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Andreas Leipner(1), Jaspar Meister(1), Stefanie Bremer(1), Meike List(1), Benny Rievers(2)

19-24 Minuten

Investigation of Future Geodesy Mission Concepts for their Feasibility and Requirements to the AOCS Subsystem

Andreas Leipner(1), Jaspar Meister(1), Stefanie Bremer(1), Meike List(1), Benny Rievers(2)

(1) German Aerospace Center (DLR) Institute for Satellite Geodesy and Inertial Sensing, (2) ZARM University of Bremen

Background/ Motivation of Work

Missions like GRACE and GRACE-FO have successfully established a continuous time series of data for Earth gravity field estimation. The continuous observation of Earth's gravitational field is essential for the understanding of mass transport processes and climate change. Since GRACE-FO is already in service and the demand of more accurate data series arises, new mission concepts need to be investigated to (i) guarantee the continuation of the data time series and (ii) to increase the accuracy of Earth's gravity field estimation.

The GRACE and GRACE-FO mission concepts rely on a distance measurement between two satellites following each other in an orbit around the Earth. A change in distance between the two satellites is linked to a change in gravitative attraction. Using this parameter one can calculate a gravitational field based on spherically harmonic coefficients. This process is called Gravity Field Recovery (GFR).

A well known problem due to the chosen GRACE and GRACE-FO mission design is a less sensitive east west measuring direction. The applied distance measurement concept leads to the most sensitive direction in the flying direction of the satellites. This limits the accuracy of the gravitational field calcuated from GRACE or GRACE-FO data.

New mission concepts like Bender type orbits, swarm constellations including a different satellite geometry are promising mission concepts which could introduce additional measuring directions and information to the GFR from satellite data. Bender type orbits are mission concepts in which two GRACE-FO like missions are flown at the same time. Linking the measurements of these two satellites pairs could yield to a more precise GFR. A known problem with Bender type orbits is the synchronisation of the two satellite pairs measurement data due to the large distance between the two flying pairs. Swarm constellations could introduce additional measuring directions and information as well. With this type of mission concept there is no need of data syncronisation because the satellites fly much closer to each other. In addition the satellites fly much more collectively and can be easier maintained. These types of mission concepts are part of this research.

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Methodology

The German Aerospace Center (DLR) Institute for Satellite Geodesy and Inertial Sensing(SI), as well as ZARM, University of Bremen, is developing a simulation environment called the Hybrid Simulation Platform for Space Systems (HPS) to examine future geodesy satellite mission concepts. The simulation platform is capable of modelling the atmospheric, magnetic, radiative, and gravitational environment in orbits around the Earth and the coupling of resulting effects into onboard systems and due to that, sensor-specific effects. This work focuses on next-generation gravimetry mission (NGGM) concepts with multiple satellites and different satellite constellation approaches, such as pendulum orbits, bender orbits and swarm constellations, being examined with the help of the HPS simulator. In addition, new quantum sensors are considered to measure Earth's gravitational field which put increased requirements on the attitude and orbit control system (AOCS), especially when considering drag-free attitude control concepts. These new quantum sensors should be implemented into the HPS simulator. Requirements for the AOCS subsystem will be derived to evaluate the feasibility of such mission concepts and sensors. In parallel, collaborations with experts in orbit propagation and quantum sensors are being established within the scope of the DFG Collaborative Research Center 1464 TerraQ (projectnumber 434617780) focusing on the improvement of gravity field determination both on ground and space level.

Additionally the derived requirements for the AOCS subsystem should be realized in the HPS simulation.

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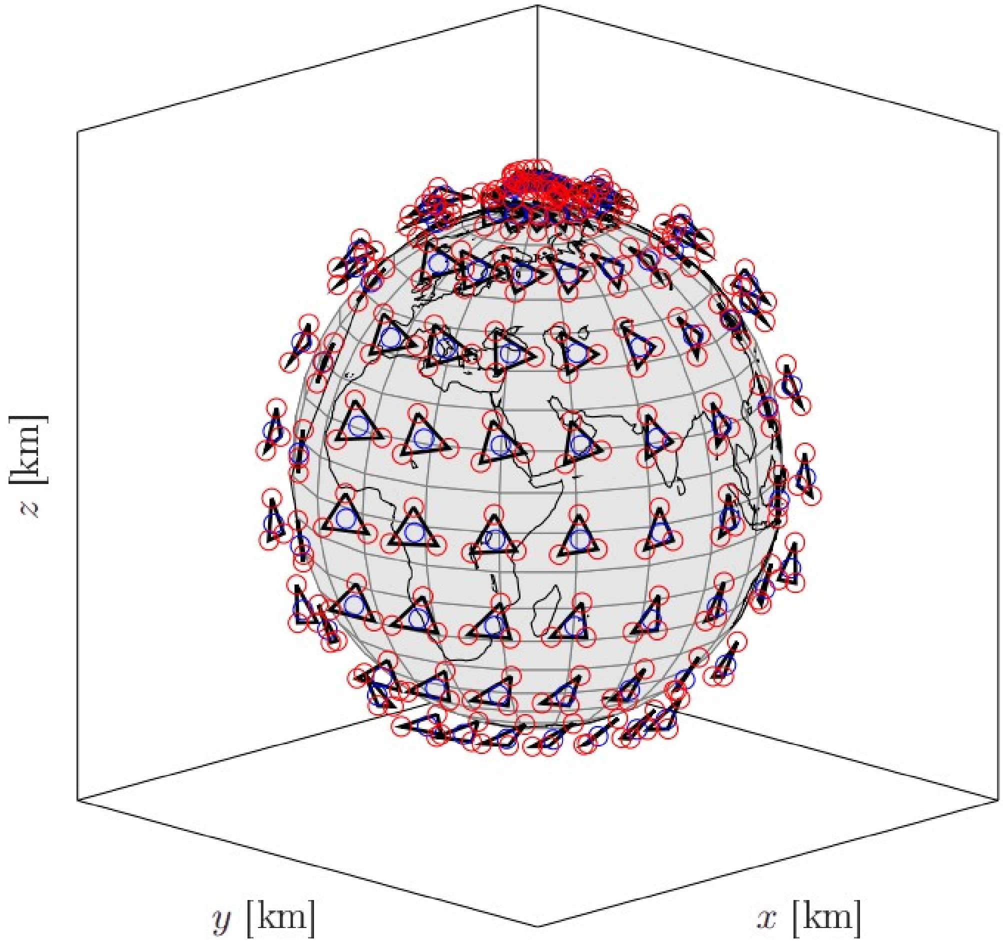
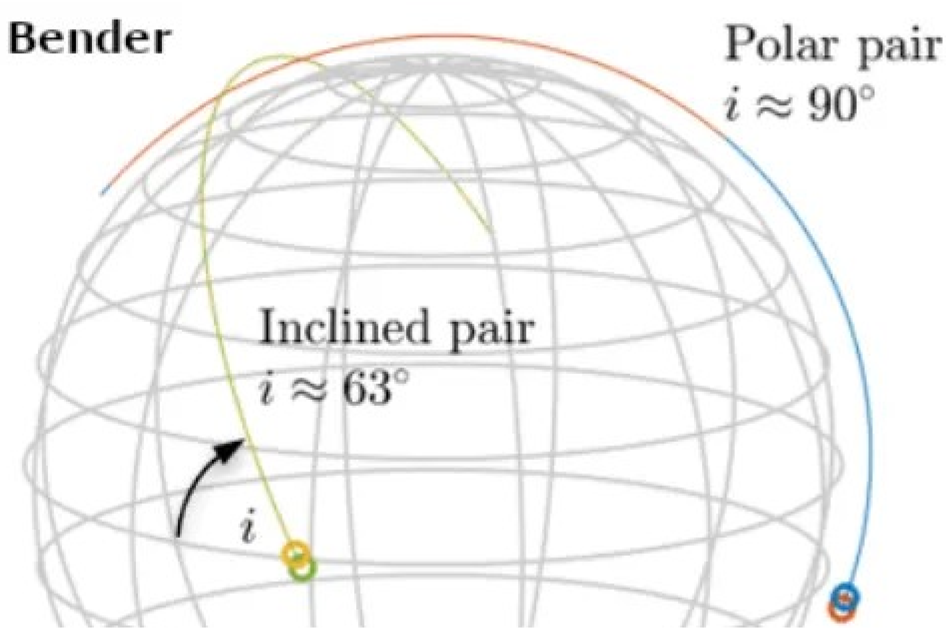
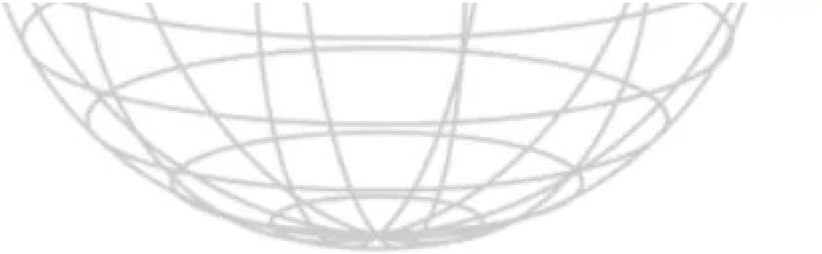
Key Insights

Getting better Gravity Field Data from Swarm Satellite Constellations



Satellite Swarm Constellations for improved Gravity Field Data





Bender type Orbit for improved Gravity Field Data

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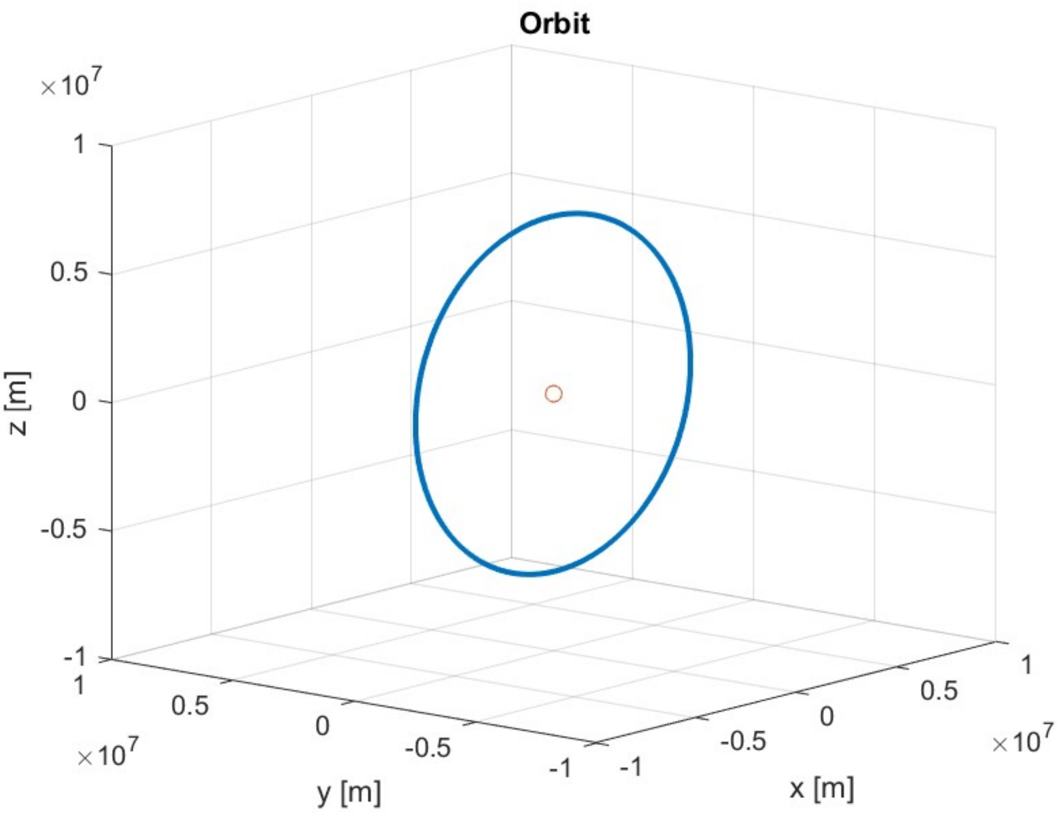
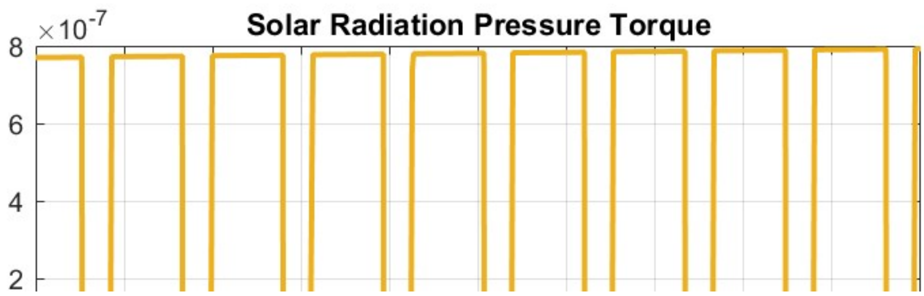
Current Results

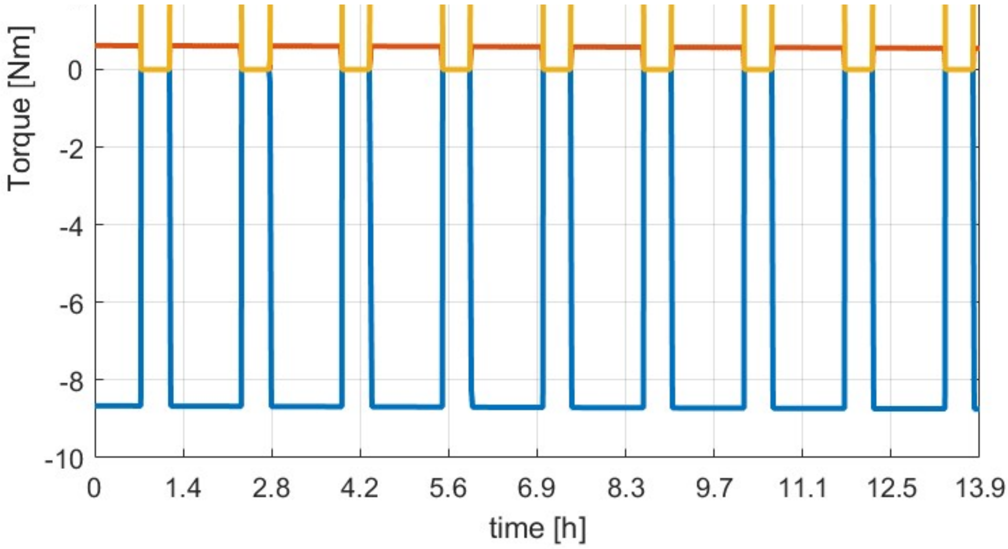


GRACE like Orbit for Reference Simulation: Inclination 89°, Orbit height 6843km

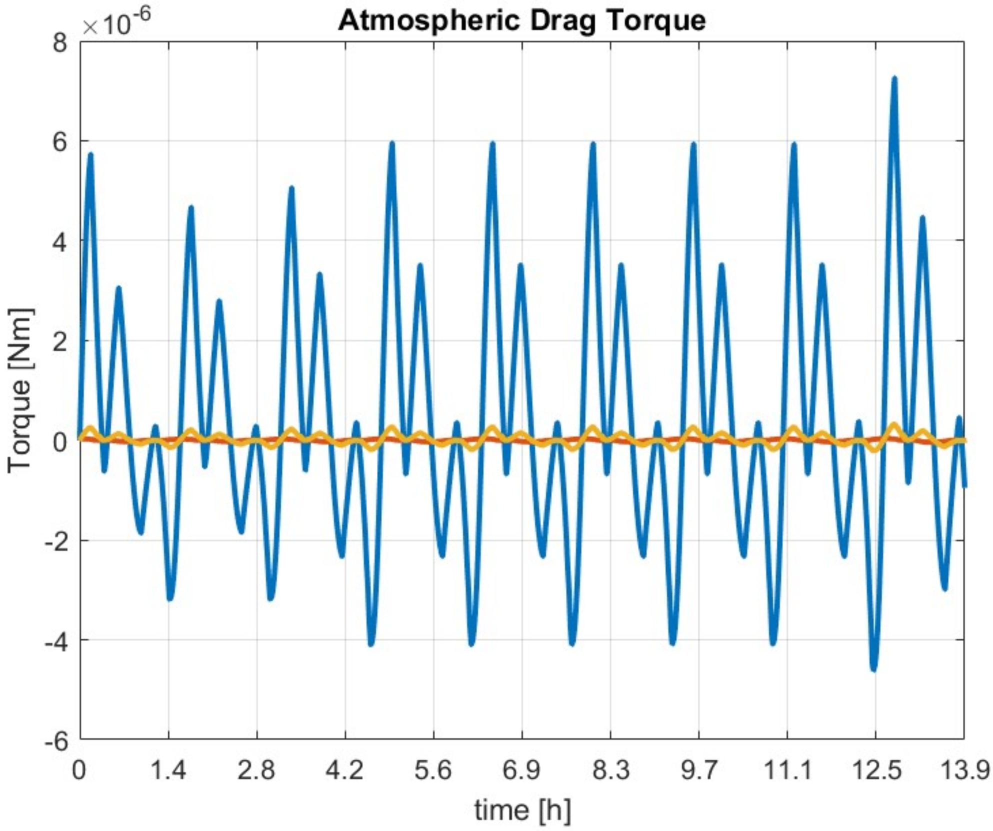
Controlled satellite

Disturbance Torques



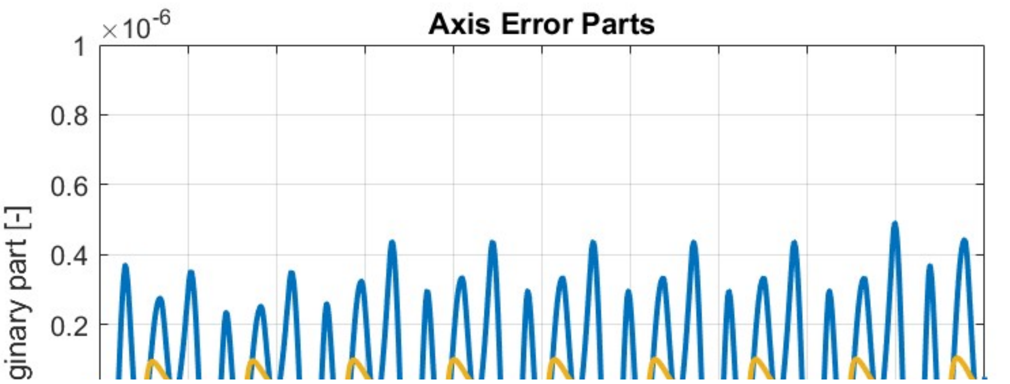


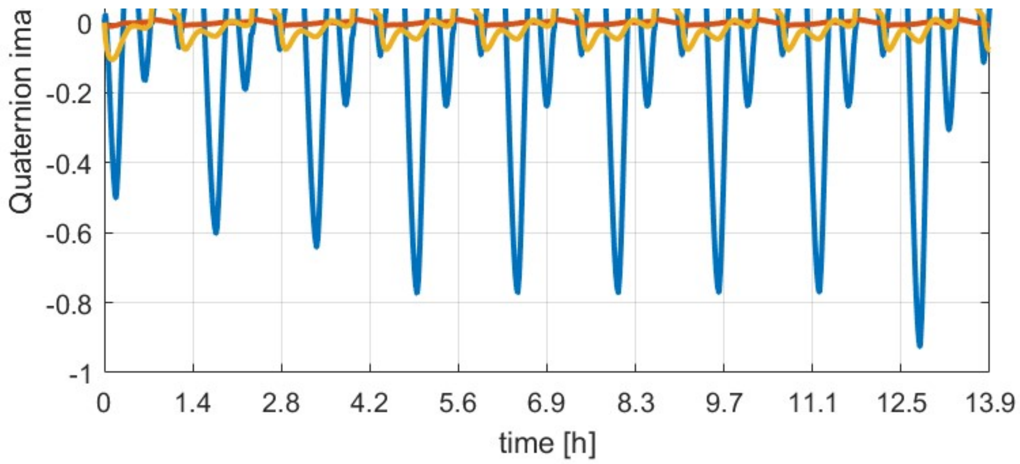
Solar Radiation Pressure Torque acting on satellite



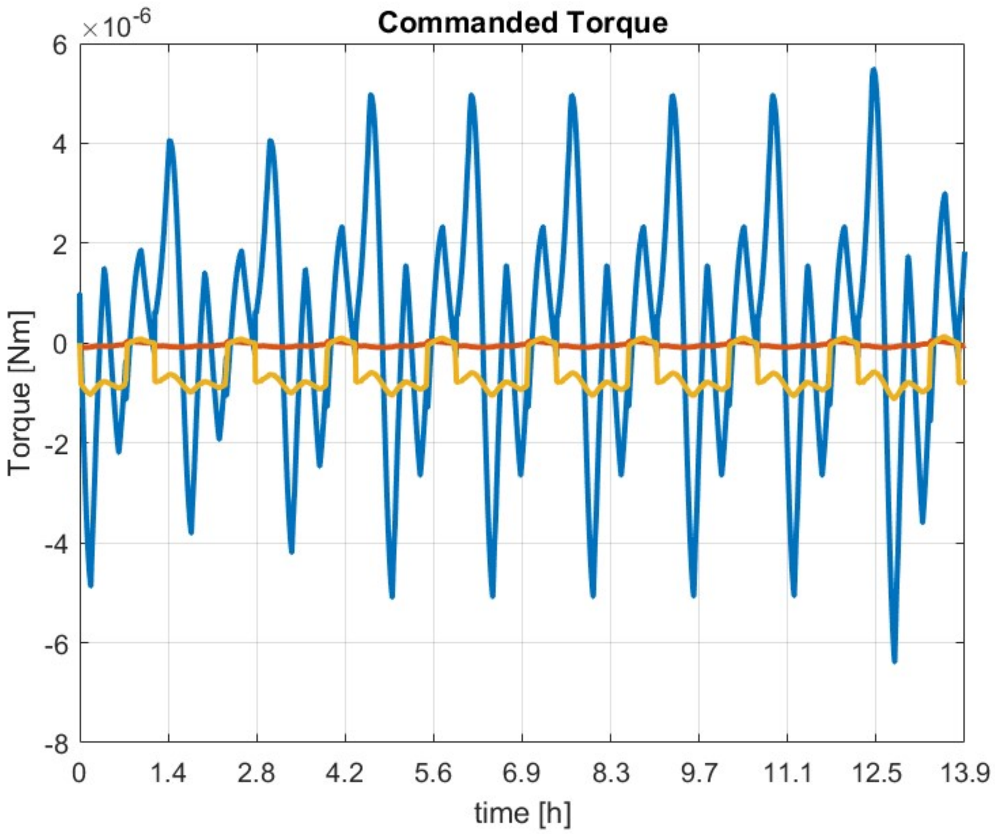
Drag Torque acting on satellite

Controller





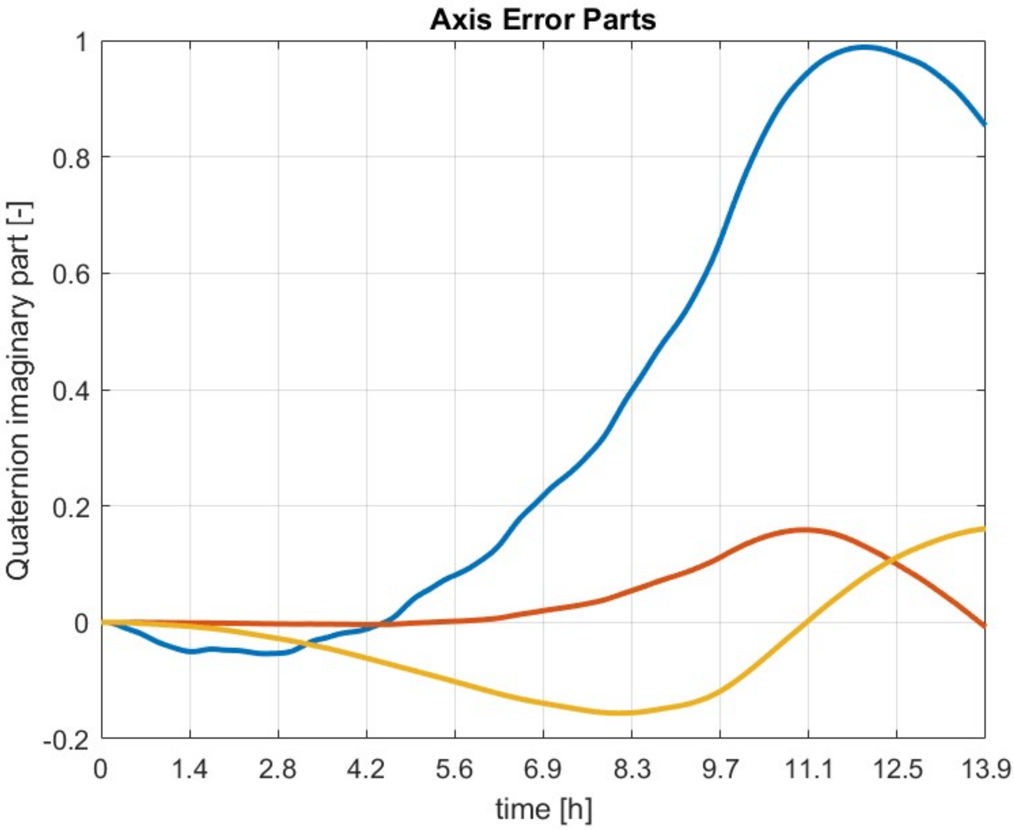
Axis Error calculated by controller



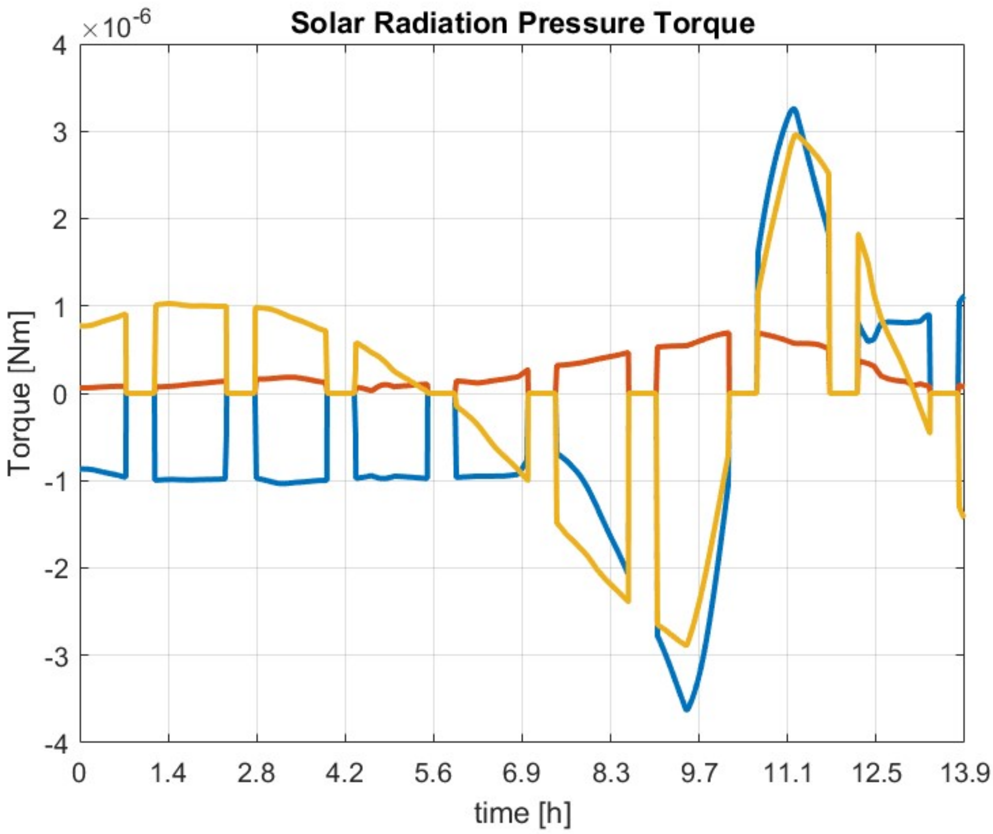
Commanded Torque acting on satellite as calculated by controller

Above the disturbance torques originating from solar radiation and Earth's atmosphere are plotted for an attitude controlled satellite in a GRACE like orbit. The axis error are the imaginary quaternion parts of the quaternion rotating the body fixed frame into the desired attitude frame. With a magnitude of 10^-6 the error is in an acceptable range. The commanded correction torque ist the inverted sum of the disturbance torques, which is expected.

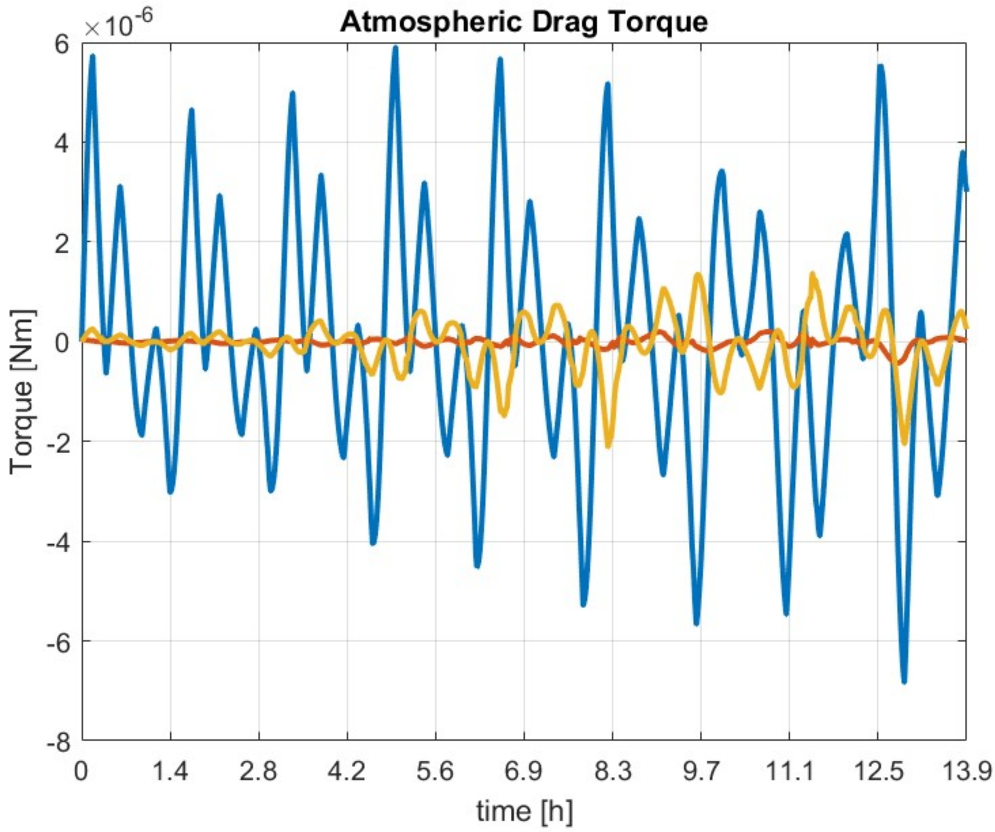
Uncontrolled satellite



Axis Error for an uncontrolled satellite



Solar Radiation Pressure Torque for an uncontrolled satellite



Atmospheric Drag Torque for an uncontrolled satellite

Above are the plots of the distubrance torqes and attitude quaternion for an uncontrolled satellite. The attitude quaternion shows a gread deviation over time, which shows that the satellite rotates uncontrolled under the influence of the disturbance torques. The disturbance torques react to the differen attitudes over time and change their magnitude accordingly.

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Future Work

For future work the HPS simulation should be extended to simulate multiple satellites at once to investigate the performance of a constellation. The number of satellites and the satellite formation in a constellation is subject of research. To investigate the performance, a constellation control system needs to be implemented into the simulation tool HPS. For this purpose a single satellite attitude control system was implemented. It needs to be extended by an orbit control system and an advanced attitude control system including state estimators, sensor models and actuator models. Sensor models should provide the nesseceray attitude and orbit information and should implement the most common used sensors on geodesy satellites. Actuator models should realize the control commands and should implement the most common used actuators. With the helped of the deveolped attitude control system the constellation should be kept in formation.

With a completed attitude and formation control system new mission concepts will be investigated. The GRACE and GRACE-FO mission will be remodeled as a reference and will be used as a performance index with regards to GFR. All investigated constellations are compared to the reference GRACE and GRACE-FO missions in terms of GFR performance.

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Abstract

Missions like GRACE and GRACE-FO have successfully established a continuous time series of data for Earth gravity field estimation. The continuous observation of Earths gravitational field is essential for the understanding of Earths mass transportation and climate change. Since GRACE-FO is already in service and the demand of more accurate data series arises, new Mission concepts need to be investigated to guarantee the continuation of the data time series and to increase the accuracy of Earth's gravity field estimation.

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such mission concepts and sensors. In parallel, collaborations with experts in orbit propagation and quantum sensors are being established within the scope of the DFG Collaborative Research Center 1464 TerraQ focusing on the improvement of Gravity field determination both on ground and space level. This paper presents the current status of the research.

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