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MINICAS – A NOVEL TYPE OF CONSTELLATION ACQUISITION SYSTEM

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Abstract

We present a novel type of satellite payload entitled MiniCAS (Miniaturized Constellation Acquisition System). MiniCAS will comprise an optical receiver paired with a dedicated light source. Identical sensor systems will be installed on two spacecraft. By detecting the light emitted by one spacecraft, the receiver on the distant spacecraft determines its misalignment with respect to the connecting line between the two satellites, the so-called Line of Sight (LOS). This measurement is directly related to the relative tilt of the respective spacecraft in relation to the LOS. A system like MiniCAS is essential to facilitate relative attitude control of constellations of two or more spacecraft with microradian sensitivity, potentially surpassing the achievable precision of conventional GNSS-based approaches. Naturally, MiniCAS is independent of the availability of GNSS signals, allowing for precise constellation acquisition in orbits around other celestial bodies instead of the Earth. A classic field of application is satellite gravimetry missions such as GRACE-C or NGGM (Next Generation Gravity Mission). These missions require an initial calibration of the local tilts of the two satellites with respect to the LOS to enable the establishment of an interferometric laser link. In principle, however, the MiniCAS technology offers added value wherever the relative alignment of any two spatially separated objects is of interest. We introduce the basic concept of the system as well as give an overview of the application scenarios.

Keywords: Constellation Acquisition System, Link Acquisition, Laser interferometer

1. Introduction

We are presenting the Miniaturized Constellation Acquisition System (MiniCAS), which can be applied for the acquisition of interferometric laser links between two spacecraft.

A classic field of application for MiniCAS is satellite gravimetry missions such as GRACE-C or NGGM (Next Generation Gravity Mission). These missions require an initial calibration of the local tilts of the two satellites and the optical on-board sub-systems, with respect to the line-of-sight (LOS), to establish an interferometric laser link [1]. In principle, however, the MiniCAS technology offers added value wherever the relative alignment of any two spatially separated objects is of interest.

NGGM will employ the technique of satellite to satellite tracking between a satellite pair flying in a low-Earth orbit by employing a highly sensitive laser interferometer [2]. The overall goal of this mission is to measure the temporal variations in Earth's gravity field with high precision. In doing so, NGGM aims to provide critical data for understanding changes in Earth's mass redistribution and its implications for climate change, sea level rise, and geophysical processes [3].

1.1 MiniCAS Overview

A crucial step during the commissioning phase of the NGGM laser interferometer will be the acquisition of the laser link between the satellites. This process could be significantly sped up, and the associated risks mitigated, by the usage of a Constellation Acquisition System. Hence, NGGM was chosen as the application scenario for developing MiniCAS.

MiniCAS will consist of a modular system that pairs an optical receiver with a dedicated light source (emitter). Identical systems will be installed on two spacecraft (see Figure 1). By detecting the light emitted by one spacecraft, the receiver on the other spacecraft can determine its misalignment relative to the line connecting the two satellites, known as the Line of Sight (LOS). This measurement is directly linked to the relative tilt of the spacecraft with respect to the LOS.

During the commissioning phase unknown errors arise in estimating the true LOS. These errors can emerge from manufacturing and integration tolerances, which are inevitable when constructing and assembling precise optical systems. Additionally, transitioning from Earth’s gravity to microgravity causes the spacecraft to de-bend in space. Vibrations during the rocket launch and setting effects will affect the alignment of the optical sub-systems on the spacecraft.

To address these challenges, MiniCAS measures the relative orientation of the spacecraft and their payloads with high precision. This makes MiniCAS an essential

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tool for achieving accurate relative attitude control within constellations of two or more spacecraft.

MiniCAS will provide an angular sensitivity in the microradian range and a field of view of a few milliradians.

2. Measurement Principle

The MiniCAS emitter consists of a light source, whose characteristics will be specifically designed to meet the requirements of the MiniCAS receiver. Additionally, it will feature a beam divergence that is sufficiently large to cover the entire angular uncertainty cone, ensuring reliable signal reception. On the receiving end, the light enters the MiniCAS system through an aperture and then impinges on a lens system that focuses the light onto the sensor, consisting of an Indium Gallium Arsenide (InGaAs) focal plane array (FPA). Due to the long inter-satellite distance, which will be on the order of 220 km, the beam emitted by the emitter resembles a spherical wavefront at the receiving spacecraft.

If the emitting spacecraft tilts, the beam tilts. However, the section of the beam that enters the receiver aperture does not show a change in the angle (see Figure 1b).

If the receiving spacecraft tilts, the beam enters the aperture at an angle (see Figure 1c). The lens system translates this tilt into a beam displacement on the sensor. Conversely, significant tilts of the local spacecraft of the receiver will cause a detectable angular shift in the beam's position on the sensor, allowing precise measurement and accurate determination of the spacecraft's orientation.

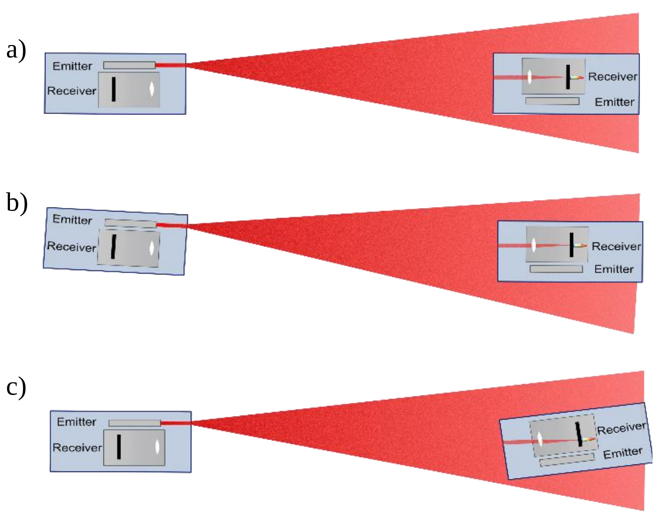

Figure 1: (a) Shows a perfectly aligned sensor where the laser beam passes directly through the lens to the sensor. (b) Illustrates a tilt of the emitting spacecraft. Due to the spherical wavefront, the beam does not enter the receiver at an angle. (c) If the receiving spacecraft is tilted the light enters the receiver at an angle which results in a displacement of the beam on the detector.

3. Definition of Sensor Type

An Indium Gallium Arsenide (InGaAs) focal plane array (FPA) was chosen as the optical sensor for the MiniCAS system. This sensor features a CMOS-based readout integrated circuit (ROIC) to efficiently read out the pixel amplitudes. In this configuration, each individual pixel is directly connected to its own pre-amplifier, enhancing the signal processing capabilities. The InGaAs sensor operates in the Short-Wave Infrared (SWIR) spectrum, of specific interest is the wavelengths between 1064 nm and 1550 nm, as flight-proven and very efficient light sources exist that emit at these wavelengths

4. Conclusion

MiniCAS represents a major advancement for satellite gravimetry missions like NGGM, where precise alignment between satellites is crucial for accurate gravity field measurements. It ensures stable laser links with microradian precision, which is essential for capturing high-precision data needed to study global changes such as climate dynamics and sea-level rise.

Additionally, MiniCAS can provide added value wherever the relative alignment of any two spatially separated objects is of interest.

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