Comparing different gradiometer configurations for underwater survey and demining

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Abstract

This paper compares the simulation of the use of gradiometers made of two, three of four magnetometers in estimating the three components of the gradient of the intensity of the magnetic field. The simulations take into account the sensor characteristics (measurement frequency, etc.), the target's magnetic properties (magnetic moment dipole) and the description of a survey where the gradiometer is towed behind a ship (ship speed, sensor depth, track inter-distance, etc.)

The simulations show quantitatively that, if the vertical gradient can theoretically be reconstructed from the measurements of two magnetometers, in practice the estimation may be very noisy. A more precise, direct measurement can be obtained by a third magnetometer. A four magnetometer can be used to increase the precision of the estimation of the gradient along-track.

1. Objectives

Mines and any large mass of ferromagnetic metal locally modify the ambient magnetic field. Measuring the intensity of the magnetic field can therefore be used to detect mines underwater even if they are buried. Measuring the gradient of the magnetic field (rather that the magnetic field itself) can help distinguish two metal objects close to each other. Each of the three components of the gradient can be either measured directly by using the difference of the measurements of two different magnetometers used together, or reconstructed from the different measurements of a single magnetometer along a survey.

This leads to different possible configurations for a gradiometer depending on the number and relative locations of the magnetometers [1][3][4]. In this paper we will consider three configurations. One is a gradiometer composed of two magnetometers located laterally with respect to the movement direction: one on port and one on starboard. Then the across-track gradient can be estimated directly. The along-track gradient can be recovered by difference of measurements along the track, and the vertical gradient can be estimated from the two components of the horizontal gradient. The second configuration is when a third magnetometer is added on top or below the first two. This allows the vertical gradient to be measured directly. And finally the third configuration is when a fourth magnetometer is added behind the first two. Then all three components of the gradient can be estimated at each time.

In this paper the following conventions will apply. When a gradient is computed by combing measurements collected at the same time, the gradient will be said to be *measured*. If it is computed from data collected over time, it will be said to be *estimated*.

Measuring the gradient is better than estimating it [2]. The objective of the paper is to confirm and quantify this improvement.

In the simulations described below, the magnetometers will have an acquisition frequency of 1 Hz.

2. The added value of the third magnetometer

In order to analyse the added value of the third magnetometer, a simulation was done with a simulator described in [5].

The parameters of the simulation are as follows:

- The gradiometer is towed behind a ship.
- We assume the Earth's magnetic field to be close to what it is in the North Sea.
- We assume that the magnetic moment of the target is in the direction of the Earth's magnetic field with an intensity of 10 Am^2.

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- The ship's trajectory consists of 60 tracks back and forth, in the North-South direction, two metres apart; the speed is 5 knots.
- The gradiometer is 10 metres above the sea ground.
- A uniform noise is added to the gradiometer locations with a largest value varying from 0 cm to 50 cm.
- Magnetic maps are built from the data collected from this survey.
- The theoretical vertical gradient is computed.
- The vertical gradient estimated from the data of two horizontal magnetometers is simulated.
- The vertical gradient as measured by the three magnetometers is simulated.
- For each configuration the relative error with the theoretical gradient is computed.

The estimation of the vertical gradient from the horizontal gradient is theoretically correct if the horizontal gradient is known perfectly on an infinite surface. Therefore in practice it will be better if it is based on a large set of measurements, either by a finer grid or a lower speed. The above simulation is therefore only an example.

That being said, the results can be found in Figure 1

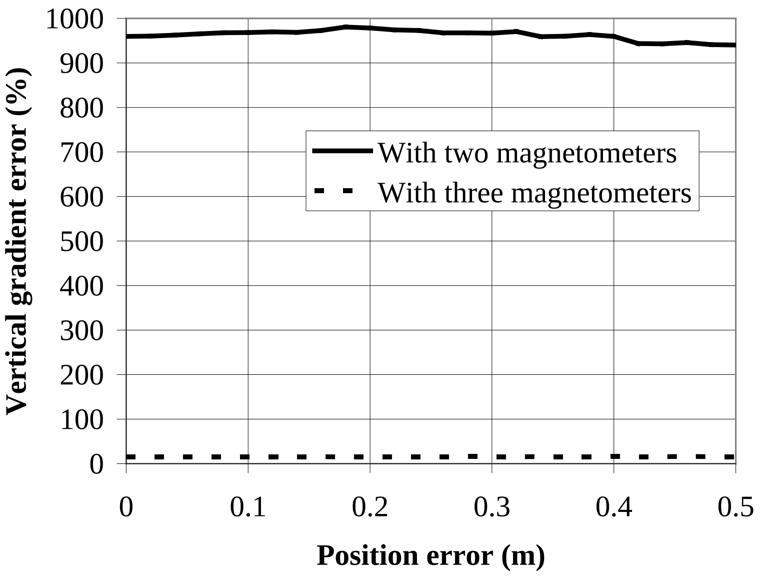

Figure 1—Vertical gradient errors when estimated with two magnetometers and measured with three magnetometers (1 Hz)

The estimation of the vertical gradient with only two magnetometers is far poorer than the direct measurement with three magnetometers.

Figure 2 shows the results if the magnetometers have an acquisition frequency of 10 Hz instead of 1 Hz. The estimation of the vertical gradient, although still noisy, is better.

It is theoretically possible to estimate the vertical gradient with measurements collected by two horizontal magnetometers, but the direct measurement with a third magnetometer is far better. With two horizontal magnetometers you can estimate the vertical gradient provided the horizontal gradient is known on an infinite surface. In practice the horizontal gradient is known only where measurements have been collected. This lack of data generates important errors when estimating the vertical gradient.

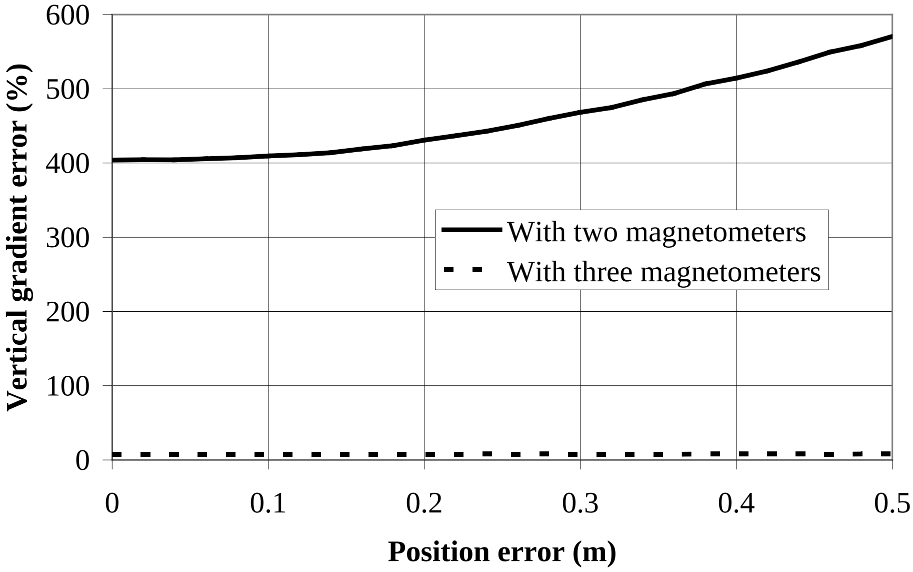

Figure 2—Vertical gradient errors when estimated with two magnetometers and measured with three magnetometers (10 Hz)

3. The added value of the fourth magnetometer

The fourth magnetometer allow the along-track gradient to be measured directly and not only estimated from data collected along the track.

In order to analyze the added value of the fourth magnetometer, a simulation is performed. The same parameters as above are used with the following differences.

- The theoretical along-track gradient is computed.
- The along-track gradient estimated from the data of three magnetometers is simulated.
- The along-track gradient as measured by the fourth magnetometers is simulated.
- For each configuration the relative error with the theoretical gradient is computed.

Results are shown in Figure 3.

It is possible to estimate the along-track gradient by combining the measurements along the track, but the direct measure of the gradient is better.

4. Conclusions

The following conclusions can be drawn:

1. It is theoretically possible to estimate the vertical gradient with only two horizontal gradient but the estimate is very noisy.
2. Measuring the vertical gradient with three magnetometers is better than estimating it with two.
3. Measuring the along-track gradient is better than estimating it.

This paper provides data to support quantitavely these conclusions.

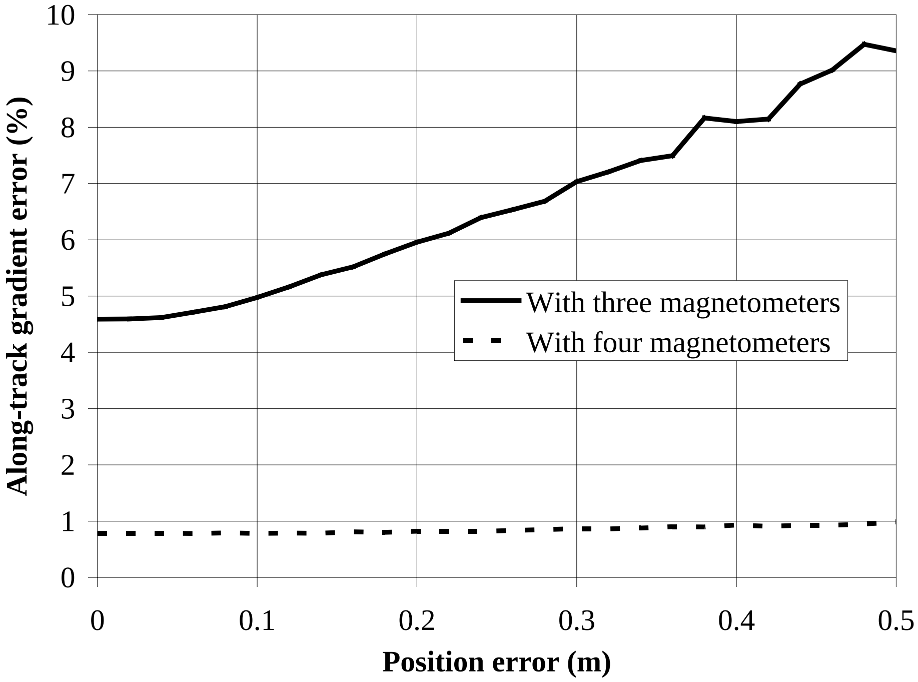

Figure 3—Along-track gradient errors when estimated with three magnetometers and measured with four magnetometers

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