A practical MEMS gravimeter

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Introduction
Gravimeters are used for measuring small density variations underground. A microelectromechanical system (MEMS) gravimeter has been developed at the Institute for Gravitational Research (IGR), in collaboration with the James Watt Nanofabrication Centre (JWNC), at the University of Glasgow. This device can measure a sensitivity of 40 μGal/Hz (1 Gal = 0.01 ms⁻¹) and was used to measure the elastic deformation of the Earth due to tidal forces from the Moon and Sun (see figure 1) [1]. To reach such a sensitivity, the device was operated underground. A microelectromechanical system (MEMS) gravimeter

Experimental set-up
The major components of the gravimeter system are the proof mass, electronics board and vacuum system (see figure 2).

The proof mass is supported by 3 geometrical anti-springs and its position is monitored using an optical shadow sensor. A change in gravitational acceleration can then be detected as a change in the displacement of the proof mass below its resonant frequency. An LED illuminates the proof mass which casts a shadow on two photodiodes positioned behind it and hence, from a change in photocurrent, the proof mass position can be found.

The signal is dependent on temperature, as well as any change in the angle of the ground with respect to the proof mass. Hence, the system must be operated under vacuum to reduce conductive heating and the temperature and ground till must be monitored.

Figure 1: Tidal elastic deformation of the Earth’s crust [1]

Miniaturisation
A battery powered, portable field unit has now been produced. A portable electronics board has been developed that can, through a microcontroller, drive an LED; convert a current from the photodiodes into a useable signal; monitor temperature and power heaters to control temperature via a PID controller, tag data using a GPS and clock and store data to an SD card. Additionally, the microcontroller is used to run a software-based lock-in amplifier for the electronics board.

The vacuum system has also been made portable. The MEMS is now housed in a small vacuum cube (see figure 2) and the vacuum is held using a powerless getter system. These upgrades have allowed the first out-of-lab measurements using this MEMS device.

Initial Results
• Lift Tests: Following the miniaturisation, measurements were carried out in a lift within the Kelvin Building at the University of Glasgow. Measurements were taken at the top and bottom of the lift shaft, representing an altitude change of ~20 m. This corresponds to a signal of 6 mGal which was successfully measured using the device (see figure 3).

• Chilean Earthquake: Over the Christmas period the gravimeter was operated within the lab and was able to detect a signal from the 7.7 magnitude earthquake that occurred on Christmas day in southern Chile (see figure 4).

Conclusions
The miniaturisation of the systems required for the operation of the device have allowed initial out-of-lab experiments. This work demonstrates the device’s suitability as a portable gravimeter. Additionally, further confirmation of the high sensitivity of the device has been gained. A MEMS gravimeter such as this has significant potential to make a transformative step in the field of gravity imaging, with applications in the oil and gas industry, environmental monitoring and defence and security.

In the coming months this prototype will be used in two field tests:
• A time-lapse survey of an hydroelectric dam as it drains
• A line survey a known gravitational anomaly

Further miniaturisation work will include a redesign of the geometry of the proof mass such that it will fit into a standardised MEMS package.