Nyx, An Open Source Space Astrodynamics Toolkit

Chris Rabotin[1]

[1]Guidance, Navigation, and Control
Masten Space Systems

8th IEEE International Conference on Space Mission Challenges for Information Technology, 2021

Outline

Limited options

- Related software:
  - GMAT, STK Astrogator, FreeFlyer, JPL Monte
- All closed-source and expensive apart from GMAT
- All cumbersome if trying to run on Docker containers (GMAT, Monte)
- All are purely desktop software

Limited options

- Related software:
  - GMAT, STK Astrogator, FreeFlyer, JPL Monte
- All closed-source and expensive apart from GMAT
- All cumbersome if trying to run on Docker containers (GMAT, Monte)
- All are purely desktop software

Purpose of Nyx

- Open-source code, issues and documentation
- Allow users to report bugs, request features and trivially propose changes
- Business compatible license without compromising the open-source contributions
- AGPLv3 License
  - Use it as you wish as long as you don't distribute it outside your business
  - If you distribute it outside your business, you must use an official version of Nyx and customers may request a copy of the code
  - If distributing your custom version of Nyx, you must publicly release all changes you've made for free

Purpose of Nyx

- Open-source code, issues and documentation
- Allow users to report bugs, request features and trivially propose changes
- Business compatible license without compromising the open-source contributions
- AGPLv3 License
  - Use it as you wish as long as you don't distribute it outside your business
  - If you distribute it outside your business, you must use an official version of Nyx and customers may request a copy of the code
  - If distributing your custom version of Nyx, you must publicly release all changes you've made for free

Status of Nyx

- In development since January 2018
- Code entirely in Rust with very minimal memory allocations
- Tested on x64 and embedded ARM processors
- Everything validated against GMAT

Outline

Orbit propagation

- Orbit manipulation
  - Initialize and convert from Cartesian to Keplerian representations
  - Convert between frames, rotations included, using JPL DE438 ephemerides and IAU body fixed frames
- Propagation/integration
  - Propagation using several Runge Kutta integrators (RK4 through RK89)
  - Forward and backward propagation
  - Allows for custom dynamical models

Orbit propagation

- Orbit manipulation
  - Initialize and convert from Cartesian to Keplerian representations
  - Convert between frames, rotations included, using JPL DE438 ephemerides and IAU body fixed frames
- Propagation/integration
  - Propagation using several Runge Kutta integrators (RK4 through RK89)
  - Forward and backward propagation
  - Allows for custom dynamical models

Dynamical models

- Point mass gravity of any celestial object in the DE438 ephemerides file
- Spherical harmonics:
  - Earth (GRACE EGM2008 model)
  - Moon (GRAIL JGGRX model)
  - Any SHADR or TAB file is supported
- Solar radiation pressure
- 1976 Standard Atmospheric drag
  - High fidelity Jacchia Robberts model in development

Dynamical models

- Point mass gravity of any celestial object in the DE438 ephemerides file
- Spherical harmonics:
  - Earth (GRACE EGM2008 model)
  - Moon (GRAIL JGGRX model)
  - Any SHADR or TAB file is supported
- Solar radiation pressure
- 1976 Standard Atmospheric drag
  - High fidelity Jacchia Robberts model in development

Dynamical models

- Point mass gravity of any celestial object in the DE438 ephemerides file
- Spherical harmonics:
  - Earth (GRACE EGM2008 model)
  - Moon (GRAIL JGGRX model)
  - Any SHADR or TAB file is supported
- Solar radiation pressure
- 1976 Standard Atmospheric drag
  - High fidelity Jacchia Robberts model in development

Outline

Trajectory analysis

- Interpolated trajectory from a propagation segment on demand
  - Lagrange interpolation of any state vector
  - Multi-threaded querying
- Reference frames
  - Generated from the propagation frame
  - May be converted into another frame
- Event finder
  - Any state parameter (true anomaly, geodetic height)
  - Eclipsing state, e.g. 29% penumbra

Trajectory analysis

- Interpolated trajectory from a propagation segment on demand
  - Lagrange interpolation of any state vector
  - Multi-threaded querying
- Reference frames
  - Generated from the propagation frame
  - May be converted into another frame
- Event finder
  - Any state parameter (true anomaly, geodetic height)
  - Eclipsing state, e.g. 29% penumbra

Trajectory analysis

- Interpolated trajectory from a propagation segment on demand
  - Lagrange interpolation of any state vector
  - Multi-threaded querying
- Reference frames
  - Generated from the propagation frame
  - May be converted into another frame
- Event finder
  - Any state parameter (true anomaly, geodetic height)
  - Eclipsing state, e.g. 29% penumbra

Maneuver design

- Impulsive maneuver design
  - Support for targeting any arbitrary orbital element
    - Method presented in "Hyperdual Numbers for Arbitrary Orbit Targeting", C. Rabotin, AAS Astrodynamics Specialist Conference, Big Sky 2021
- Control law design
  - Support for the Ruggerio low-thrust control law
  - Additional control laws may be built with this framework
- Planned work includes:
  - Finite burn maneuver planning
  - Multiple shooting algorithms for optimal low thrust trajectories

Maneuver design

- Impulsive maneuver design
  - Support for targeting any arbitrary orbital element
    - Method presented in "Hyperdual Numbers for Arbitrary Orbit Targeting", C. Rabotin, AAS Astrodynamics Specialist Conference, Big Sky 2021
- Control law design
  - Support for the Ruggerio low-thrust control law
  - Additional control laws may be built with this framework
- Planned work includes:
  - Finite burn maneuver planning
  - Multiple shooting algorithms for optimal low thrust trajectories

Maneuver design

- Impulsive maneuver design
  - Support for targeting any arbitrary orbital element
    - Method presented in "Hyperdual Numbers for Arbitrary Orbit Targeting", C. Rabotin, AAS Astrodynamics Specialist Conference, Big Sky 2021
- Control law design
  - Support for the Ruggerio low-thrust control law
  - Additional control laws may be built with this framework
- Planned work includes:
  - Finite burn maneuver planning
  - Multiple shooting algorithms for optimal low thrust trajectories

Outline

Simulated measurements

- Enables coverage analysis from ground stations
- Generation of measurements from ground stations
  - Soon to be in CCSDS TDM format
- Supports "flying" orbit determination partners, such as another spacecraft
  - Cislunar Autonomous Positioning System relied on Nyx for all its simulations

Simulated measurements

- Enables coverage analysis from ground stations
- Generation of measurements from ground stations
  - Soon to be in CCSDS TDM format
- Supports "flying" orbit determination partners, such as another spacecraft
  - Cislunar Autonomous Positioning System relied on Nyx for all its simulations

Filtering

- Current capabilities
  - Classical and Extended Kalman filters
  - Iteration and smoothing
- *Currently sufficient for analysis, not yet for flight operations*

Filtering

- Current capabilities
  - Classical and Extended Kalman filters
  - Iteration and smoothing
- *Currently sufficient for analysis, not yet for flight operations*

Interactive workshop

- *Go directly to [https://gitpod.io/#https://gitlab.com/nyx-space/showcase/propagation-tutorial]*
- Or go to *[nyxspace.com] and click "Get started on Gitpod"*

For Further Reading I

C. Rabotin.
Nyx Space website [nyxspace.com]

C. Rabotin.
Nyx Space MathSpec [nyxspace.com/MathSpec/]

C. Rabotin.
Nyx Space Demo on Gitpod [link to gitpod.io]