Sea mine detection using a magnetic gradiometer

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Abstract

It is important to neutralise the sea mines for the security of seaways. The sea mines that we consider are placed directly on the seafloor (bottom mines). They can be challenging to detect since they can be buried in the sediment or in the sand. We present a method to detect buried mines using a magnetic gradiometer. This method is more accurate than traditional mapping techniques and it provides information about the magnetic moment and burial depth which can be used to reduce the false alarm rate. We also show some experimental results achieved in the Belgian area of the North sea.

The magnetic gradiometer

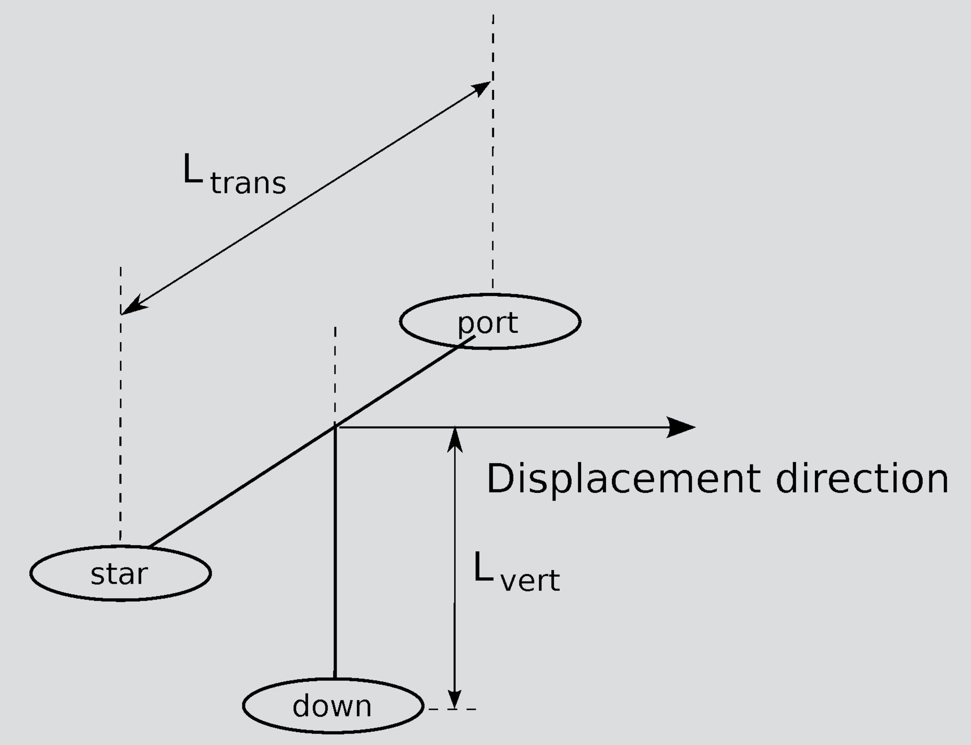

Figure 1: The considered gradiometer is composed of three magnetometers separated by the distances L_{trans} and L_{vert}.

- Three magnetometers (starboard, port and down) separated by distances L_{trans} and L_{vert}.
- Measurement of the magnetic field magnitude $|\vec{B}_s^i|$, $|\vec{B}_p^i|$ and $|\vec{B}_d^i|$, $i \in \{1, \ldots, N\}$ at
- N different locations $\vec{r}^i = (x^i, y^i, z^i)$.
- Computation of an approximation of the gradient:

$$\begin{pmatrix} G^i_{trans} \\ G^i_{long} \\ G^i_{vert} \end{pmatrix} = \begin{pmatrix} \frac{|\vec{B}_s^i| - |\vec{B}_p^i|}{L_{trans}} \\ \frac{(|\vec{B}_s^i| + |\vec{B}_p^i|) - (|\vec{B}_s^{i-1}| + |\vec{B}_p^{i-1}|)}{2|\vec{r}^i - \vec{r}^{i-1}|} \\ \frac{(|\vec{B}_s^i| + |\vec{B}_p^i|) - 2|\vec{B}_d^i|}{2L_{vert}} \end{pmatrix} \quad (1)$$

- In an absolute reference frame:

$$\begin{pmatrix} G^i_x \\ G^i_y \\ G^i_z \end{pmatrix} = \Omega^i \begin{pmatrix} G^i_{trans} \\ G^i_{long} \\ G^i_{vert} \end{pmatrix}$$

Inversion method

- Traditional method: map of $|\vec{G}|$.
- Proposed method
  - Mine: dipole of moment $\vec{M}$ and position $\vec{r}_t$. Earth magnetic field: $\vec{B}_e$.

$$|\vec{B}^i| = |\vec{B}_e + \vec{B}_t^i| \quad (2)$$

$$\vec{B}_t^i = \frac{\mu_0}{4\pi} \frac{3\vec{R}^i(\vec{M} \cdot \vec{R}^i) - |\vec{R}^i|^2 \vec{M}}{|\vec{R}^i|^5} \quad (3)$$

$$\vec{R}^i = \vec{r}^i - \vec{r}_t$$

  - Inversion: estimating the target magnetic moment $\vec{M}$ and position $\vec{r}_t$ knowing $(\vec{r}^i, \Omega^i, |\vec{B}_s^i|, |\vec{B}_p^i|, |\vec{B}_d^i|)$.
  - Iterative problem. The initial values are given by a linear model.
- Advantages over the traditional method:
  - Better accuracy.
  - Works regardless of the latitude.
  - No interpollation problem.
  - Real time processing.
  - Estimation of $\vec{M}$ and z_t usefull to reduce the false alarm rate.

Simulation results

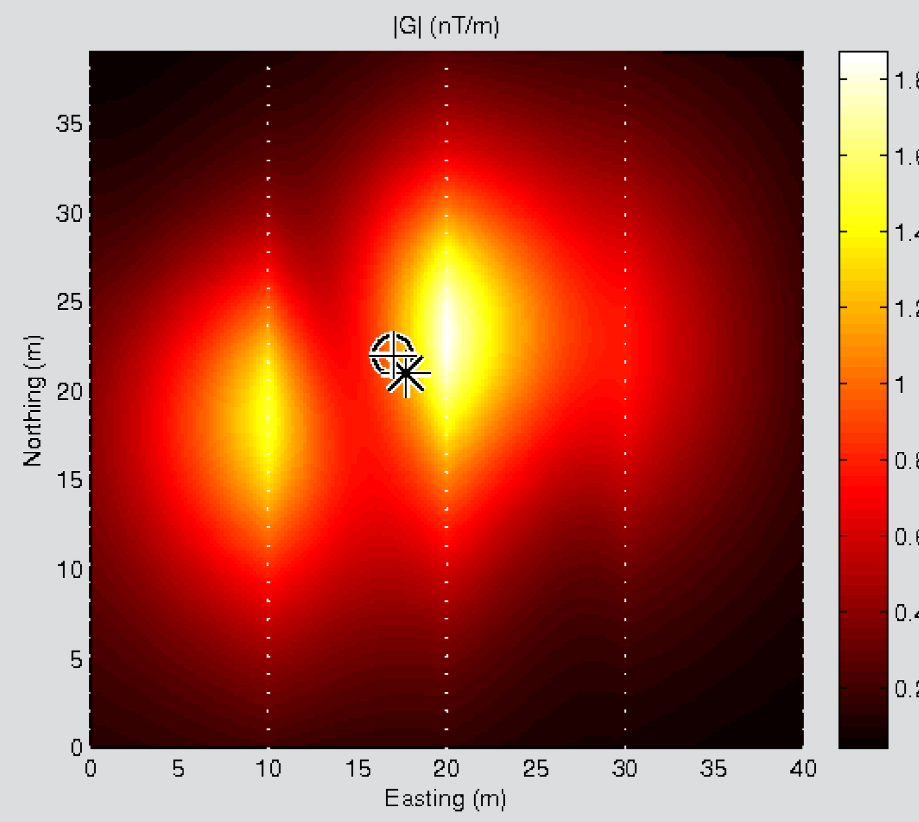

Figure 2: Comparison of the different localisation methods. The map represents the simulated magnitude of the gradient due to a dipole target. The circle is the true position of the dipole. The star is the the position found with the linear method and the cross is the position found with the nonlinear method.

Experimental results

The proposed approach was tested on measurements made in the Belgian area of the North sea on a candidate dipolar target. The fit is good and the estimated depth is plausible, since the target is estimated to be placed on the bottom.

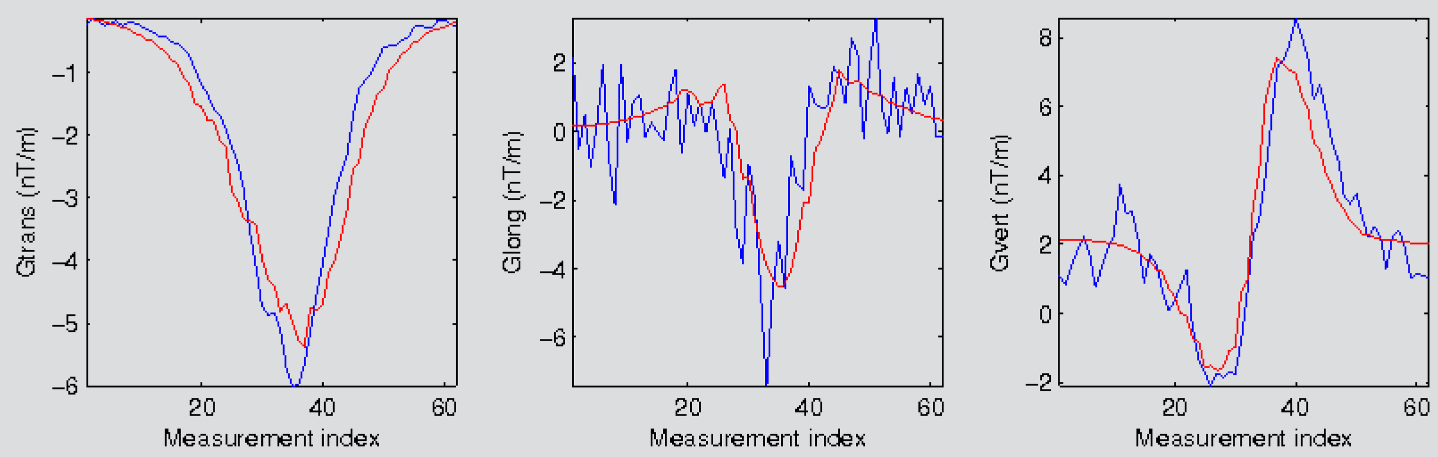

Figure 3: Transversal, longitudinal, and vertical gradients measured (in blue) and for the dipolar model (in red).

Parameter	Estimated value
Easting	506714.1 m
Northing	5699131.9 m
Altitude	0.8 m
Mx	78 Am^2
My	109 Am^2
Mz	25 Am^2

Table 1: Estimated parameters for the dipolar model.

References

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