The IMGC-02 Absolute Gravimeter

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Absolute gravimeters, ballistic or atomic, can exploit:
- free fall motion
- rise and fall motion

Common units are:
$1 \mu\text{Gal} = 10^{-8} \text{m s}^{-2}$

Common features:
- repeatability of about $5 \mu\text{Gal}$
- extended uncertainty of about $15 \mu\text{Gal}$
- relative uncertainty of $10^{-9}$
Completely developed at Turin, Italy as a prototype
Used both for research and measurement session
The idea:
• find a reference point
• throw up a test object in the vacuum
• measure the vertical distance between the object and the reference point
• measure the time of the flight
• reconstruct the trajectory
• calculate $g$

$$s(t) = \frac{1}{2} gt^2$$
Operating principle - real life

The real life:

- find a reference point realized with a quasi-inertial system cutting high frequency noise
- throw up a test object in the vacuum with a verticality of 50 $\mu$rad
- measure the vertical distance using interferometer and laser
- measure the time of the flight using an atomic clock
- reconstruct the trajectory starting from 700 asymmetric time-space coordinates
- calculate $g$ using dedicated model and applied corrections
Main parts - scheme

1) launch system
2) measure system
3) front-end electronics
4) vacuum system

- seismometer
- interferometer
- photo-detector
- frame
- launch chamber
- laser
- computer
- electronics
Main parts - picture

1. launch system
2. measure system
3. front-end electronics
4. vacuum system
Launch system

**test object**

corner-cube prism (10 \( \mu \text{rad} \))
container of Aluminum
total mass of 78 g
accurately balanced
optical center \( \equiv \) center of mass

**throw, catch, center**

4 iron springs
recirculating ball slides
verticality adjusted up to 50 \( \mu \text{rad} \)
force of 70 N
path of 20 mm
Measure system

- quasi inertial system i.e. long period seismometer (20 s) with reference mirror
- Mach-Zender interferometer
- Aluminum structure
- optical fiber with adjustable mirrors to set the verticality of the beam
- photo-multiplier to detect the fringe signal
- quad-cell detector to monitor parasitic movements of the test objects
Front-end electronics and vacuum system

Front-end electronics

- Standard reference system of time and space:
  - Rubidium oscillator at $\nu = 10$ MHz
  - He-Ne laser $\lambda = 632$ nm
- PXI computer $\rightarrow$ recording and processing data
- Auxiliar instruments
  - Barometer $\rightarrow$ pressure correction
  - Vacuometer $\rightarrow$ check the launch chamber pressure
  - Thermometer
- Trigger units and power supplies

Vacuum system

- Rotative mechanical vacuum pump $\rightarrow 10^{-3}$ mbar
- Turbo-molecular pump $\rightarrow 10^{-6}$ mbar
- Glass vacuum chamber
Data processing

The main algorithm for each drop:

1. start from a single array of $N$ time values $T_i$
2. obtain space-time coordinates $(T_i, S_i)$ as $S_i = N \cdot \lambda/2$
3. find the apex position and invert the fall branch coordinates
4. fit the trajectory using least square method
5. apply the correction and extract $g$. 

![Graph showing time vs. station number and distance vs. time]
Some open issues

To achieve the requested accuracy, some issues must be monitored and investigated.

- **Trajectory.** Asymmetry of the parabola, *decalage* effect.

- **Physical model.** Linear or non-linear? Residual friction of the air? Drift effect?

- **Height.** The extracted $g$ is referred to the of the trajectory? Best reference height? (warning: vertical gravity gradient $\approx 0.300 \, \mu\text{Gal/mm}$)

- **Drop goodness.** Is the drop vertical? Is it affected by rotation or shift during the flight (Coriolis force)?

- **Noise.** Electronics, human, floor recoil, temperature, humidity.
Corrections and uncertainty

For each drop, the following effects are corrected (if necessary) and accounted in the uncertainty budget.

**Instrumental effects**

Drag, outgassing, magnetic field, electrostatic field, air gap modulation, index of refraction, fringe timing, finite value of speed of light, radiation pressure → negligible

temperature gradient, self-attraction, laser beam verticality and divergence, clock delay, reference height → $u < 1 \, \mu\text{Gal}$

retroreflector balancing → $u \simeq 3.6 \, \mu\text{Gal}$

**Site dependent effects**

Polar motion, floor recoil → negligible

Atmospheric pressure, tide, ocean loading, standard deviation → $u < 2 \, \mu\text{Gal}$

Coriolis force $u \simeq 1.5 \, \mu\text{Gal}$

$\Downarrow$

⇒ combined uncertainty: $u \simeq 4.5 \, \mu\text{Gal}$
Example of measurement - 1

For each drop, a dedicated software process data on fly giving

- parameters from the least square fit
- reference height
- plot of the signal amplitude (to monitor verticality of the drop)
- plot of all processed drops versus time after application of Chauvenet criterion
Example of measurement - II

- tide correction values calculated using FORTRAN software
- local atmospheric pressure correction values
- values coming from fit about the friction effect

- list of enabled corrections
- average and last drop residuals coming from the fit
Conclusion

The IMGC-02 Absolute Gravimeter is used for:

- measurements of $g$ with an accuracy of few parts in $10^9$
  - for geophysical analysis: seismic, vulcanology, etc.
  - for metrological purposes: as the Watt balance, relativistic correction, International Comparisons, etc.
- detailed study on the parasitic effects can influence the measurements
- development of new and more transportable Absolute Gravimeters

Thanks for the attention.