Quantum Gravity Sensors for Geophysical Applications: The FIQUgS Project

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Abstract

The FIQUgS project, funded by the European Commission, aims to develop advanced quantum gravity sensors to measure gravity and its vertical gradient, addressing transportability and robustness challenges. The project and its key achievements are presented.

Measurements of gravitational acceleration and its variations play an important role in studying a wide range of phenomena across scientific and industrial fields. Key applications include the exploration of natural resources (such as mining, oil and gas etc.), monitoring mass changes [1] and hydrological variations [2], conducting archaeological investigations, and ensuring the safety of civil structures by detecting voids and cavities.

In recent years, gravity sensors based on quantum technology have emerged as a promising alternative to traditional gravimeters. These quantum devices offer enhanced accuracy and allow direct observation of the absolute value of the gravity field [3]. The FIeld QUantum Gravity Sensors (FIQUgS) project, funded by the European Commission in 2022, brought together an international consortium dedicated to the development of a new generation of quantum gravity sensors (QGs) with the aim to overcome transportability and robustness limitations, that render the first generation of quantum sensors unsuitable for outdoor use. The project's agenda involves creating a more sophisticated version of the Absolute Quantum Gravimeter (AQG) as well as the first field-ready Differential Quantum Gravimeter (DQG). Alongside advancements in hardware, the FIQUgS initiative has focused on the development of auxiliary software tools aimed at extracting maximum information from gravity and gradiometer data. A custom survey planning tool has been created, applying statistical inference to optimize survey paths. Additionally, specific data processing tools have been designed, integrating conventional routines with innovative multi-resolution terrain correction algorithms. Furthermore, an automated inversion module has been developed to infer 3D mass density distributions from gravity and gravity gradient data, with the capability to incorporate data from other geophysical methods, such as ground-penetrating radar, to improve the inversion results. In this work, we present the FIQUgS project and its preliminary findings, with a focus on a first field test conducted in Lisbon to detect a subsurface cavity. For this case study, prior to the survey, the FIQUgS planner tool was used to determine the optimal spacing of observation points and the most efficient path for identifying the target. This approach minimized the number of observations required for both gravity anomalies and vertical gravity gradients. After data collection, the processing and inversion software were used to isolate the anomaly and then model the target cavity. The results prove the effectiveness of quantum instruments, particularly the DQG, in identifying both the presence and configuration of an empty tunnel with a section of approximately 5 m^2, located below the surface. Additionally, the analysis highlighted the advantages of using vertical gravity gradient data over traditional gravity anomalies, as it eliminates the need for tidal and latitude corrections, reduces the influence of distant masses (such as nearby buildings), and minimizes the impact of variations in observation point altitudes.

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References

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