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A LabVIEW environment to compensate temperature-driven fluctuations in the signal from continuously running spring gravimeters

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ABSTRACT

Environmental parameters can seriously affect the performances of continuously running spring gravimeters. Temperature is a primary interfering quantity and its effect must be reduced through algorithms implementing a suitable compensation scheme. Algorithms to reduce the signals coming from continuously running gravimeters for the effect of meteorological perturbations have been developed and implemented in tools running in offline-mode.

Anyway, the need for "on–the-fly" processing emerges when the recorded signals are used for volcano monitoring purposes, since any information on the volcanic phenomena under development must be assessed immediately. In this paper the implementation, in a dedicated LabVIEW application, of an algorithm performing temperature reduction on gravity signals is discussed and features of the software's user interface are presented.

1. Introduction

Mt Etna volcano (Sicily, south of Italy), is covered with several networks of sensors aimed at detecting changes in those physical and chemical parameters which are relevant for monitoring and forecasting purposes (Bonaccorso et al., 2004). To assess meaningful anomalies, some instruments need to be placed as close as possible to the active craters. Unfortunately, the conditions at such sites (high altitude, inaccessibility for several months at a time, lack of mains electricity for power, high peak-to-peak diurnal and seasonal temperature changes, and high seismicity) are far from the laboratory standard, and thus is difficult to obtain the required precision of the data (Torge, 1989).

Microgravity studies are performed at active volcanoes to detect underground mass redistributions which may supply important information on the dynamics behind the volcanic activity. These studies are mainly accomplished through spring gravimeters since, with respect to superconducting meters or devices which operates by using the free-fall method (Yoshida et al., 1997; Imanishi, 2001; Imanishi et al., 2004), they are cheaper, smaller (thus easier to transport and install) and take much less power to work. Past studies demonstrated that some external parameters can dramatically affect the behavior of spring gravimeters (Doebelin, 2003; El Wahabi et al., 1997). It should be emphasized that, since very low variations in the amplitude of the gravity field are to be observed (of the order of a few to a few tens of μgal; $1\,\mu\text{gal} = 10^{-8}\,\text{ms}^{-2}$), sensors with high sensitivity and high resolution must be adopted, which are more prone to the effect of ambient parameter fluctuations (Andò et al., 2004).

In particular, Carbone et al. (2003) proved that, over a yearly period, temperature changes can cause an instrumental effect up to 10^3 μgal. An admittance up to 200 μgal/°C, over the seasonal period, was evidenced by El Wahabi et al. (1997). It is now well established that apparent gravity changes depend on the temporal development and magnitude of the meteorological change that caused them, as well as on the insulation and compensation of the spring gravimeter utilized. Thus, the correction formulas are instrument-specific and often frequency-dependent (Carbone et al., 2003). Accordingly, dedicated approaches must be followed to reduce the signal from a continuously running gravity meter for the effect of meteorological parameters.

Andò and Carbone (2001) investigated the possibility of a neuro-fuzzy algorithm as a tool for reducing the gravity signal from a remote Etna station for the effect of meteorological perturbations (namely atmospheric temperature and pressure). Successively, the capabilities of the same compensation algorithm were tested using the signals from three different instruments, recording simultaneously for 50 days at a site far away from active zones, thus where gravity changes of geodynamic origin were not expected (Andò and Carbone, 2004). The reduced output from the three instruments (after the implementation of the compensation strategy) was within 15 μgal at the 99% confidence interval, and

Abbreviations: CTG, compensation tool for gravimeters; PTT, processing and test tool; MOST, model order selection tool

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was uncorrelated with temperature. The global validity of the compensation strategy was discussed by Andò and Carbone (2006), who used records from the same instrument operating in different monitoring sites. Such approach demonstrates the local validity of the compensation model: the effect of influencing quantities on the instrument operation depends on the installation site.

The above cited experiences prove the possibility of the adopted methodology as a tool for compensating the signal from continuously running gravimeters for the effect of meteorological perturbations.

When the recorded signals are used for volcano monitoring purposes, the need arises for a tool able to implement "on-the-fly" the temperature compensation algorithms.

In this work a tool, hereinafter the *Compensation Tool for Gravimeters* (*CTG*), aimed at reducing the output signal from a gravimeter for the effect of temperature, is presented. This tool can be easily integrated in a LabVIEW application already developed and aimed at handling the data coming from remote continuous gravity stations (Carbone, 2002). The *CTG* is intended as a tool for volcano monitoring designed to handle short-lasting sequences (of the order of a few days), i.e., the very last data coming from the remote stations. The compensation strategy adopts a dynamic model implemented into the LabVIEW *CTG* tool through a Matlab® routine exploiting the Matlab® identification toolbox.

The *CTG* can process data from any monitoring site, once a suitable tuning procedure is accomplished, as already evidenced by Andò and Carbone (2001, 2004). In order to suitably tune the compensation strategy, two additional tools are implemented, the *processing and test tool* (*PTT*) and the *model order selection tool* (*MOST*).

The aim of the PTT is twofold: (i) it implements algorithms to pre-process the data sequences that will serve as an input to the *MOST* and (ii) furthermore, once the order of the analytical model implementing the temperature reduction from the gravimetric signal is selected, it allows to evaluate the performance of the compensation strategy. The most suitable model order can be selected through the *MOST*. Considering that the model order could be strictly dependent on the monitoring site, the *MOST* should be used every time a new station is installed.

Once the tuning phase has been accomplished, the gravity signal coming from a remote site can be reduced for the effect of temperature fluctuations using the *CTG*, as sketched in Fig. 1.

2. The strategy for temperature compensation

The strategy, implemented in the CTG tool and aimed at reducing the gravity signal for the effect of temperature (Andò and Carbone, 2001, 2004), is presented in Fig. 1.

As a first step, a model between the gravimeter output, G, and temperature T, is estimated.

When a good identification of this model is obtained, the residual, R, between the effect of temperature variations, simulated by the model, $\hat{G}$, and the meter output, G, is calculated

$$R = G - \hat{G} \quad (1)$$

Performing the interference compensation sketched in Fig. 1 allows splitting the meter output into two pieces of information. The first, $\hat{G}$, represents the component of the signal due to the temperature variations while the second, R, is correlated to all the other possible causes and represents the reduced signal.

Fig. 2. Set-up of a gravity station on Etna.

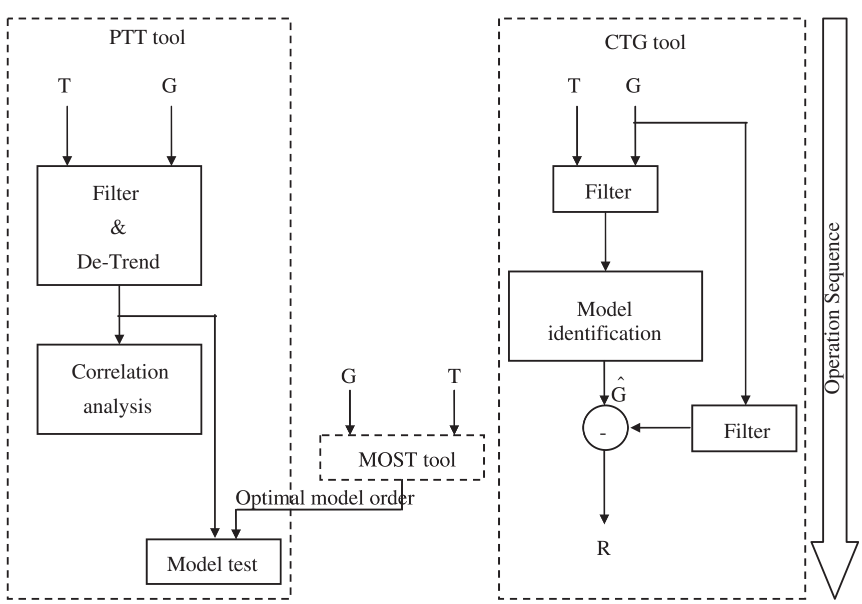

Fig. 1. Scheme of compensation environment.