SIMULATING SPACECRAFT IN LOW EARTH ORBIT

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Overview

SPACECRAFT RENDEZVOUS

Motivation

- Course project (Prof. Howell, Purdue University)
- Trick Familiarization
- Experience presenting to NASA JSC
- Build simulation from scratch (course and follow on work)

Objectives

- Simulate Low Earth Orbit (LEO) Rendezvous
- Real time video animation (I don't have a copy)
- Develop flexible simulation framework
- Course requirement: Model using Hill-Clohessy-Wiltshire (HCW) Equations of Motion (EOM)

Model Assumptions

- Point Masses, rigid bodies, constant mass
- Forces and moments decoupled
- Circular orbit, plus HCW controller
- Second order approximation of gravity moment
- Linear error-feedback controller applied to nonlinear attitude dynamics
- Earth only attracting body (i.e., 2BP)
- Upper atmosphere effects not modeled

Software Overview

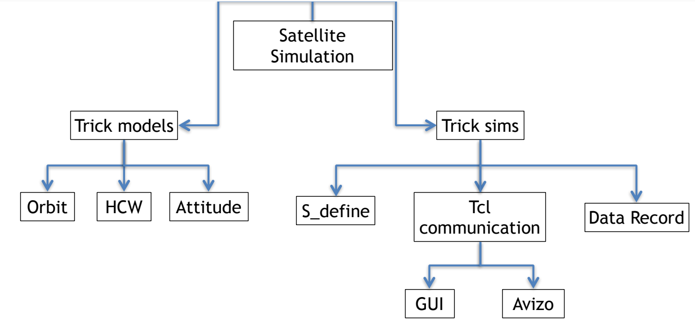


Figure: Software Hierarchy; from [1]

Hardware Communications Overview

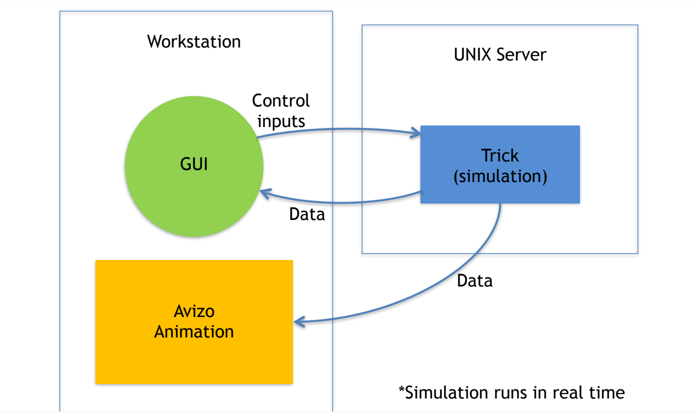
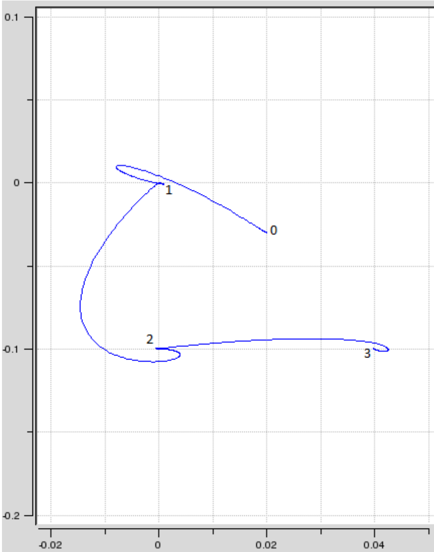
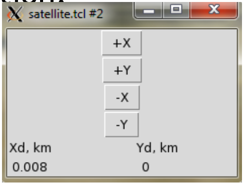


Figure: Communications Interface; from [1]

Trick GUI: HCW Controller

- GUI allows for human in the loop capability with the HCW controller.
- Uses the variable server to directly modify variables within the simulation.
- When a button is clicked, the desired relative location of the Displaced Spacecraft increments in the corresponding direction.

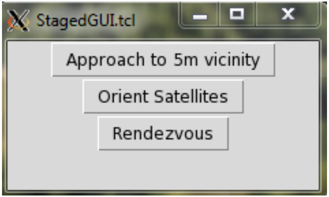




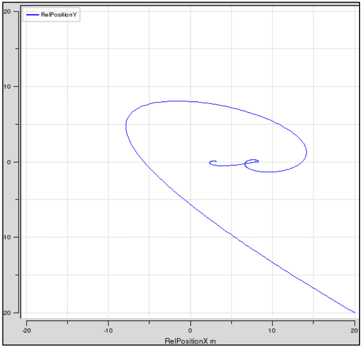
PURDUE UNIVERSITY

Trick GUI: Staged Rendezvous

- GUI created to control staged events of rendezvous
  - Bring Displaced Spacecraft to within 5m of Reference Spacecraft
  - Stabilize the orientation of both spacecrafts
  - Bring Displaced Spacecraft to rendezvous with Reference Spacecraft



Relative Position Time History



Evaluate accuracy of HCW equations

All else being equal, larger initial displacements between two spacecraft will result in less time for the error in the Hill-Clohessy-Wiltshire model to exceed a prescribed threshold.

Error is the **distance** between the two Displaced Spacecraft models.

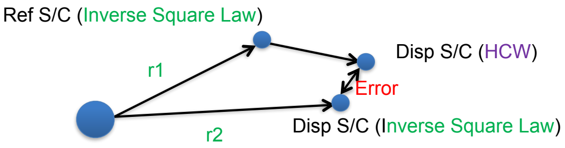


Figure: Spacecraft schematic; from [1]

Orbit Model Experiment 1

- Dynamic events job sets acceleration to zero at threshold error (1 km)

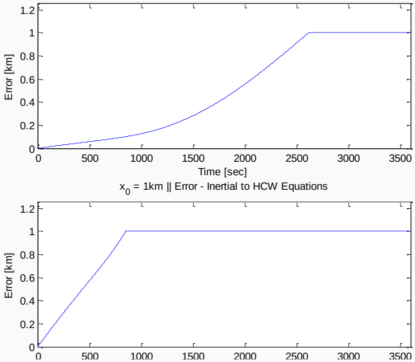


Figure: Error time history plots; from [2]

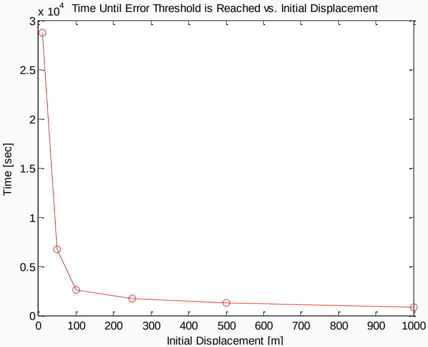


Figure: Time to reach threshold for various initial conditions; from [2]

Orbit Model Experiment 2

- State feedback with integral control

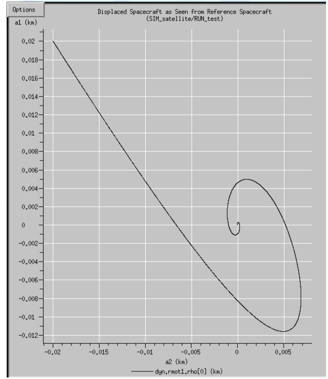


Figure: Control of HCW EOM; from [1]

Staged Controller Demonstration (Attitude)

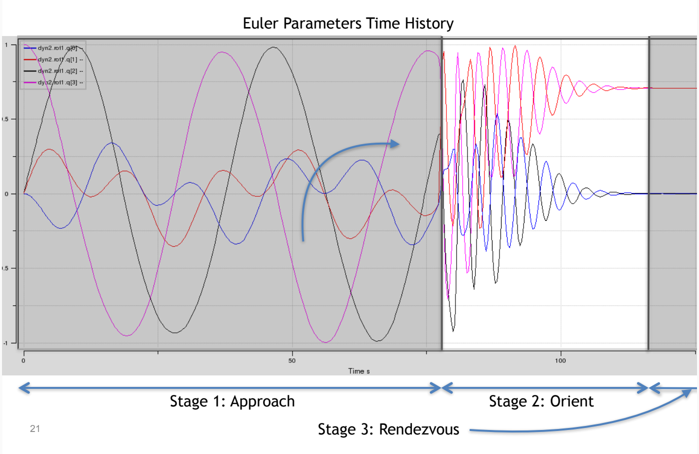


Figure: Quaternion Time History from Demonstration; from [1]

Spacecraft Rendezvous - Conclusion

- Time to prescribed position error threshold inversely proportional to initial relative positions of spacecraft using HCW model
- Error grows as linear + sinusoidal function of time
- 2nd order approximation not adequate to control 6th order system
- Use LQR method for HCW control
- Linear attitude control very sensitive to initial conditions (could not reproduce staged rendezvous live)

Acknowledgments

Modeling and Simulation course taught by Prof. Howell at Purdue University
Team members Nick Kowalczyk, Mitch Sangalis, Collin York, Daniel Zhou Course project

STABILITY ANALYSIS

SC_ATTITUDE

- Follow on to Modeling and Simulation course
- Models single spacecraft in LEO with same assumptions as before
- Gyrostats in multiple configurations (fixed in spacecraft)
- Outputs inertia ellipsoid with angular velocity trace (3D plot)
- Objective to Analyze stability by examining angular velocity
- Configurable for single run and batch run/Monte Carlo dispersion

Motivation and Objective

- Typically Euler Angles (nutation) are inspected
- Angular velocity time history (polhode curve) illustrates stability for torque-free motion
- Can polhode curves give rise to the same conclusion?

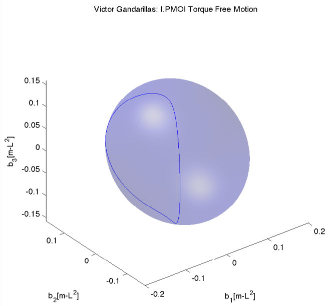


Figure: Unstable torque free motion about intermediate PMOI ($\hat{b}_3$) [3]

Introducing Gravity

- Polhode curve normalized - max value on surface of inertia ellipsoid
- Kinetic energy not conserved when gravity is applied

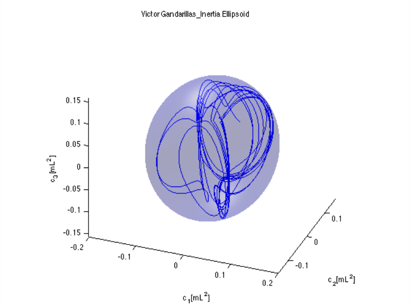


Figure: Destabilizing effect of gravity on spacecraft motion

Region 1 Spacecraft - Bounded Motion

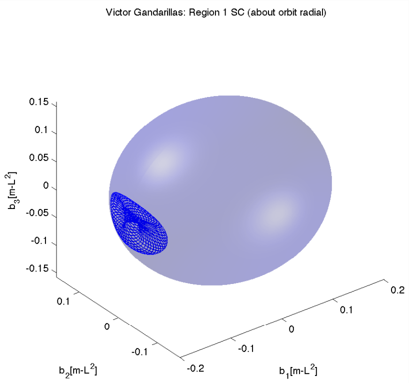


Figure: Bounded motion for spacecraft spun about orbit radial ($\hat{b}_1$); from [3]

Region 1 Spacecraft with Stabilizing Rotor

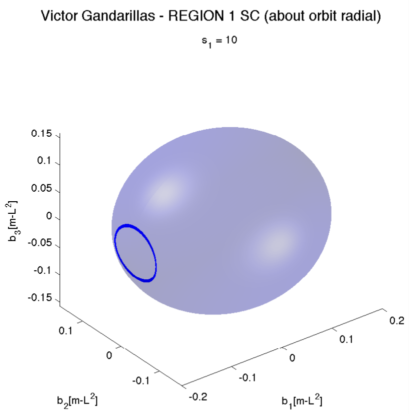


Figure: Bounded motion for spacecraft spun about orbit radial ($\hat{b}_1$) with stabilizing rotor about $\hat{b}_1$; from [3]

Region 1 Spacecraft with Destabilizing Rotor

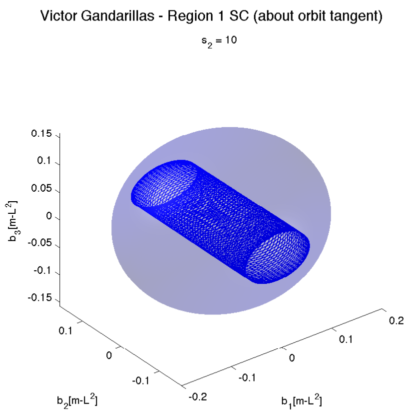


Figure: Bounded motion for spacecraft spun about orbit tangent ($\hat{b}_2$) with stabilizing rotor about $\hat{b}_2$; from [3]

Region 7 Spacecraft with Dual Rotors

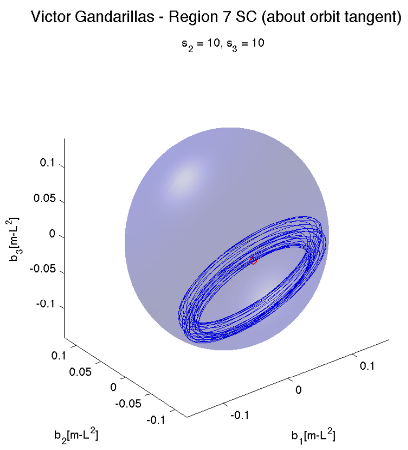


Figure: Bounded motion for spacecraft spun about orbit tangent ($\hat{b}_2$) with stabilizing rotors about $\hat{b}_2$, $\hat{b}_3$; from [3]

Further Considerations

- Compare to nutation time history
- Conservation of Energy
- Introduce Simulink model
- Poincaré Maps

REFERENCES

References

[1] V. Gandarillas, N. Kowalczyk, M. Sangalis, C. York, D. Zhou. Blue Team Final Presentation. Modeling and Simluation, Purdue University, 2013

[2] V. Gandarillas, N. Kowalczyk, M. Sangalis, C. York, D. Zhou. Blue Team Final Report. Modeling and Simluation, Purdue University, 2013

[3] V. Gandarillas. Stability Analysis of Rigid Bodies and Visualization of their Angular Velocities, https://vgandari.github.io, Retrieved 22 August 2014

[4] Source code for sc_attitude available on GitHub

[5] T. Kane, P. Likins, D. Levinson. Spacecraft Dynamics. Mcgraw-Hill, 1981