Calibration/Validation concepts for future SST mission scenarios

Zukunftskonzepte für Schwerefeld-Satellitenmissionen

GEOTECHNOLOGIEN

P. Brieden[(1)], B. Sheard[(2,3)], J. Müller[(1,3)], G. Heinzel[(2,3)], J. Flury[(1,3)]

Introduction:

The vast majority of future gravity field mission concepts being discussed at present focus on the determination of the Earth's gravity field and especially its time variability. To achieve this scientific goal, most future mission concepts are based on two satellite bodies, similar to the GRACE mission. In the GRACE mission, the twin satellites are interconnected by a K/Ka-band microwave link to measure the exact separation distance and its rate of change. These low-low satellite-to-satellite tracking (ll-SST) instrument is discussed to be replaced by a laser interferometer for future missions.

Through the use of laser interferometer for ll-SST, not only highly precise distance change measurements, but also independent measurements of changes in orientation become available. First ideas are presented here that use these new measurement quantities for calibration, validation and combination tasks.

The current concept of the GRACE Follow-On mission offers unique possibilities for calibration/validation purposes: Two independent instruments should measure the distance changes between the two satellite bodies. What these 'dual measurements' can be used for is also being investigated.

Orientation information from laser interferometer

The baseline architecture of current laser interferometer for SST developed at Albert-Einstein-Institute (AEI) is an offset phase locked transponder. The concept uses one laser on each satellite that interfere with each other on a four-quadrant photodiode (Figure 1). According to the principle of differential wavefront sensing (DWS), the angle between the wavefronts can be detected.

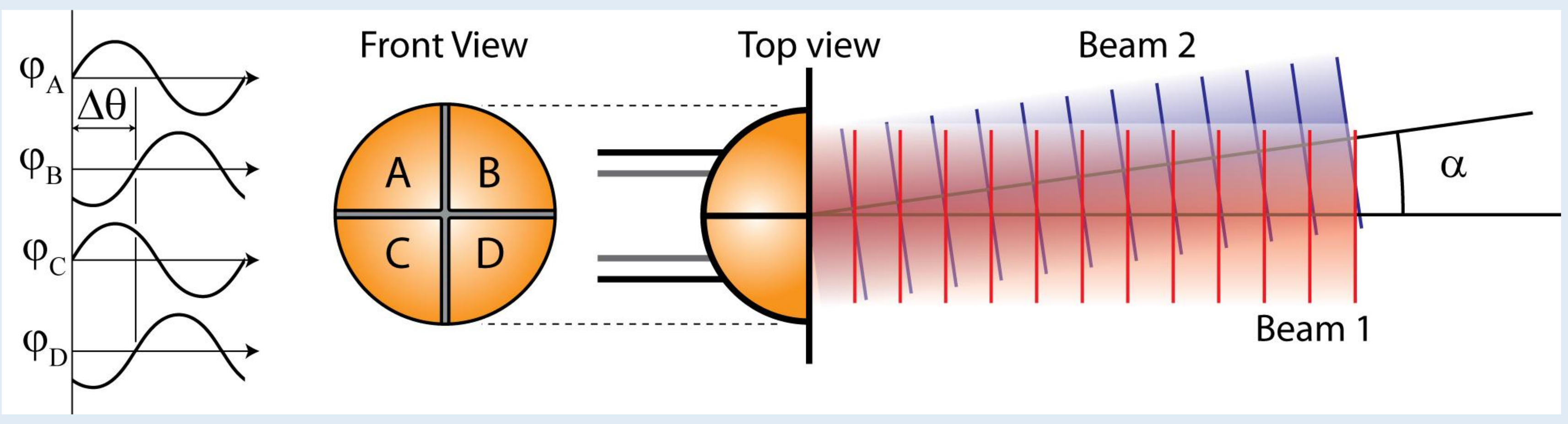
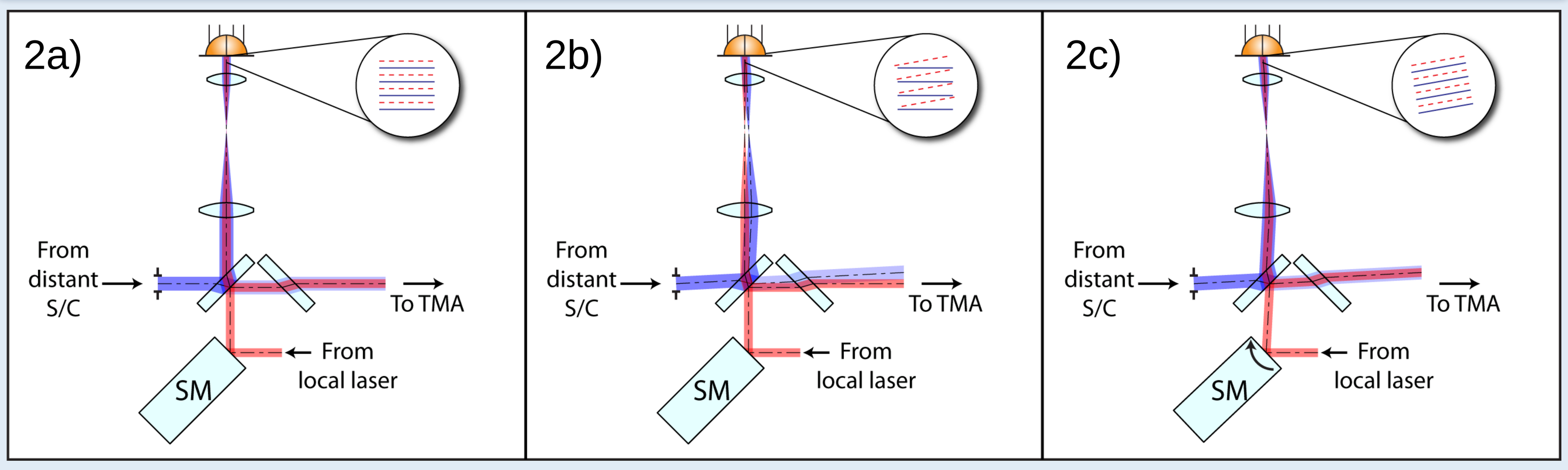


Figure 1: DWS principle on a four-quadrant photodiode

Changes in laser-phase on quadrants are the key to derive changes in:

- distance → same amount of phase shifts on all quadrants,
- orientation of the satellite → different phase shifts $\Delta\theta \approx K_{DWS}\,\alpha$,
  - Pitch angle: $\Delta\theta_p = \theta_T - \theta_B = \left(\frac{\varphi_A+\varphi_B}{2}\right) - \left(\frac{\varphi_C+\varphi_D}{2}\right)$,
  - Yaw angle: $\Delta\theta_y = \theta_L - \theta_R = \left(\frac{\varphi_A+\varphi_C}{2}\right) - \left(\frac{\varphi_B+\varphi_D}{2}\right)$.

Sensing rotation angles (pitch and yaw)



The current concept of the laser ranging instrument (LRI) provides to compare the incoming beam from the distant S/C to local laser:

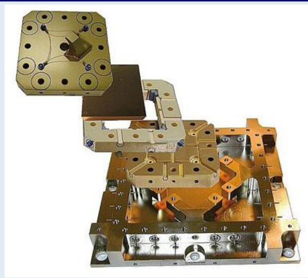
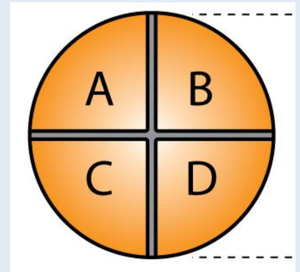
- Both laser beams perfectly aligned → DWS = 0 (Fig. 2a),
- Change in orientation → DWS ≠ 0 (Fig. 2b),
- Closed loop controlled steering mirror (SM) changes the direction of the local laser, parallelizes both beams → DWS = 0 (Fig. 2c).

The problem for calibration purposes: DWS angles recorded are zero!

To make use of the quantity 'change in orientation angle' from the LRI, angles have to be detected. Either the control voltages of the SM or internal sensors such as strain gauges in the steering mirror can be used to measure angle changes that are proportional to S/C orientation changes.

Calibration/Validation of different attitude sensors

The LRI provides changes in two orientation angles, that are pitch and yaw. Since the orientation of the satellites has been determined from a combination of star sensors and accelerometers until now, another set of independently determined orientation information becomes available.

Sensors:	 **star sensor**	 **accelerometer**	 **LRI**
Frequency range with high quality attitude information:	low frequencies	high frequencies	mid to high frequencies

New potential for calibration, validation and combination purposes:

- LRI-based change in pitch and yaw angle should be used for validation/calibration of accelerometer-derived attitude changes, having high quality in similar frequency ranges.
- Orientation information of all sensors in table 1 can be combined taking into account the frequency-dependet signal quality.

Calibration factors via comparison of SST measurements

The concept for GRACE follow-on provides two independent instruments for SST measurement: K/Ka-band microwave link and a laser-demonstrator as inter-satellite link. The unique opportunity to compare these dual measurements can be used to measure calibration factors, as indicated below.

Comparison of length measurement: $\boldsymbol{\Delta l(t) = l_{KBR}(t) - l_{LRI}(t)}$

$$l_{KBR}(t) \approx l_{sat-sat}(t) + K_p^{KBR}\,\theta_p(t) + K_y^{KBR}\theta_y(t) + K_{pT_i}^{KBR}T_i(t) + \cdots$$
$$l_{LRI}(t) \approx l_{sat-sat}(t) + \underbrace{K_p^{LRI}\,\theta_p(t)}_{\text{pitch angle}} + \underbrace{K_y^{LRI}\,\theta_y(t)}_{\text{yaw angle}} + \underbrace{K_{T_i}^{LRI}\,T_i(t)}_{\text{thermal expansions}} + \cdots$$

Length changes related to: pitch angle, yaw angle, thermal expansions

The formulas indicate certain factors influencing the line-of-sight measurement: attitude angles, change in satellite structure, …

All these measurements may be *temperature dependent*. Despite the prediction of a primarily linear behavior of the calibration factors ($K_{instr.}$), they have to be determined for independent instruments and their calibration and mutual validation will be of great interest.

Conclusion

- The laser ranging instrument (LRI) being developed at AEI for measuring the distance variations between two satellites via a laser interferometer provides the opportunity to derive independent information on the change in S/C orientation angles pitch and yaw.
- The orientation changes are currently used only in a closed loop. Since they are of great interest for many tasks, the angles should be recorded at the steering mirror, which is controlled within the closed loop.
- New independently determined attitude change in pitch and yaw can be used to be combined with and compared to attitude information derived from star trackers and accelerometers.
- The GRACE follow-on concept provides two independent measurements of the line-of-sight. A comparison of the two allows to determine instrument-dependent calibration factors.

References

B. S. Sheard, G. Heinzel, K. Danzmann, D. A. Shaddock, W. M. Klipstein and W. M. Folkner: *Intersatellite laser ranging instrument for a GRACE follow-on mission* (in preparation).

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(1) Institut für Erdmessung, Leibniz Universität Hannover (LUH), Schneiderberg 50, 30167 Hannover

(2) Max-Planck-Institut für Gravitationsphysik, Albert-Einstein-Institut, LUH, Callinstraße 38, 30167 Hannover

(3) Centre for Quantum Engineering and Space-Time Research (QUEST), LUH, Welfengarten 1, 30167 Hannover

Kontakt: brieden@ife.uni-hannover.de, benjamin.sheard@aei.mpg.de, mueller / flury@ife.uni-hannover.de, gerhard.heinzel@aei.mpg.de

quest

Leibniz Universität Hannover