldsymbol{I}+\boldsymbol{k})\boldsymbol{x}(t-\tau) + \boldsymbol{b}_x(t-\tau) + \boldsymbol{n}_x(t-\tau) \tag{6}$$

with $\boldsymbol{T}$ and $\boldsymbol{k}$ denoting the misalignement and the scale factor, respectively, $\boldsymbol{b}_x$ and $\boldsymbol{n}_x$ represent the bias and the stochastic noise, whereas τ is the delay. The simulator allows to set magnitudes and frequences of sensors noises, as well as the biases and the misalignements.

Models of chaser's thrusters include the main error sources, such as thrust magnitude errors, thrust direction errors, rise/fall time and delays. Control allocation logic is implemented as in [7], avoiding the use of a Pulse Width Modulation (PWM) by computing the optimal combination of duty-cycles and fuel consumption. Chaser vehicle is modelled as a cylinder. The user can set chaser dimensions, the positions of the thursters, and their saturation limits.

A general description of sensors and actuators models used in the tool can be found in [5].

2.3 Rendezvous Guidance and Control

Figure 4 shows the different guidance and control algorithms implemented.

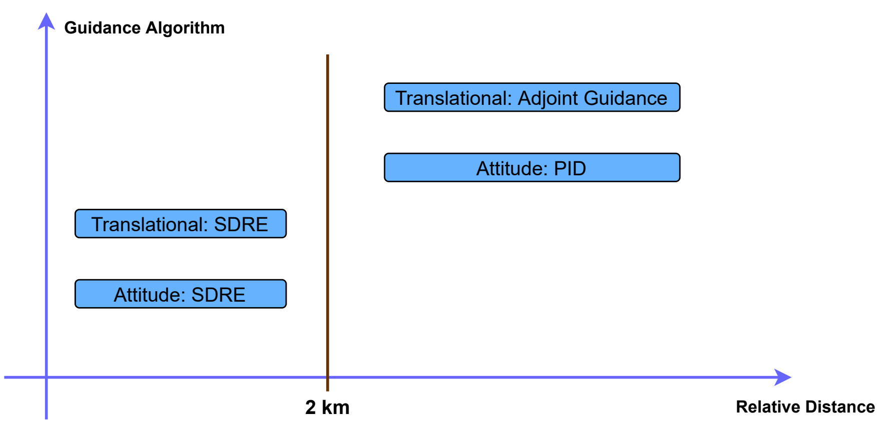


Figure 4: Guidance sequence scheme

Above the 2 km relative distance, open-loop guidance for translational motion is used, whereas the attitude controller is a Proportional Integral Derivative (PID) controller. The open loop guidance algorithm exploits the adjoint theory for computation of impulsive or continuous thrust maneuvers to move from a waypoint to another. Either the ER3BP or CR3BP models can be used for maneuvers computation, as described in [4].
At lower distances, closed-loop 6-DOF guidance and control is implemented through a State Dependent Riccati Equation (SDRE) algorithm which fully captures the nonlinearities of the system, bringing the nonlinear system to a (non unique) linear structure having state-dependent coefficient matrices, and minimizing a nonlinear performance index having a quadratic-like structure. An interesting survey on the method can be found in [8] whereas an application on spacecraft formation flying under the CR3BP dynamics is described in [9].
The user can tune the PID and SDRE parameters to obtain the best guidance performances for the defined architecture.

3 SOFTWARE STRUCTURE

ROSSONERO is composed by three main elements: the Graphical User Interface (GUI), which is shown in Figure 5, a set of MATLAB scripts to define chaser's geometry, docking/berthing ports positions, sensors and actuators positions, guidance parameters, etc., and a set of Simulink models for dynamics simulation.

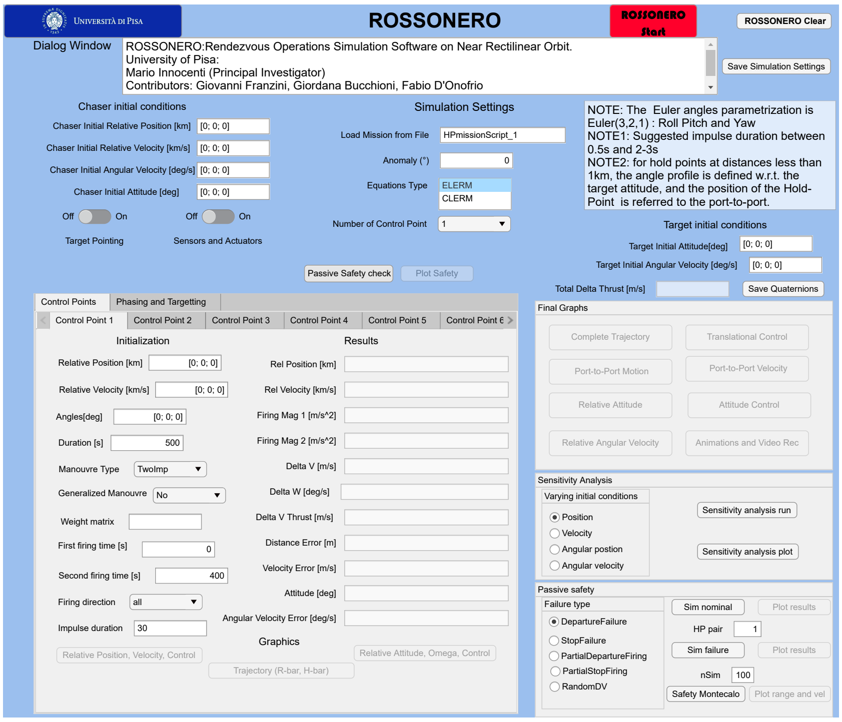
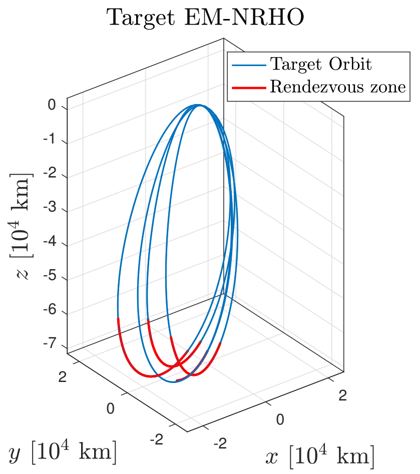


Figure 5: ROSSONERO graphical user interface

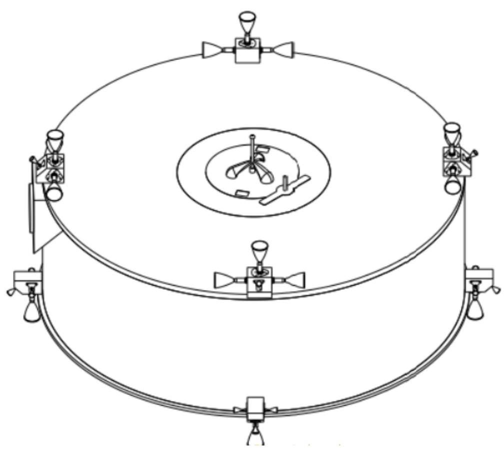
3.1 Rendezvous Definition and Simulation

The rendezvous manouvre can be defined either through the GUI or with a MATLAB script with a predifined structure. Both ways allow to initialize a set of chaser's Hold Points, each of which

consisting of the desired relative position, velocity, attitude and angular velocity between the two spacecraft. For each transfer, the user can specify the time of flight, the firing direction (tangential, radial, normal or all directions) and the firing times. Maneuvers can be either impulsive or continuous maneuvers computed with adjoint models of the linearized relative motion equations under either the ER3BP or CR3BP assumptions.
The target orbit is loaded from the data sets available and an approximated saw tooth profile around the LVLH frame is generated for its attitude.
The reference mission scenario in which ROSSONERO has been developed is the ESA's HERACLES program [10], although the tool is structured in a way to allow rendezvous mission design in different environments.
Figure 6a shows the target orbit in the Moon-centered rotating frame. It is a southern NRHO of the Earth-Moon L2 Lagrangian point with an average period of about 6 days, an aposelene located at approximately 70000 km from the Moon, and a periselene at around 3000 km. The red zone around the aposelene is the potential region for rendezvous, as discussed in [10]. Figure 6b is a 3D CAD rendering of the chaser thruster architecture. The chaser propulsion system is implemented by a main engine and 16 RCS-thrusters of 10N each.



(a) Target reference orbit



(b) Chaser thruster architecture

Figure 6: Target orbit and chaser architecture

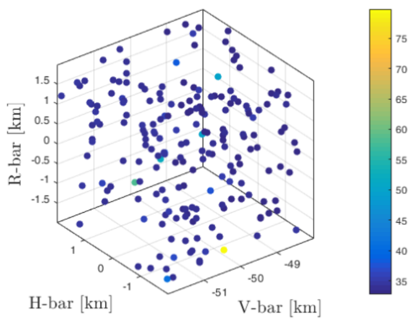
At the end of each simulation, plots of relative trajectory, attitude, angular velocity, as well as translational and attitude control histories can be generated to inspect the obtained results. A three-dimensional animation of the rendezvous trajectory can be generated as well. Simulation settings can be saved in order to be reused for comparing different rendezvous sequences in terms of time of flight, ΔV consumption, and so on.

4 NEW FUNCTIONALITIES

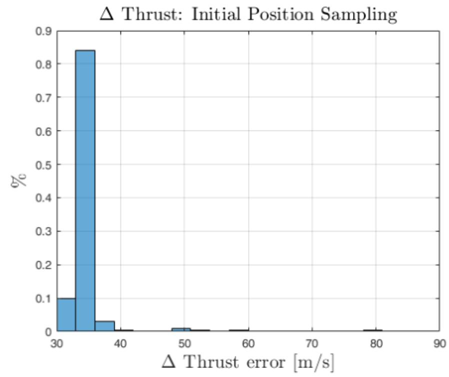
This section describe ROSSONERO's new functionalities, which include sensitivity and passive safety analyses of rendezvous manouvres, as well as design of phasing manouvres from a Low Lunar Orbit (LLO) to the target NRHO.

4.1 Rendezvous Sensitivity Analysis

Sensitivity analysis to changes in initial relative position, velocity, attitude and angular velocity, can be carried out through MonteCarlo simulations. An example on how the rendezvous energy consumption can be affected by variation of initial relative position is given in Figure 7. Figure 7a shows the distribution of initial relative position, starting from -50 km on the V-bar axis of the LVLH frame, and adding a uniformly distributed random variation between -1 and +1 km on each axis. The different colors represent the different levels of ΔV required to complete the rendezvous maneuver. The distribution of ΔV values is reported in Figure 7b, where an average enery consumption of about 35 m/s can be visualized. A more complete example of sensitivity analysis can be found in [11].



(a) ΔV variation



(b) ΔV variation distribution

Figure 7: ΔV sensitivity to initial relative position

4.2 Phasing Manoeuvre Design

Phasing simulation from a Low Lunar Orbit to the target orbit can be performed through the corresponding tab shown in Figure 8. Phasing manoeuvre is designed exploiting the stable manifolds associated to the CR3BP approximation of the target orbit and a numerical optimization algorithm to compute the required impulsive maneuvers.
The user can select the desired number of instantaneous impulses that compose the phasing manoeuvre, as well as the propagation time and the weights of the optimization algorithm. More details about the used method can be found in [12]. The outputs are the complete phasing trajectory and the total ΔV expenditure as well as the direction and timing of the required impulsive maneuvers.

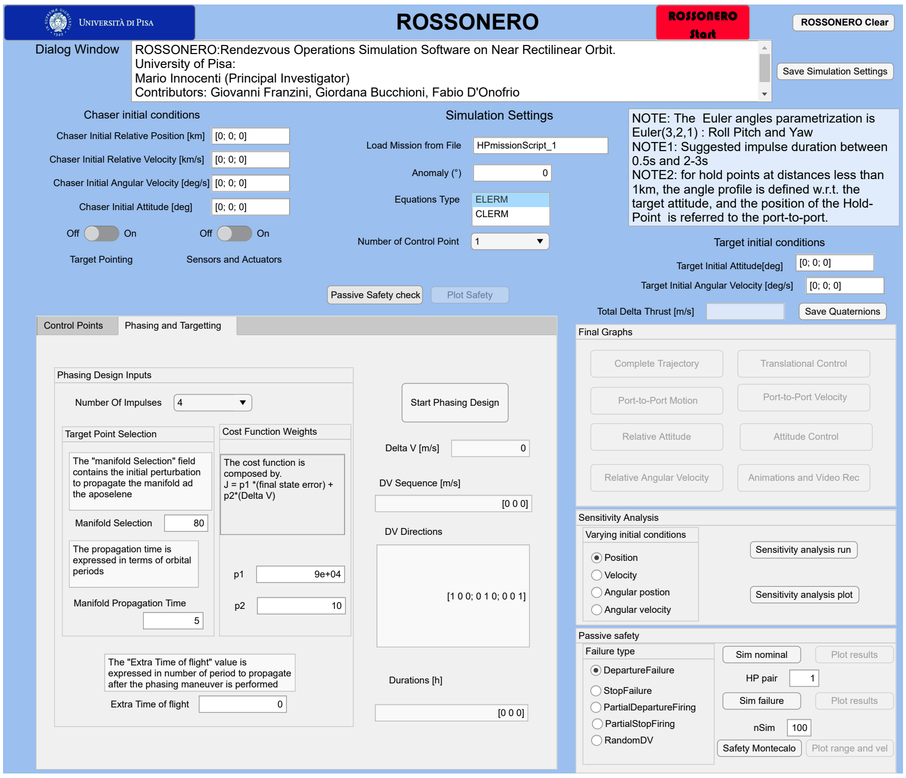


Figure 8: ROSSONERO graphical user interface - Phasing tab

4.3 Passive Safety Analysis

The tool provides the possibility of analyzing passive safety of the rendezvous profile defined by the user. For each Hold Point in the rendezvous sequence, missed departing and stopping firings are simulated, and the relative range between the two spacecraft is computed for one target orbital period, under the ER3BP model. If the relative distance drops below a safety threshold, which is defined as the radius of a Keep Out Zone (KOZ), then passive safety is violated and the Hold Points are modified in order to output a passively safe sequence with respect to fully missed firings.
Figure 9 shows a scheme of a rendezvous sequence, with the KOZ represented in red.

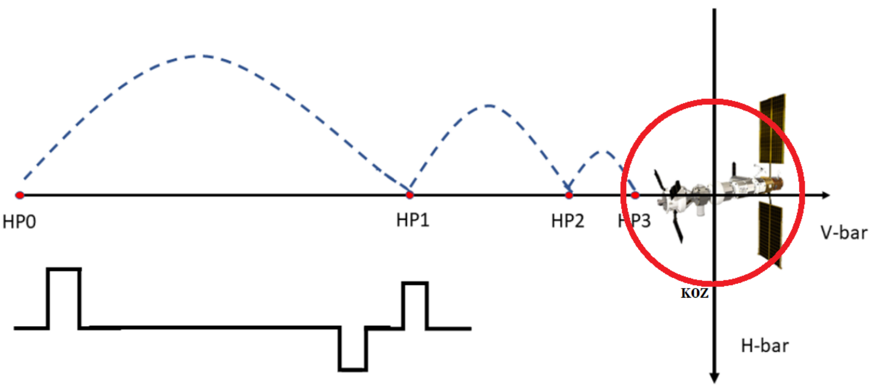


Figure 9: Rendezvous approaching sequence

The user can also perform MonteCarlo analysis to test passive safety with respect to partially performed maneuvers and random unintended maneuvers occuring between consecutive Hold Points. The passive safety algorithm is outlined in Figure 10.

Figure 10: Passive safety algorithm

The algorithm computes safe Hold Points sequences by exploiting the unstable manifolds of the CR3BP approximation of the target orbit. This way, the obtained sequence is guaranteed to be passively safe with respect to fully missed firings because of the intrinsic dynamics properties of the orbit's unstable manifolds, which ensure free-drift chaser paths safely departing from the target. The Hold Points are reallocated to lie on unstable manifolds and at distances from the target close as much as possible to the ones selected by the user.

5 MISSION EXAMPLE

This section presents a mission example simulated using ROSSONERO. The reference scenario was described in Section 3, and the target NRHO of the Earth-Moon L2 point was given in Figure 6a. First, a phasing trajectory between a polar circular Low Lunar Orbit of 100 km height and the target NRHO is computed by setting the number of impulsive maneuvers to four. The trajectory obtained in the CR3BP is shown in Figure 11. The selected stable manifold in which the chaser is injected is also depicted, as well as the target orbit in the CR3BP. The total ΔV required by the phasing manouevre is $673m/s$.

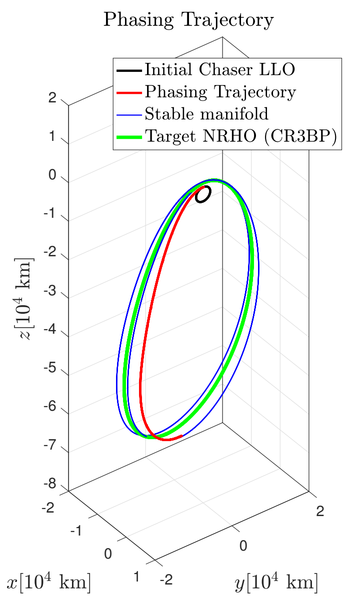


Figure 11: ROSSONERO phasing trajectory simulation in the CR3BP

A rendezvous manoeuvre simulation is then provided. The sequence of Hold Points is as follows:

- $\mathbf{HP_0} \rightarrow \boldsymbol{\rho}_0 = \begin{bmatrix} -50, & 0, & 15 \end{bmatrix}$ km ;
- $\mathbf{HP_1} \rightarrow \boldsymbol{\rho}_1 = \begin{bmatrix} -20, & 0, & 15 \end{bmatrix}$ km with time of flight 20 h ;
- $\mathbf{HP_2} \rightarrow \boldsymbol{\rho}_2 = \begin{bmatrix} -10, & 0, & 15 \end{bmatrix}$ km with time of flight 10 h ;
- $\mathbf{HP_3} \rightarrow \boldsymbol{\rho}_3 = \begin{bmatrix} -2, & 0, & 0 \end{bmatrix}$ km with time of flight 10 h ;
- $\mathbf{HP_4} \rightarrow \boldsymbol{\rho}_4 = \begin{bmatrix} 0, & 0, & 0 \end{bmatrix}$ km with time of flight 4 h ;

The Hold Points sequence is depicted in Figure 12 in the in-track plane of the LVLH frame. The approach direction is from the negative V-bar axis. The Keep Out Zone is modelled as a 10 km radius sphere.

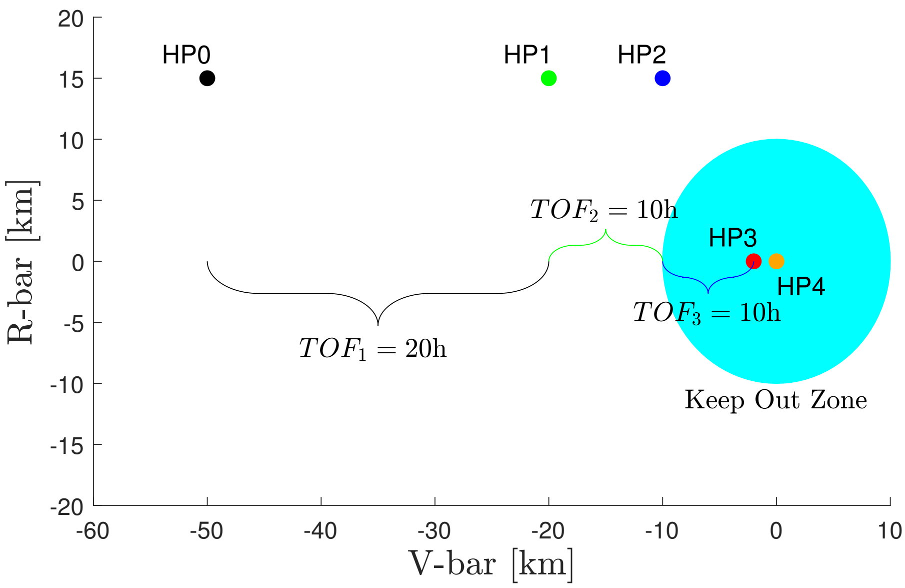
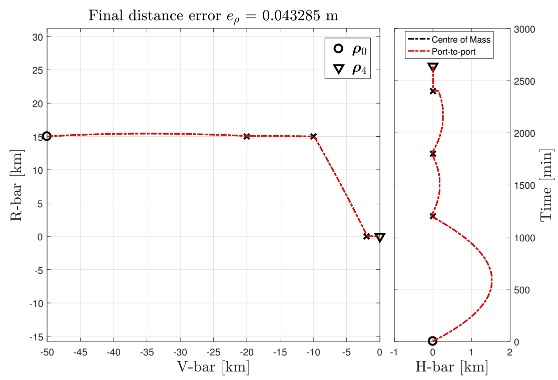
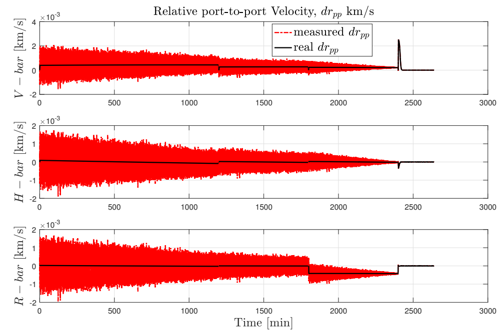


Figure 12: Hold Points sequence in the in-track plane of the LVLH frame

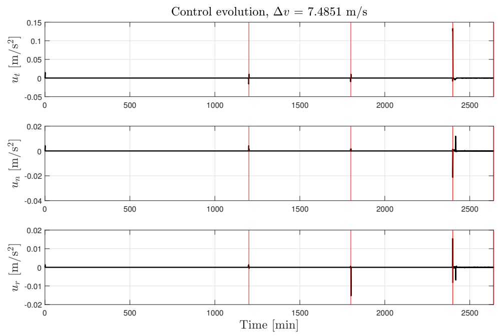
The relative translational velocity, as well as the relative attitude and angular velocity are set to zero at each waypoint. Each transfer is performed through impulsive maneuvers, except for the last one between $\mathbf{HP_3}$ and $\mathbf{HP_4}$, in which closed loop translational guidance is used to precisely control the relative motion untill the berthing point. The total time of flight is 44 hours. Figure 15 summarizes the simulation results. Figures 13a and 13b show the relative trajectory and the port-to-port relative velocity. Figures 13c and 13d report the translational and attitude control histories. The total ΔV required for the entire rendezvous manoeuvre is about 7.7 m/s, whereas the total ΔV required by the thrusters to control the relative attitude is 15 Nm. Finally, Figures 13e and 13f contain the relative Euler angles and the relative velocity.



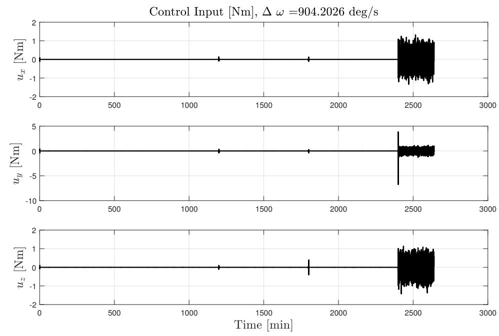
(a) Centre of mass and port-to-port relative motion



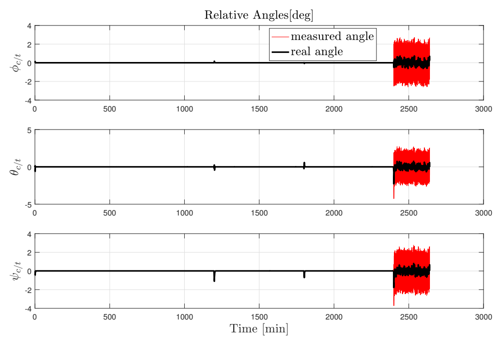
(b) Port-to-Port relative velocity



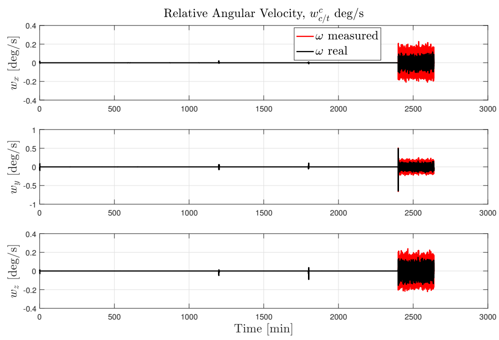
(c) Translational control



(d) Attitude control



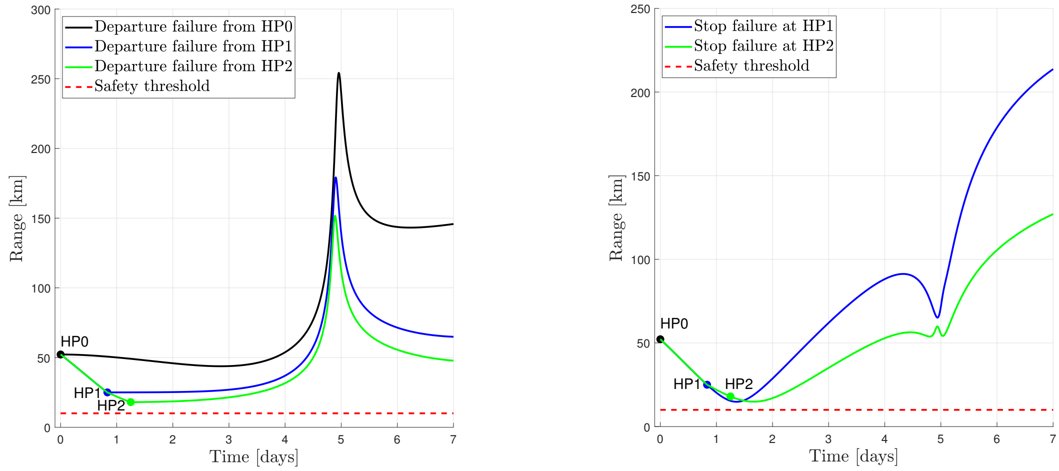
(e) Relative angles



(f) Relative angular velocity

Figure 13: ROSSONERO rendezvous simulation output example

Passive safety of the previous sequence is then analysed. In particular, missed departure and stop firings at each Hold Point are simulated under the ER3BP. Every time a failure occurs, the relative dynamics is propagated for one target orbital period, and the relative range is monitored: if it drops below the 10 km safety threshold, then the sequence is considereded unsafe.
Figures 14a shows the relative range for the departure failures from each Hold Point outside the 10 km radius sphere representing the Keep Out Zone. Inside the KOZ, passive safety can not be achieved, therefore active collision avoidance maneuvers should be considered. Figure 14b shows the two cases corresponding to a stop failure at $\mathbf{HP_1}$ and at $\mathbf{HP_2}$, respectively.

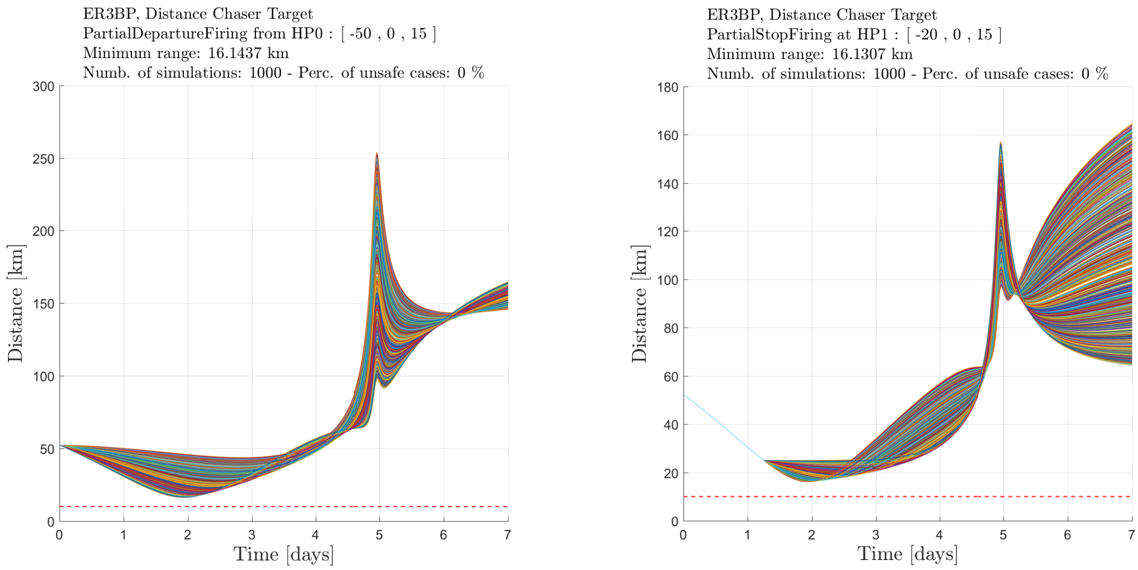


(a) Passive Safety analysis - Departure failures

(b) Passive Safety analysis - Stop failures

Figure 14: Passive Safety of the rendezvous sequence

No safety violation occur, being the relative range always larger than the 10 km threshold represented by a red dashed line in both figures. Moreover, the relative distance after one target orbital period (about 6 days), is still enough low to allow a second rendezvous attempt if desired.
Safety with respect to partially performed departing firing from $\mathbf{HP_0}$ and partially performed stopping firing at $\mathbf{HP_1}$ is performed through MonteCarlo analysis. Results are shown in Figures 15a and 15b, respectively.



(a) Partial departure firing from $\mathbf{HP_0}$

(b) Partial stop firing at $\mathbf{HP_1}$

Figure 15: Partially performed firings in the transfer $\mathbf{HP_0}$-$\mathbf{HP_1}$

6 CONCLUSIONS

A simulation tool, ROSSONERO, was developed for analyzing and performing preliminary design of the rendezvous missions with a target in a three-body problem scenario, such as a cislunar space station in the Earth-Moon system. The tool simulates the nonlinear relative dynamics of two spacecraft in presence of non negligible third-body perturbation.
Phasing trajectories can be designed by exploiting CR3BP invariant manifolds and numerical oprimization to compute the required impulsive maneuvers to change the chaser orbit from a low lunar orbit to the target orbit.
During the following rendezvous phase, two-impulse or continuous thrust maneuvers are executed for moving from a Hold Point to another. The final approach is performed with closed-loop guidance based on State Dependent Riccati Equation technique.
Sensitivity of the rendezvous sequence to initial relative position and velocity, as well as passive safety analysis with respect to missed and random firings can be carried out.
Sensors and actuators models are included in the tool to assess realistic performances of the guidance and control algorithms implemented for relative attitude and translational motion. Control allocation method is exploited to compute the distribution of the control inputs over the chaser's thrusters.
ROSSONERO offers an intuitive user interface that allows the user to easily configure the rendezvous mission and efficiently analyze the results.

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