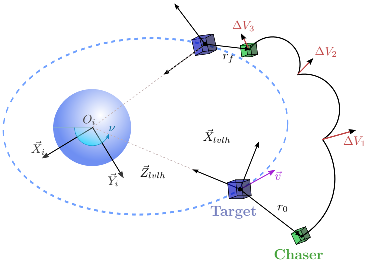
LAAS Days
Research & Technology

Spacecraft rendezvous: developing and implementing a Guidance & Control algorithm
The LAAS RT Days

P.R. Arantes Gilz, M. Joldes, C. Louembet, F. Camps

22 June 2018



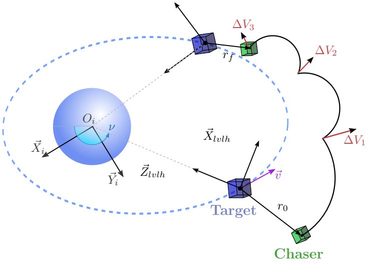
RdV missions

- ISS docking;
- On-orbit servicing (Space Tug): refuelling, orbits correction, debris removal.

Requirements

- Autonomy, Safety, Cost (maximizing spacecraft lifetime).

Orbital rendezvous and Goals



RdV missions

- ISS docking;
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Requirements

- Autonomy, Safety, Cost (maximizing spacecraft lifetime).

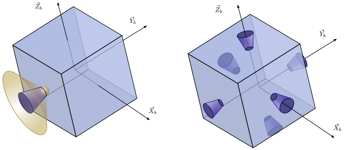
Goals:

- To conceive an optimization-based algorithm for rendezvous optimal guidance and robust control:
  - Comprehensive enough to account for the above requirements;
  - Simple/fast enough to be on-boarded and executed in real-time during spaceflight missions;
- To provide the libraries, compilation chains and instructions to embed the proposed algorithm on a board containing a FPGA-synthesized LEON3 microprocessor.

Mission must be completed accounting for:

Thruster limitations:

- minimal magnitude;
- maximal magnitude.



(a) $\|\Delta V\|_2 \leq \overline{\Delta V}$ (b) $\|\Delta V\|_\infty \leq \overline{\Delta V}$

Figure: Thrusters configuration.

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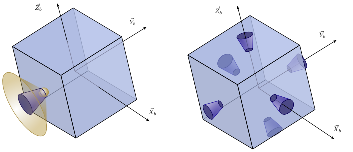

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Proximity operations:

- visibility cone;
- safety distance.

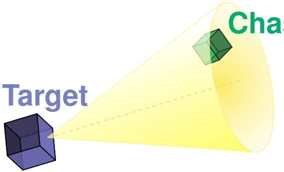

Figure: Visibility constraints.

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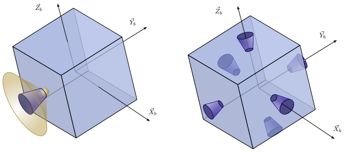
Station keeping:
- hovering zone.



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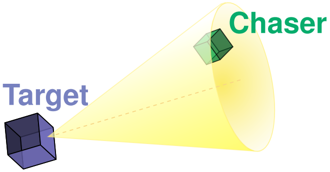

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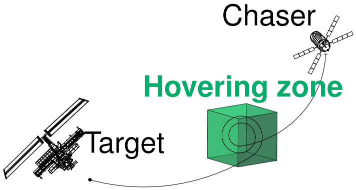

Figure: Keeping station in a hovering zone.

Less conservative than existing proposed methods:

”Pogo” strategy:

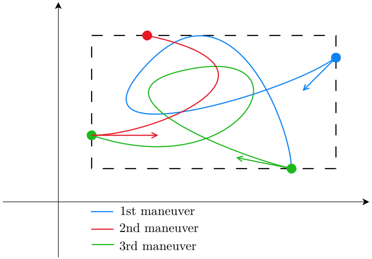

Figure: ”Pogo” strategy.

Innovation of the proposed algorithm

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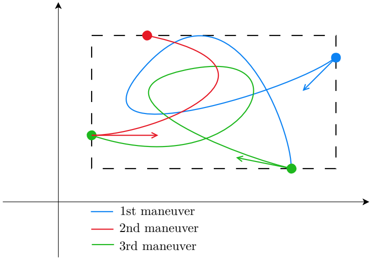
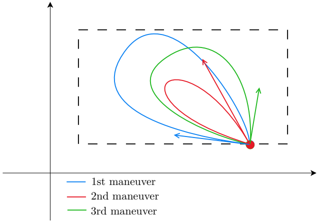


Figure: "Pogo" strategy.

"Teardrop" strategy:



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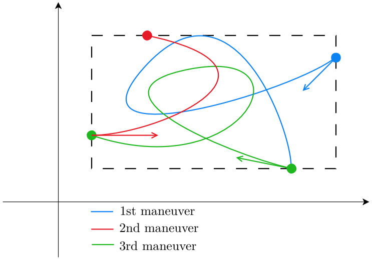

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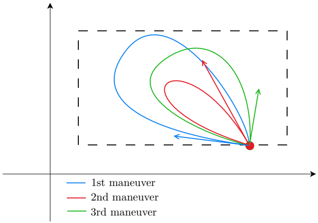

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Proposed strategy:

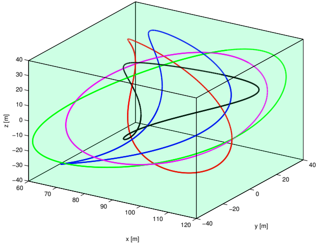


Figure: Constrained periodic relative orbits

P.R. Arantes Gilz, M. Joldes, C. Louembet, F. Camps, Model predictive control for rendezvous hovering phases based on a novel description of constrained trajectories. IFAC World Congress 2017.

P.R. Arantes Gilz, C. Louembet, Predictive control algorithm for spacecraft rendezvous hovering phases. ECC 2015

Optimal control formulation and MPC strategy

- Optimal control problem under states/inputs constraints;
- Finite description of constrained trajectories included in linear subspace;
- Formulation of an equivalent optimization problem;
- Stabilization via MPC strategy.

$$\min_{\Delta V} \; J(\Delta V) \qquad \text{Fuel-consumption}$$

$$\text{s.t.} \begin{cases} D(\nu_1) = D_1, & \text{Initial state} \\ D^+(\nu_N) = \Phi_D(\nu_N, \nu_1) D(\nu_1) + M(\nu_1, \ldots, \nu_N)\,\Delta V, & \text{State propagation} \\ d_0^+(\nu_N) = 0, & \text{Periodicity} \\ |\Delta V(\nu_i)|_\infty \leq \overline{\Delta V}, \quad i \in \{1, \ldots, N\} & \text{Saturation} \\ g_w(D^+(\nu_N)) \leq 0, \; w \in \{\underline{x}, \overline{x}, \underline{y}, \overline{y}, \underline{z}, \overline{z}\} & \text{Hovering region} \end{cases}$$

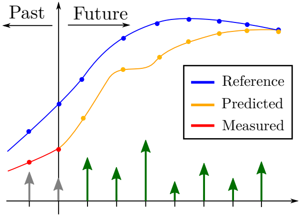


Figure: MPC strategy.

P.R. Arantes Gilz, M. Joldes, C. Louembet, F. Camps, Stable Model Predictive Strategy for Rendezvous Hovering Phases Allowing for Control Saturation. Submitted to AIAA JGCD 2018

Numerical implementation and Test environment

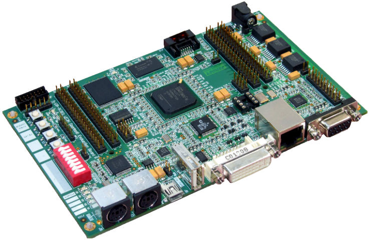


Figure: AEROFLEX GAISLER GR-XC6S

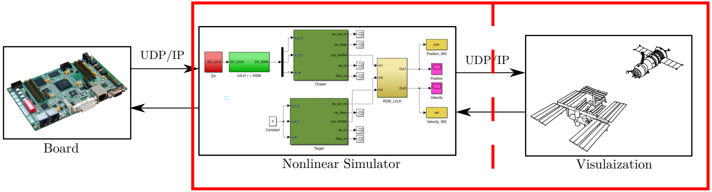
Main characteristics:

- Main oscillator 50 MHz;
- PROM: 8 Mbyte FLASH (organized x8);
- DDR2 RAM: 128 Mbyte DDR2 RAM on board (16 bits wide interface);

- Synthesized LEON3 microprocessor, SPARC V8 architecture, Linux 2.6 environment;
- Developement of specific library and static linkage of existant ones:
  - `libgfortran.so.3`, (FORTRAN), `libc.so.6` (C), `libm.so.6` (Math. functions), `sdp` (CSDP)
- Cross compilers for sparc V8: fortran, gcc, g++

F. Camps, P.R. Arantes Gilz, M. Joldes, C. Louembet, Embedding a SDP-based control algorithm for the orbital rendezvous hovering phases. ICINS 2018.

Hardware-in-the-loop simulations and Results



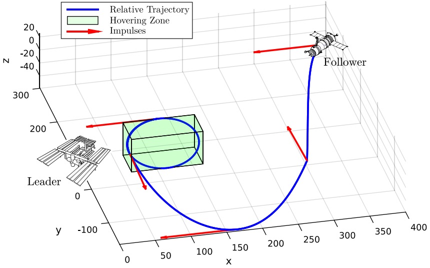


Figure: Relative trajectory

Target parameters					
a [m]	e	ν_1 [rad]	$\Delta\nu$ [rad]	N	$\overline{\Delta V}$ [m/s]
6777280	0.00039	π (apogee)	$\pi/2$	5	1
Hovering zone					
$\underline{x}$	$\overline{x}$	$\underline{y}$	$\overline{y}$	$\underline{z}$	$\overline{z}$
50 m	150 m	-25 m	25 m	-25 m	25 m

Table: Mission Parameters

Real-time demonstrator

Click here for the video.

Achievements

Scientific Productions:

- A Guidance & Control application for rendezvous missions;
- Portability on spaceflight-certified embedded computer;
- Sparc V8 cross-compilation chains and libraries (CSDP);
- A Real-time demonstrator composed of:
  - LEON3 μproc board executing the algorithm executable code;
  - C-coded and open-source nonlinear relative motion simulator (available on HAL);
  - Interactive graphical windows.

Involved people:

- PhD Student: P.R. Arantes Gilz;
- Intern : B. Benetti;
- Researchers & Engineer : F. Camps, M. Joldes, C. Louembet.

Perspectives

- RTEMS: enhancement of the performances by eliminating context switching;
- Certification with synchronous programming language;
- Board the algorithm on a real satellite:
  - small satellite dedicated for scientific tests;
  - end-of-life satellite.

Questions ?