Performance of a New Digital Servo Sensor for Relative Gravimeter and a Technique of Data Processing

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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 anomaly on a mobile carrier, such as vehicle, ship, aircraft and so on. In a case where a gravimeter is used with a mobile carrier, 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 carrier etc. This means that the 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 new sensor with digital feedback system. The performance of the sensor is examined in the field.

2. A New Sensor with Digital Feedback System

We use force-balanced-type accelerometer to measure gravity, because this type of sensor is smaller and stronger than the spring-type gravimeter. Force-balanced-type sensor has analogue feedback system. Feedback system gives a coil electric current to keep the position of pendulum at the balanced point while it measures the variation of acceleration by outputting the value of electric current. However, analogue circuit is unstable for feeble current because of various noise. This means that noise prevents the resolution from improving. We can obtain high resolution only when we give up the obtainment of dynamic range.

To obtain high resolution and large dynamic range, we have developed a new sensor with digital feedback system, which is called digital-servo sensor, hereafter. The new system applies a digital computer to control the feedback system. This can reduce the effect of noise to be minimum.

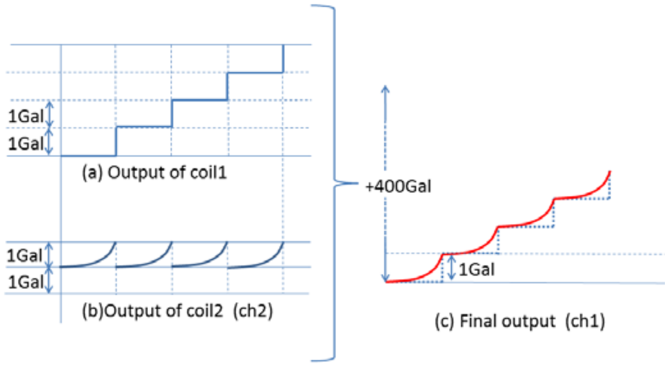

Fig. 1: Schematic diagram of concept for the new digital-servo sensor. (a) and (b) show outputs from different coils, which control large and small fluctuation, respectively. (c) can be obtained from merging outputs of (a) and (b).

The procedure to control a pendulum of sensor is follows:

1. Signal from the gap sensor for a pendulum is sent to A/D converter, immediately.
2. A microprocessor calculates the value of electric current which is required to control position of the pendulum.
3. The result of calculation is output as response of the pendulum.
4. After sending the result of calculation to D/A converter, electric current is given feedback coil, and then the position of the pendulum is set at balanced point.

Two feedback coils with different gains are used for the new system. This is important point to insure the high resolution and large dynamic range. A coil with low gain is controlled by analogue circuit for feedback, and its feedback current is converted to about 21-bit PCM data by A/D converter. The other coil with high gain is controlled by digital computer with about 10-bit with low resolution. These two feedback signals are merged together into the output signal with 32-bit resolution.

Fig.1 shows the concept of the system schematically. After the output value of ch2 reaches $\pm$1 Gal, the control by ch2 is

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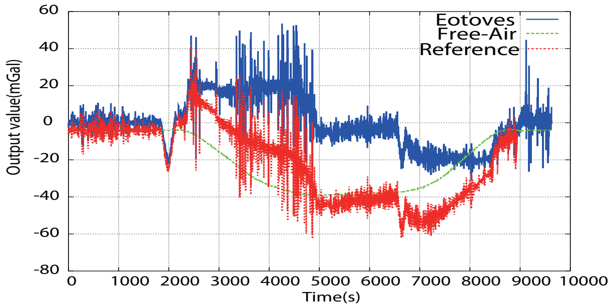

Fig. 2: Reference value in red color.

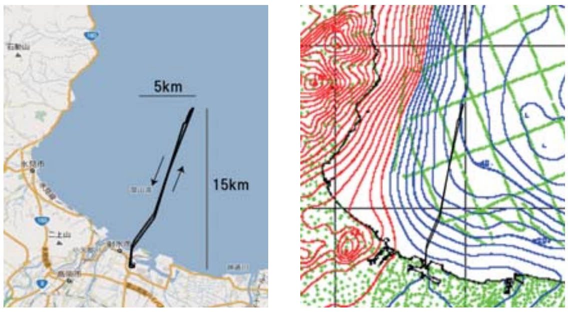

Fig. 3: Route of the ship (left) and free air anomaly around Toyama Bay (right).

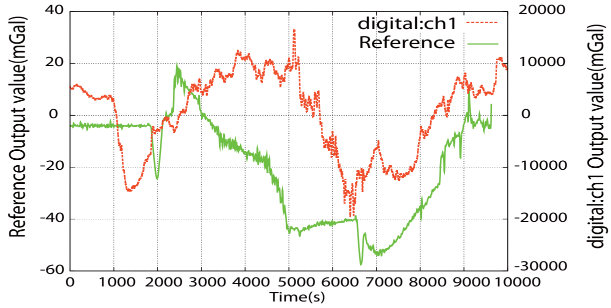

Fig. 4: Reference data and time series after applying a low-pass filter to the output of digital-servo sensor.

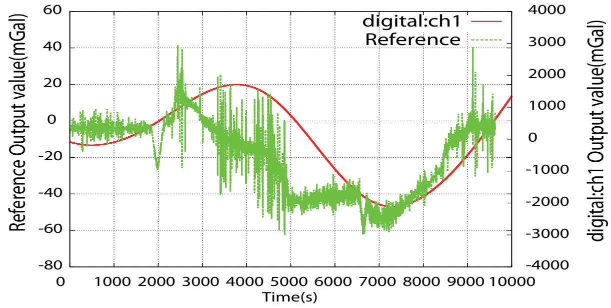

Fig. 5: Reference data and a component with longest period decomposed by HHT technique.

reset and ±1 Gal is added to ch1. Then, ch1 insures large dynamic range and ch2 insures high resolution.

3. Observation on a Ship To discuss the performance of the new sensor on a mobile carrier, we set the sensor on a ship. The observation was carried out around Toyama Bay on Oct. 31, 2011. We also set a GPS to determine the position of the ship. The validity of the observed data is discussed through the comparison to an ideal signal which can be obtained from the previously available data: free air anomaly of Toyama Bay. The ideal signal, furthermore, is affected by the Coliori's force, which is so called Etövös' effect[1].

Etövös' effect is calculated from the GPS data[2]. The reference value, which is mentioned above as an ideal signal, is obtained as the sum of Etövös' effect and free air anomaly. Free air anomaly, Etövös' effect, and the reference values are shown in Fig.2. Fig.3 shows the route of the ship and free air anomaly obtained previously around Toyama Bay.

The vibration of the ship is so strong that the output of ch2 is saturated, though, the values is obtained in ch1. We apply a low-pass filter to the data in order to remove short-period noise caused by the ship. Fig.4 shows the reference value and output of digital-servo sensor after applying a low-pass filter. The observed data is so different from the reference one in the amplitude and the phase. Especially, the sensor provides 1000 times larger than the reference with respect to the amplitude.

We apply the technique named Hilbert-Huang transform (HHT) [3] to the data and decompose them into some components with different periods. A component with the longest period seems to agree with the reference as shown in Fig.5. From this result, we may say that HHT must be useful tool to find the gravity from noisy data. However, it is noted that we have no way to determine the appropriate components of HHT without any information of target.This means that we have to develop a method to choose components corresponding to gravity.

4. Conclusion We developed a digital-servo sensor to observe gravity on a mobile carrier and carried out observation to examine the performance of the sensor. We analyzed the data using low-pass filter and HHT technique.

From the observation on a ship, high frequency vibration which has big amplitude make the gravity blind. If the vibration by a carrier is so large, it is impossible to find the gravity using simple filtering technique. However, we can obtain a signal corresponding to the gravity using HHT technique. This suggests that HHT technique is useful to find gravity anomaly from noisy data.

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Reference

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