MARINE BURIED MINES DETECTION USING MAGNETIC GRADIOMETRY

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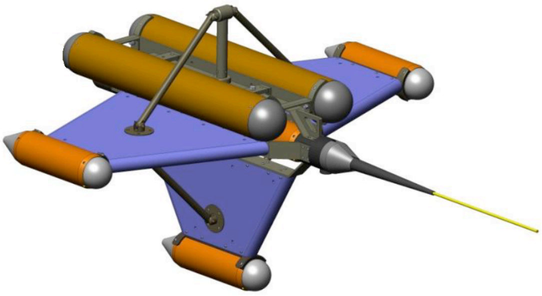
The detection of marine mines is important for the security of seaways. Classic techniques based on acoustic wave propagation have shown their limitations for the detection of buried mines and this represents a challenge for NATO. One promising technique is the magnetic gradiometry. We describe a new inversion method for which the position and the magnetic moment of a dipolar source are retrieved from a gradiometer survey. The effect of the geologic noise on the position error and on the magnetic moment error is also investigated, as well the effect of an error on the position of the gradiometer.

I. THE GRADIOMETER



The gradiometer we consider is made of three magnetometers which measure the intensity of the magnetic field $|\vec{B}|$ with an absolute accuracy of 0.1 nT. By combining the three magnetometers, it is possible to get the gradient :

$$(G_1, G_2, G_3) = \vec{\nabla}|\vec{B}|$$

The field $\vec{B}$ is the sum of the earth magnetic field $\vec{B}_e$ and the field $\vec{B}_s$ due to a dipolar source. Using the gradient measured at several locations, our objective is to determine the position (x_s, y_s, z_s) and the magnetic moment $\vec{M}$ of a mine buried in the seafloor.

II. THE INVERSION METHOD

First step : Linear model

If the dipolar source is generating a field $\vec{B}_s$ such that $|\vec{B}_s| << |\vec{B}_e|$, the intensity of the total magnetic field writes :

$$|\vec{B}| \approx |\vec{B}_e| + \vec{B}_s \cdot \frac{\vec{B}_e}{|\vec{B}_e|}$$

Under this condition, The position (x_s, y_s, z_s) of the source can be retrieved by the least square method on the Euler's homogeneity equations :

$$(x_g - x_s)G_1 + (y_g - y_s)G_2 + (z_g - z_s)G_3 = -3(|\vec{B}| - |\vec{B}_e|)$$

(x_g, y_g, z_g) are the known coordinates of the gradiometer, the components of the gradient G_i are given by the gradiometer, as well as $|\vec{B}|$. $\vec{B}_e$ is assumed to be known.

Once the position of the source is known, we use the expression of a dipolar field for $\vec{B}_s$, we write $\vec{r} = (x_g - x_s, y_g - y_s, z_g - z_s)$, and we derivate the approximate expression of $|\vec{B}|$ to find an expression of the gradient linear in M_i :

$$G_i = \frac{\mu_0}{4\pi}\frac{1}{B_e}\left(-\frac{5r_i}{r^7}\right)\left(3\vec{M}\cdot\left(\vec{r}(\vec{B}_e\cdot\vec{r}) - \vec{B}_e r^2\right)\right)$$
$$+\frac{\mu_0}{4\pi}\frac{1}{B_e}\left(\frac{1}{r^5}\right)\left(3B_{ei}\left(\vec{M}\cdot\vec{r}\right) + 3M_i\left(\vec{r}\cdot\vec{B}_e\right) - 2r_i\left(\vec{M}\cdot\vec{B}_e\right)\right)$$

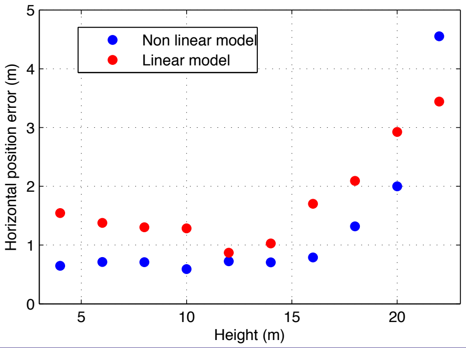
Second Step : Non linear model

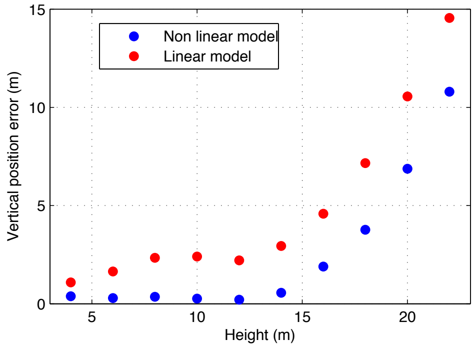
In the first step, we assumed that the gradiometer was measuring the actual gradient. In fact, if the distance between the gradiometer and the source is too small, the magnetic field doesn't vary linearly at the scale of the gradiometer. This leads to a bad estimation of z_s and $\vec{M}$. Once we have an estimation of the magnetic moment and the position of the source, we refine this estimation by taking into account the size of the gradiometer and its orientation. We calculate the exact intensity of the magnetic field due to a dipolar source and to the earth magnetic field at the locations of each magnetometer. Then we build the difference between thes intensities to calculate the gradient. This leads to a non linear system of equations that gives us the position and the magnetic moment of the source.

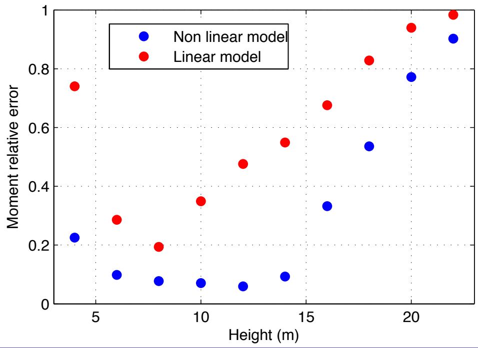
III. THE EFFECT OF THE NOISE

The effect of the noise is assesed by synthetic data. We consider the effect of a geologic noise, modeled as a uniform white noise of amplitude of $1/\sqrt{3}$ nT/m added independently to each component of the gradient. We also take into account an error on the position of the sensor modeled as a uniform white noise of amplitude of 1 m on each coordinate of the gradiometer. The results presented here are characterized by a vertical magnetic moment of 500 Am², five tracks of 60 m separated by 15 m and for which a measurement is done every 1.03 m. Each point corresponds to the median value of 50 runs.

The following figures show the effect of the noise on the position and on the magnetic moment estimation for different altitudes of the gradiometer and for the linear and the non linear models. The non linear model gives better results than the linear model. Due to the noise, we see that an altitude between 6 and 14 m is optimal for a good precision on the magnetic moment. For low altitudes, the effect of the error on the position of the gradiometer dominates and for high altitudes, the signal-to-noise ratio decreases.







IV. CONCLUSIONS

We have shown that it is possible to retrieve the position and the magnetic moment of a dipolar source from a gradiometer survey by solving a linear system of equations. In order to take into account the size of the gradiometer, we solve an additional non linear problem. This second step improves significantly the precision on the parameters. With the considered parameters, an optimum is observed between 6 and 14 m for the magnetic moment error.

AKNOWLEDGEMENT

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