Evaluation of a survey style quantum absolute gravimeter

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SUMMARY

We will present the status of the first survey style quantum absolute gravimeter developed at Nomad Atomics.

We will report on the results of a comparison study between current state-of-the-art absolute gravimeters (FG5 and A10 Micro-g LaCoste) and the quantum gravimeter developed by Nomad Atomics. The comparison provides an assessment of the performance, portability, and metrology capabilities, and discusses the suitability of the generated gravity data for geodetic absolute gravimetry fieldwork.

We will outline future possibilities enabled by survey style quantum gravimeters, from new applications in long-term monitoring through to the development of airborne drone-based gravimeters.

Key words: Absolute gravity. Gravimeter comparison. Quantum sensing.

INTRODUCTION

Gravity exploration and monitoring has the potential to have a significant impact across numerous commercial and research sectors including geodesy, hydrography, resource exploration, navigation, civil engineering, and long-term monitoring of subsurface dynamics.

However, many of these applications require an understanding of absolute quantities, which can only be inferred from the knowledge of the true value of the acceleration pull of the bodies. Measuring true gravity can only be done with absolute gravimeters. Current commercial devices have a complicated architecture, their large size, fragility, and high cost prevent their use in gravity surveys as performed with relative spring gravimeters.

Advances in quantum technologies are enabling the development of smaller, and more robust absolute gravimeters that address the limitations of current commercially available devices. By exploiting the intrinsic properties of atoms and their interactions with light, quantum gravimeters offer unprecedented accuracy and precision, as well as the possibility of miniaturisation. This allows us to combine the best features of both current absolute and relative devices: the stability and accuracy of absolute gravimeters with the portability and affordability of relative gravimeters, greatly simplifying survey logistics and expanding capabilities.

In this talk, we will present the status of the first survey-style quantum gravimeter, developed by Nomad Atomics. We will assess its operation, portability, and metrology capabilities, and how it compares to other commercial devices. Additionally, we will present a comparative study of its suitability for geodetic absolute gravimetry fieldwork against the two absolute devices that are currently employed to maintain the Australian Fundamental Gravity Network (AFGN) and the Australian Geodetic Gravity Network, the FG5 and A10 Micro-g LaCoste absolute gravimeters.

THE SURVEY STYLE QUANTUM ABSOLUTE GRAVIMETER

Quantum absolute gravimeters based on cold-atoms, like classic absolute systems, exploit the principle that a free-falling mass, provides an absolute determination of the local gravitational field. The test mass in the quantum systems is a laser-cooled cloud of atoms that interact with a light pattern forming an atom interferometer. The output phase of the interferometer depends only on the gravitational acceleration strength, and absolute properties of the atoms. This sole dependence on the unchanging fundamental properties of the atoms, rather than on material physical properties, imply that quantum gravimeters are inherently absolute, drift-free devices (dos Santos *et al*., 2016; Freier *et al*., 2016).

Quantum gravimeters have been realized not only in laboratories, but they have also been used to perform land-based, marine, and airborne gravimetry (Ménoret *et al*., 2018; Stray *et al.*, 2022; Bidel *et al.*, 2018; Bidel *et al.*, 2020). These quantum devices although transportable, are still heavier than 100 kg and over 1 m^3 in size, very similar to absolute gravimeters based on classical systems.

We have recently developed a cold atom-based survey style quantum absolute gravimeter designed to feature ~µGal level of accuracy and stability and achieve µGal precision within minutes. With a size of 20 cm x 20 cm x 30 cm, 13 kg of weight and 70 W power consumption, the Nomad Atomics quantum absolute gravimeter features a survey style integration approaching current start-of-the-art relative gravimeters like the CG6 by Scintrex. This is a significant step change in the deployment of absolute gravimeters for large scale surveying and monitoring applications.

COMPARATIVE ASSESSMENT OF STATE-OF-THE-ART ABSOLUTE GRAVIMETERS

The Australian Fundamental Gravity Network (AFGN) provides the reference frame for gravity surveys conducted throughout Australia. The AFGN is a network of permanently marked and documented gravity base stations which allow relative gravity survey measurements to be aligned to provide a continuous gravity dataset at regional and continental scales. These datasets can be used for large scale resource exploration via a geophysical understanding of the subsurface, and development of the national geoid model (Featherstone et al, 2017) used for positioning via Global Navigation Satellite Systems (GNSS). In order to maintain the AFGN, a significant number of absolute gravity measurements need to be performed across the continent with high precision and accuracy. Currently, two instruments are used to establish and monitor changes in absolute gravity at gravity benchmarks in Australia, an FG5 and an A10 Micro-g LaCoste absolute gravimeters.

In order to maintain, expand and improve these endeavours, we will perform a comparison study between these instruments and the quantum gravimeter developed by Nomad Atomics. The objective of this comparison is to evaluate the sensitivity and accuracy under various conditions and its suitability for geodetic purposes with respect to the IGRS Conventions 2020 detailed in Wziontek et al. (2021). We will assess the relative logistics of the fieldwork with each gravimeter by comparing their portability and operational requirements.

The study will be conducted in two phases. Phase one will consist of a direct comparison of the sensors co-located in a stable and controlled environment. From the gravity measurements at different integration times, the accuracy (bias), precision (bias drift) and acquisition rates will be determined.

The second phase will assess the field environment performance of the sensors. We will perform gravity measurements at the mount Stromlo Gravity Station and determine the accuracy (bias), precision (bias drift) and acquisition rates expected in surveying conditions.

DISCUSSION

We will present the status of the first survey style quantum gravimeter developed at Nomad Atomics. By assessing performance, portability, and metrology capabilities, we will present the results of a comparison study against current state-of-the-art absolute gravimeters. Additionally, we will discuss the new possibilities enabled by survey style quantum gravimeters which combine the best features of both current absolute and relative devices: the stability and accuracy of absolute gravimeters with the portability and affordability of relative gravimeters. These capabilities offer a pathway from precise and highly accurate land-based long-term monitoring to the development of airborne drone-based absolute gravimeters.

REFERENCES

Bidel, Y., Zahzam, N., Blanchard, C., Bonnin, A., Cadoret, M., Bresson, A., Rouxel, D., and Lequentrec-Lalancette, M. F., 2018, Absolute marine gravimetry with matter-wave interferometry, Nature Communications, 9, 627.

Bidel, Y., Zahzam, N., Bresson, A., Blanchard, C., Cadoret, M., Olesen, A. V., Forsberg, R., 2020, Absolute airborne gravimetry with a cold atom sensor. Journal of Geodesy, 94, 20.

dos Santos, F.P., Bonvalot, S., 2016, Cold-Atom Absolute Gravimetry. In: Grafarend, E. (eds) Encyclopedia of Geodesy. Springer, Cham. https://doi.org/10.1007/978-3-319-02370-0_30-2

Featherstone, W.E., McCubbine, J.C., Brown, N.J. et al., 2018, The first Australian gravimetric quasigeoid model with location-specific uncertainty estimates. J Geod 92, 149–168. https://doi.org/10.1007/s00190-017-1053-7

Frier, C., Hauth, M., Schkolnik, V., Leykauf, B., Schilling, M., Wziontek, H., Scherneck, H-G., M¨uller, J. and Peters, A., 2016, Mobile quantum gravity sensor with unprecedented stability, Journal of Physics: Conference Series, 723, 012050.

Ménoret, V., Vermeulen, P., Le Moigne, N., Bonvalot, S., Bouyer, P., Landragin, A., and Desruelle, B., 2018, Gravity measurements below 10−9 g with a transportable absolute quantum gravimeter, Scientific Reports 8, 12300.

Stray, B. *et al.*, 2022. Quantum sensing for gravity cartography, Nature 602, 590–594.

Wziontek, H., Bonvalot, S., Falk, R. et al., 2021, Status of the International Gravity Reference System and Frame. J Geod 95, 7.