A Technique for Data Processing and Performance of Digital Servo Sensor for Applying to Relative Gravimeter

Tokyo Institute of Technology Member ◯ Hitoshi Morikawa
Tokyo Sokushin Co., Ltd. Isamu Yokoi, Haruo Suda, Sadaharu Kima

1. Introduction

Modeling ground structure is one of the most important topics for the estimation of seismic hazard these days. Gravity survey is one of exploration methods. We can estimate ground structure by using information of gravity anomaly which comes from heterogeneous density structure of the ground.

For gravity survey, spring-type relative gravimeter is usually used. This type of gravimeter can provide accurate data, however, it is very expensive and difficult to handle. Furthermore, it takes much time to obtain adequate data. We, thus, began to develop a simple and inexpensive sensor which can measure gravity anomaly on a moving vehicle, such as air, land, and sea vehicles, such as airplanes, motor vehicles, and ships. In a case where a gravimeter is used with a moving vehicle, we may survey the gravity over larger area in shorter time than using conventional survey techniques.

Generally, the gravity should be measured with resolution of 10μGal at least for survey to estimate ground structure. However, the signal obtained from sensor is contaminated by various noise such as vibration of a moving vehicle etc. This means that a sensor with high resolution and large dynamic range is required. This is difficult to realize because resolution and dynamic range are conflicting requirement.

To solve this problem, we have developed a sensor with digital feedback system, which is called "D-servo" hereafter, and improved it for a few versions to adjust to the features of moving vehicles. We focus the study on the resolution of the sensor and technique of data processing.

2. Observation

We set the sensor statically in a tunnel to confirm whether the sensor can respond to the gravitational effects caused by earth tides, which is about 200 μGal of peak-to-peak with 12- and 24-hour period. To verify if the sensor has enough resolution to observe the gravity anomaly, we carried out a long-term observation in a tunnel, where the temperature can be kept constant and where there are very few disturbances. We left the sensor in the tunnel with a simple sensor for atmosphere pressure, air temperature, and humidity during three weeks, from Feb. 27 to March 18, 2013. First few days, the sensor are not stable because of setting disturbance and difference of temperature between inside and outside of tunnel.

The observed data are shown in Fig.1 for data from March 1st to 15th. From this figure, it is observed that the temperature is very stable, on the other hand, that the humidity and atomosphere are not stable. Furthermore, the output of D-servo strongly correlate with atomosphere.

The case for D-servo is made of aluminum and sealed, however, it may be deformed very slightly by the difference of atomosphere. Then, the sensor may respond the strain of the case. We, of course, have to consider a atomosphere-free case for the sensor. Furthermore, a techinque for signal processing is also necessary to derive the signal caused by earth tide.

3. Analysis and Results

To remove the effect of the atomosphere, we apply a method of second order blind identification (SOBI) [1, 2]. Basically, SOBI can estimate unknown source signals from mixed outputs of source signals, which are observed. The number of source signals should be same as the number of observed signals and the source signals should be independent mutually.

The atomosphere and earth tide must be independent, thus, we can apply SOBI to two signals of atomosphere and output of D-servo. For this analysis, some techniques for processing are also applied: giving independent Gaussian noise with 5 dB for pre-whitening, pre-processing by differentiation, and averaging 250 results by Monte Carlo method.

The two estimated source signals are shown in Fig.2. From the essntial properties of SOBI, the absolute values of amplitudes for the estimated signals have no meaning. Only the phase, that is, shape of signals can be discussed. Fig.2 shows two signals with very different shapes, which seems to correspond to atomosphere and other.

The estimated source signals are noisy because of whitening. The signal of earth tide must be signal with very long period, such as 12 and 24 hour period. To find the signal corresponding to the earth tide, we apply empilical mode decomposition, which is basic technique for the Hilbert-Huang

Keywords: Gravity survey, Force-balanced-type accelerometer, second order blind identification (SOBI), Hilbert-Huang transform (HHT)
Contact Address: Hitoshi Morikawa, Dep. Built Environment, Tokyo Institute of Technology, 4259-G3-7 Nagatsuta, Midori-ku, Yokohama 226-8502, Japan, Tel: +81-45-924-5607, Fax: +81-45-924-5601

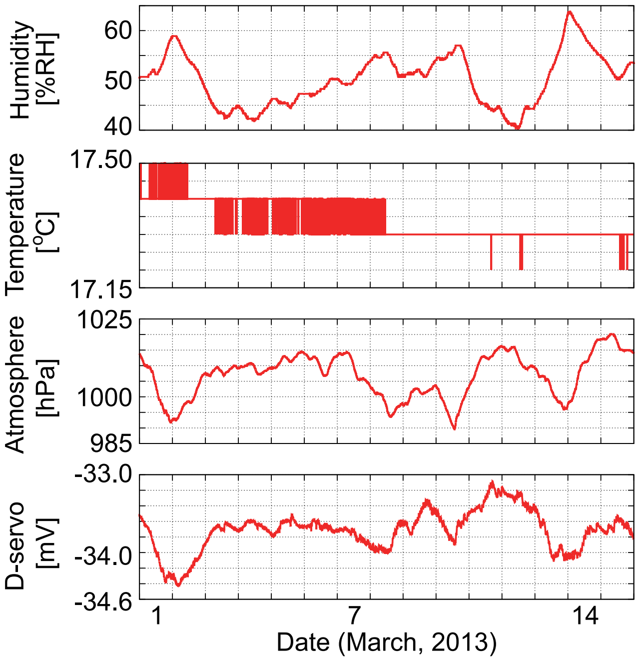

Fig. 1: Output of each sensor in tunnel for 15 days.

transform (HHT). HHT was originally proposed by Huang et al.[3]. This is advantageous for nonlinear and non-stationary data analyses and especially superior for long-term trend detection. Here, we apply an improved method called ensemble empirical mode decomposition (EEMD), proposed by Wu and Huang[4], for reducing the crosstalk among different instantaneous frequencies. EEMD can separate nonlinear and non-stationary signals, such as gravity anomalies, from observed data that have been contaminated by many kinds of noise.

It can be assumed that the signal 2 of Fig.2 includes the effects by the earth tide. Applying EEMD to signal 2, we obtain some signals with different predominant period. We, then, can pick up signals with 12- and 24-hour period and add them. The obtained signal should correspond to the earth tide. Fig.3 shows the obtained signal and analytical shape of the earth tide.

From this figure, it is observed that phase of observed signal generally agrees with the analytical one. However, the agreement of two signals on the 2nd week, March 8th to 14th, seems to be worse than on 1st week, March 1st to 7th. From the detailed observations, the fluctuation of atmosphere is relatively larger during the 2nd week than 1st week. This suggests that the signal 2 of Fig.2 is still contaminated by variations of atmosphere, especially during 2nd week, and that the variations of atmosphere disturbs to find the signal by the earth tide.

In a case where EEMD is applied to the output of D-servo without the procedure of SOBI, it is impossible to find the singnals with 12- and 24-hour period. This means that the SOBI is effective to devide the observed data into some incoherent signals.

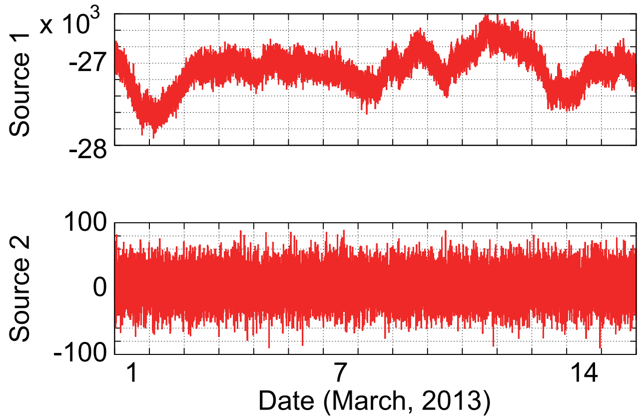

Fig. 2: Estimated source signals by SOBI. Two observed signals of atomosphere and output of D-servo are applied.

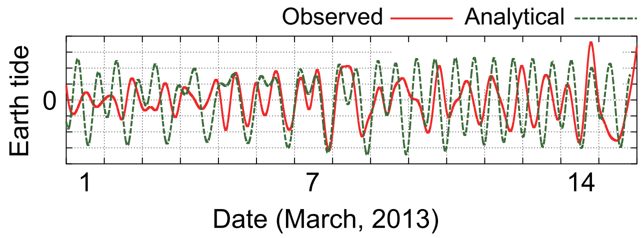

Fig. 3: 12- and 24-hour period signals obtained from signal 2 of Fig.2 through HHT. Solid and dashed lines are obtained from HHT and analytical value of earth tide, respectively. The value of vertical axis is no meaning.

4. Conclusion

We have examined the resolution of sensor for gravity survey through a static observation in tunnel. The sensor is strongly effected by the atmosphere though it is sealded in a rigid case. To remove the effect of coherent noise such as atomosphere, a technique by SOBI is effective. Of course, we have to also consider an atmosphere-free case for the sensor. Furthermore, applying the EEMD to a signal processed by SOBI, the signal corresponding to the earth tide can be found. The sensor has enough sensitivity to respond the earth tide, whose amplitude is only 200 μGal of peak-to-peak.

Acknowledgement: This study was partially supported by KAKENHI (21671003).

Reference

[1] Belouchrani, A., Abed-Meraim, K., Cardoso, J.F., and Molines, E., "A BSS technique using 2nd-order statistics," *IEEE Trans. on Signal Processing*, **45**, 1997, pp.434–444.

[2] Poncelet, F., Kerschen, G., Golinval, J.C., "Operational model analysis using second-order blind identification," *Proc. 26th International Modal Analysis Conference*, Orlando, Floride, USA, 2008.

[3] Huang, N. E., Shen, Z., Long, S.R., Wu, M.C., Shin, H.H., Zheng, Q., Yen, N.-C., Tung, C.C., and Liu, H.H., "The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis," *Proc. of the Royal Society of London*, **454**, 1998, pp.903–995.

[4] Wu, Z. and Huang, N.E., "Ensemble empirical mode decomposition: A noise assisted data analysis method," *Advances in Adaptive Data Analysis*, **1**, 2009, pp.1–41.