SENSORIS: NewSpace Constellation for Daily Gravity Field Solutions

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Abstract

Satellite gravimetry missions allow to track mass transport on global scales. The main satellite constellations for the gravity recovery are the GRACE and GRACE Follow-On missions. Typically, they provide monthly gravity field solutions which at times is suffering from data gaps. The future MAGIC constellation shall continue the time series and improve especially the spatial sampling with a possible improvement of the temporal sampling to 5 days. For higher temporal resolutions, new mission concepts are required.

One such concept is the SENSORIS constellation: It aims to provide daily solutions of the Earth's gravity field using a NewSpace approach for faster, cheaper and more flexible data acquisition for research, security and resource management.

Since December of 2025, a Phase 0/A study is being conducted through a grant of the German Space Agency (DLR) by three North German research institutions: the IAT Institute of Aerospace Technology Bremen, the ZARM of University of Bremen and the DLR Institute for Satellite Geodesy and Inertial Sensing Hanover. As part of the study, the mission configuration will be evaluated regarding its feasibility. The baseline foresees the use of identical satellites based on VIBES Pioneer, a 3U CubeSat currently under development at the IAT. Using the positional data of each spacecraft, the Earth's gravity field can be derived. While the provided solutions will have an inferior spatial resolution compared to the results of the GRACE missions, it will be possible to achieve one full solution per day.

The paper presents the preliminary findings of the study, with a specific focus on the spacecraft architecture, the orbit configuration, the number of satellites per orbital plane required to achieve daily solutions as well as the overall performance of the SENSORIS constellation. Additionally, the roadmap for the implementation of the mission is discussed.

Keywords: gravimetry, gravity field, GRACE, CubeSats, mission analysis, NewSpace, spacecraft design

Acronyms/Abbreviations

ADCS	Attitude Determination and Control System
COTS	Commercial-off-the-Shelf
GNSS	Global Navigation Satellite System
HL-SST	High-Low Satellite-to-Satellite Tracking
LEO	Low Earth Orbit
LL-SST	Low-Low Satellite-to-Satellite Tracking
MEMS	Micro-electromechanical Systems
POD	Precise Orbit Determination
SLR	Satellite Laser Ranging
SSO	Sun-Synchronous Orbit

1. Introduction

SENSORIS is a CubeSat constellation to provide daily solutions of the Earth's gravitational field utilizing a NewSpace approach. The higher temporal resolution aims to reduce the time between current gravity field solutions. With SENSORIS, valuable data can be generated faster, cheaper, and more flexible for science, safety, and resource management.

The constellation is proposed by the Institute of Aerospace Technologies (IAT) at the City University of Applied Sciences Bremen (HSB) and the Center of Applied Space Technology and Microgravity (ZARM) at the University of Bremen and is being supported by the Institute for Satellite Geodesy and Inertial Sensing (DLR-SI) at the German Aerospace Center (DLR).

The paper at hand will first introduce the SENSORIS mission. Afterwards, an overview of the current design of mission, spacecraft and payload architectures is given. Lastly, an outlook towards the implantation of SENSORIS is given.

2. Motivation & Background

Gravity observations are a unique measurement technique to observe and monitor mass and mass transport in the Earth's system. Spacecraft conducting these measurements are an integral part of the Global Geodetic Observing System and contribute data to a number of Essential Climate Variables (ECV) and serve as basis for several Essential Geodetic Variables (EGV). The GRACE mission and its successors are among the most prominent missions tracking mass transport on a global scale. Since the launch of the first GRACE mission in 2002 and the GRACE-FO mission in 2018, the level of precise observation of these mass changes has been significantly improved. The next generation called GRACE-C and NGGM are scheduled to be launched in 2028, further improving the quality and securing the availability of valuable science data.

Each full solution of the Earth's gravity field currently requires about 30 days. The main reason for this is that the GRACE-type missions utilize only two spacecraft. These two spacecraft are operating in a configuration known as Low-Low Satellite-to-Satellite Tracking (LL-SST). Here, two spacecraft are following each other on their orbital path. The distance between the two vehicles is being measured using laser-ranging interferometry. With this configuration, a high spacial resolution can be achieved. However, the configuration requires the two spacecraft to function nominally in order to deliver this precision, which further drives up the mission costs and poses a significant risk to the overall availably of data.

With the GRACE-C and NGGM spacecraft working together to form the "MAGIC" constellation, the time required per full solution can, in a best-case scenario, be reduced to five days. However, this is not sufficient to monitor nonlinear and nonperiodic events. This is specifically relevant in the context of climate change as events such as tides or floods remain difficult to observe.

Further, the background modelling is limiting the current solutions. Even though geophysical models have been improved steadily, it is desirable for reducing misinterpretations of data to have more frequent data available to capture real-world fluctuations such as sudden storms.

An alternative to the LL-SST approach can be a either satellite laser ranging (SLR) from ground or High-Low Satellite-to-Satellite Tracking (HL-SST). Weigelt et al. (2024) [1] showed among others that it is feasible to derive monthly gravity field solutions at the cost of a reduced spatial resolution. This approach uses positional data from individual satellites in a combination of tracking with GNSS satellites (also referred to as High-Low Satellite-to-Satellite Tracking) and satellite laser ranging (SLR). The approach is compared to LL-SST in Figure 1.

Using this approach, it is possible to provide solutions with a less complex and expensive mission architecture. While the initial intent of the scientists was to bridge existing data gaps, it became apparent that the HL-SST+SLR combination could enable dedicated, cost-effective missions for providing solutions at a lower resolution but with higher frequency [1].

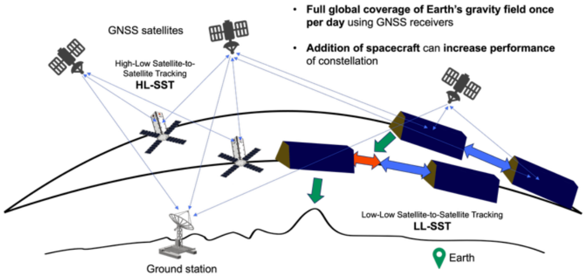

Figure 1: HL-SST and LL-SST approaches compared

3. SENSORIS Mission Definition

SENSOIRS is the implementation of this concept: a NewSpace approach to observe the low-order time variable gravity field with high temporal resolution using a constellation of CubeSats. The SENSORIS mission was proposed in response to a call of the German Space Agency at the DLR for future Earth Observation missions focussing on innovative and fast to implement mission concepts [2]. It builds on the concept of using HL-SST and SLR to provide a full gravity field solution every 24 hours.

SENSORIS addresses the challenges of current gravity field missions – high cost, temporal resolution limited to 1 month or 5 days, limited background modelling – by:

- utilising Commercial-off-the-Shelf (COTS) products and consumer electronics for space applications to create smaller, lighter and more cost-effective satellites,
- providing temporally high-resolution (daily) gravity field solutions,
- maximising the added value of the future GRACE-C and NGGM missions by addressing the problem of limiting background modelling and
- generating redundancy in gravity field determination and thus increasing resilience to failures.

4. Mission Architecture

The SENSORIS mission takes inspiration from previous gravimetry missions as well as spacecraft developed by the consortium members. For the initial baseline, the 3U CubeSat VIBES Pioneer, developed at the IAT, was chosen. This form factor provides sufficient space for the key instruments required for SENSORIS while reducing the overall spacecraft costs compared to larger systems.

Within this chapter, initially the orbital parameters of the mission will be discussed as these are crucial for determining the amount of spacecraft required for daily gravity field solutions. Afterwards, the spacecraft architecture including the payload are introduced. Lastly, the generated data products are presented.

4.1. Altitude

The orbital eccentricity can be fixed at zero, as previous gravimetry missions, as well as the VIBES Pioneer CubeSat, target near-circular orbits.

In the absence of an onboard propulsion system in the spacecraft design baseline, the orbital altitude becomes the dominant design variable, as it directly determines the achievable mission lifetime and cannot be modified after launch.

Based on an orbital decay analysis, a deployment altitude of 450 km is selected with an acceptable range of up to 500 km as CubeSat mission typically rely on rideshare opportunities. This altitude represents a balanced compromise between the achievable mission lifetime of 21 months shown in Figure 2., gravimetric measurement performance, and overall system feasibility. Lifetime prediction assumes a nominal case based on the latest ESA predictions to solar and geomagnetic activity starting in September 2029.

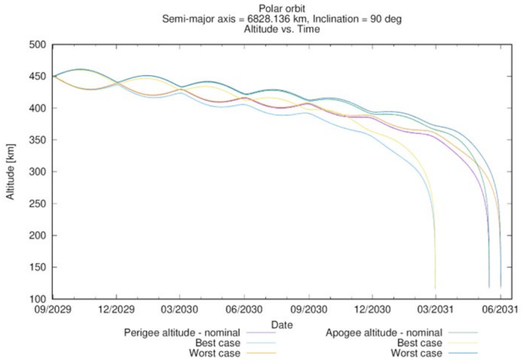

Figure 2: Orbital decay analysis

4.2. Inclination

The inclination primarily affects key mission drivers such as global coverage, eclipse duration, and access to ground stations. A sun-synchronous orbit (SSO) provides near constant illumination conditions favoured by many low earth orbit (LEO) missions as it eases the system sizing. A (near) polar orbit is commonly used for past gravimetry missions as it enables (near) global coverage at the cost of a more demanding spacecraft infrastructure. The evaluation of these criteria shows that the polar orbit achieves the highest weighted score and, therefore, is set as baseline for the SENSORIS mission.

It is emphasised that the SENSORIS mission is, in principle, feasible in a SSO. However, the reduced global coverage and the presence of a persistent polar gap would lead to significant scientific drawbacks. In particular, the lack of high-latitude data complicates gravity field recovery (GFR) and introduces additional complexity in post-processing and data harmonisation.

At the same time, the polar baseline ensures compatibility with sun-synchronous operation, allowing the spacecraft and constellation architecture to be adapted to different orbital configurations without major design modifications.

4.3. Constellation

The constellation geometry governs data availability, particularly revisit time and temporal sampling performance. Additionally, a scalable, cost-effective constellation shall be developed.

A coverage analysis based on orbit propagation indicated that a single, polar, plane with 8 spacecraft enables global coverage within a 24 h period. The underlying 3° x 3° grid was adopted from the evaluation of GRACE data sets. The results are presented in Figure 3.

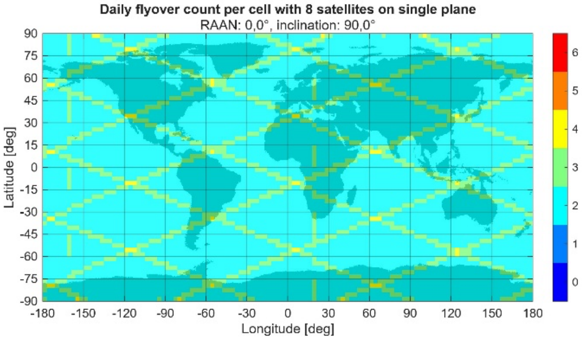

Figure 3: Coverage analysis for a single polar plane with 8 satellites

The results indicate that with 8 spacecraft, full daily global coverage can already be achieved, and scientifically meaningful gravimetry data products are feasible, making this configuration sufficient to meet the core mission objectives.

A 16-spacecraft constellation doubles the mean flyover count within the 3° x 3° grid used to count spacecraft flyovers. This underlines the inherent scalability of the SENSORIS mission concept, in which the 8-spacecraft configuration serves as a robust and cost-efficient baseline, while larger constellations remain a viable option for future mission extensions should additional resources become available.

The resulting GFR performance will be investigated as next step within the SENSORIS study. Therefore, the 8-spacecraft constellation is only recommended as mission baseline until the follow-up analysis is completed.

4.4. Spacecraft Bus Architecture

The SENSORIS spacecraft platform is implemented as a CubeSat-class bus designed to accommodate the mission payload within a compact and standardized architecture. The configuration follows a modular layout compatible with constellation-based deployment and repeatable integration.

A 3U CubeSat form factor is adopted as the current baseline configuration. The spacecraft layout shown in Figure 4 represents a preliminary accommodation concept illustrating the geometric arrangement of external and internal subsystems within the 3U envelope.

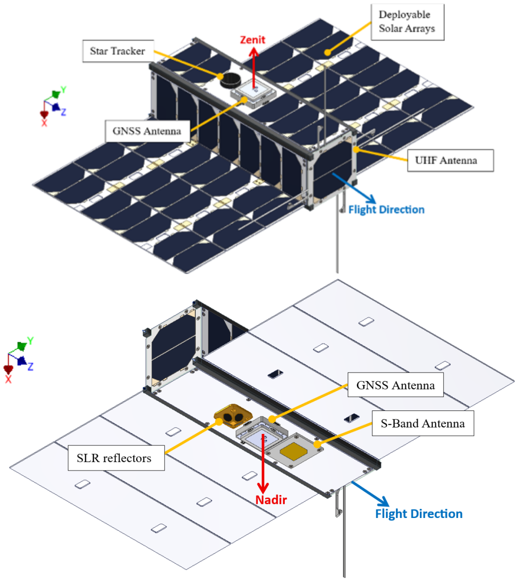

Figure 4: SENSORIS 3U configuration with external subsystem accommodation and deployable solar arrays

The presented configuration serves as a fit check at feasibility level. It demonstrates that the identified subsystems, including payload, attitude control hardware, power system components, and communication units, can be integrated within a standard 3U CubeSat structure while maintaining logical functional separation and compliance with deployer constraints.

While the current baseline configuration of the SENSORIS spacecraft is based on a 3U CubeSat platform, a 6U configuration remains under active consideration. The platform size represents a key architectural parameter, directly influencing subsystem accommodation, power generation capability, payload flexibility, and overall integration margin.

4.5. Payload Architecture

The payload is designed to generate the GNSS observables required for Precise Orbit Determination (POD). It therefore forms the measurement basis for HL-SST-based gravity field determination. The preliminary baseline comprises a GNSS antenna for receiving signals from GNSS satellites, for example from the GPS and Galileo constellations. The main GNSS antenna is oriented towards zenith to receive as many satellites as possible in higher orbits.

An additional nadir-pointing antenna is, in principle, possible to enable complementary GNSS reflectometry or to detect GNSS jamming, since interference may affect the two differently oriented antennas in different ways. A key element for achieving very precise position determination is the use of a multi-frequency GNSS receiver. By receiving GNSS signals on different frequencies, it becomes possible to calculate and reduce ionospheric delay errors and to form the wide-lane combination.

The ionospheric error depends on the electron density in the ionosphere. Free electrons cause a frequency-dependent change in signal propagation time. By receiving signals on two different frequencies, the first-order ionospheric error can be determined and reduced accordingly. In the wide-lane combination, a synthetic wavelength is generated from the two received frequencies that is larger than the wavelength of the individual signals. This improves, in particular, the estimation of the integer carrier-phase ambiguity.

The use of multiple GNSS constellations further improves the data basis. The GNSS receiver is directly connected to the antenna. The observables are transferred from the receiver to the on-board computer and stored temporarily. During a contact window with the ground station, the data are transmitted via an S-band antenna. On ground, the data are then further processed for precise orbit determination.

Further optional future payloads include high-resolution accelerometers for measuring the non-gravitational forces acting on the satellite in orbit, as well as retroreflectors, which can additionally be used for orbit determination over short time periods and, in particular, for the validation of orbit determination.

4.6. Data Products

The data processing chain of the SENSORIS mission is envisioned as presented in Figure 5.

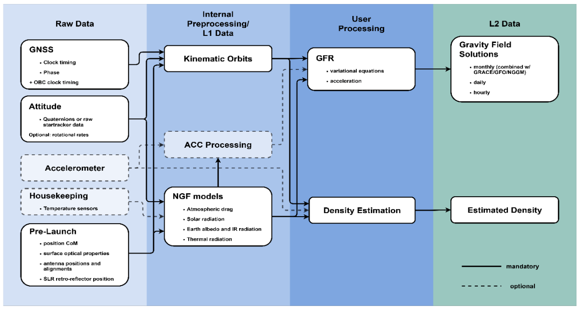

Figure 5: SENSORIS processing chain from raw observations to Level-1 and Level-2 products

On the left-hand side the raw data, scientifically important for the mission goal, are shown. The main data is collected during the mission by the satellites. Nevertheless, as the CubeSats are the "test masses" in space, they need to be characterised carefully before launch, providing necessary data for the processing. Mandatory and optional data for the mission are shown, foremost the GNSS observations, which are the most important data.

In the second column the processing of the raw data to Level 1 data is demonstrated. These are basically kinematic orbits and non-gravitational forces acting on the satellites. The best practice will be to publish or share the processed level 1 data with the scientific community or with chosen institutions. The data handling and distribution from the four major gravimetry missions has shown that this approach yielded the greatest scientific results and progress in several related fields. Furthermore, data fusion of the SENSORIS data with GRACE-FO, GRACE-C and NGGM is anticipated, thus only sharing the data with the community would realize the full scientific potential of the SENSORIS data.

From the level 1 data the gravity field solutions can be produced. The consortium has two different GFR approaches to do that internally. A secondary possible data product is thermosphere density. It needs to be investigated whether the approach based on accelerometers is applicable or if only the POD approach is suitable.

The level 2 gravity data are especially interesting for geophysical applications and researchers. It is intended to publish the data, maybe also at prominent places like ICGEM (International Centre for Global Earth Models).

5. Development Timeline and Long-Term Plans

Presently, the SENSORIS team is at the midway mark of a nine-month study commissioned by the German Space Agency (DLR) to advance the concept further [3]. The current results are presented in this paper. Within the remaining time of the study, the mission and spacecraft designs will be further developed to conclude what would typically be referred to as Phase 0/A.

However, the SENSORIS mission is being developed in an iterative spiral development model (Figure 6). This concept is based on utilising physical models which scope of functionality is being advanced in each step of the spiral, ultimately leading to a Proto-Flight Model. This approach has been pioneered at the IAT during the development of the VIBES Pioneer spacecraft and enables rapid progress with a "test what you fly, fly what you test"-philosophy.

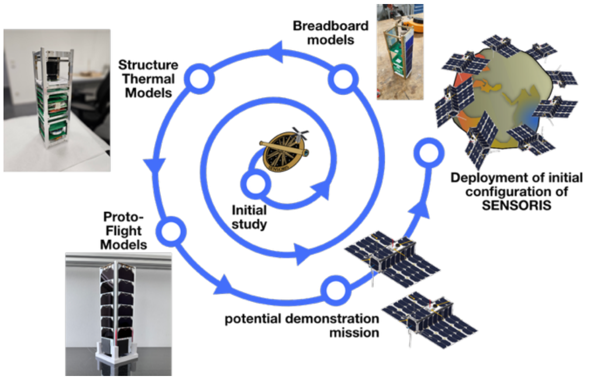

Figure 6: Spiral Development Approach which will be used

Currently, the timeline foresees the implementation of the SENSORIS mission within three years after the conclusion of the initial study. The option of launching two spacecraft for a demonstration mission is presently being evaluated. The exact number of spacecraft to be launched for the first operational version of the SENSORIS constellation will be a further output of the study and the discussions afterwards.

In any scenario, the beginning of operations will not mark the end of the development of SENSORIS; rather, constant updates will improve the capabilities of the constellation and thereby the quality of the delivered data. Among these updates might be the addition of additional spacecraft to further decrease the time per full solution, as well as spacecraft with miniaturised accelerometery, possibly using quantum technology, and compact Laser Ranging Interferometers. With the latter, a Low-Low Satellite-to-Satellite Tracking approach comparable to GRACE-type missions might be possible in a CubeSat form factor [4]. Additionally, optimisations of the spacecraft design and operation may allow missions in lower orbits down to VLEOs, thereby increasing the quality of the generated data even further.

6. Summary

The SENSORIS consortium has made significant progress developing the mission, spacecraft and payload architectures.

The mission architecture is defined at a 450-500 km polar orbit and will finalise with the evaluation of gravity field recovery performance. The spacecraft design has been adapted to the demanding conditions presented by the polar orbit and will undergo its next iterations until full design maturity. The use of COTS and consumer electronics enables a cost-effective small spacecraft.

The payload architecture comprises the measurement instruments required to generate the GNSS observables used for mission data processing. These observables are transmitted during contact windows with a ground station and are further processed on the ground for precise orbit determination. Optional additional payloads include a second nadir-pointing GNSS antenna for complementary GNSS reflectometry, retroreflectors for orbit validation, and high-precision accelerometers for measuring the non-gravitational forces acting on the satellite in orbit.

The presented data products aim to contribute valuable gravity field data to researchers. This will improve existing models and lead to a better understanding of the Earth system. With a future expansion of the constellation, these solutions could be generated even more frequent, allowing the observation of infrequent events.

Acknowledgements

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