Silent Localization of Underwater Sensors using Magnetometers

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Contribution

Sensor localization is a central problem for sensor networks. We explore the usage of triaxial magnetometers and a friendly vessel with known magnetic dipole characteristics to silently localize underwater sensors.

Background

Deploying an underwater sensor in its predetermined position can be difficult due to currents, surge and the lack of a Global Navigation Satellite System (GNSS) functioning underwater. Sometimes the sensors must be deployed fast, resulting in very uncertain sensor positions. These positions must then be estimated in order to enable the network to accurately detect classify and track an alien vessel. This work is the continuation of previous ideas from a student project course at Automatic Control in collaboration with Saab Underwater Systems.

Methodology

The sensor localization problem is basically Simultaneous Localization and Mapping (SLAM) with reversed measurements. In sensor localization the sensors are observing the vessel from the "landmarks" position. The state estimation is solved within a standard EKF-SLAM framework.

Models

The sensor positioning system is assumed to have the following process and measurement model

$$\boldsymbol{x}_{k+1} = f(\boldsymbol{x}_k) + \boldsymbol{w}_k$$
$$\boldsymbol{y}_k = h(\boldsymbol{x}_k, \boldsymbol{u}_k, \boldsymbol{e}_k^u) + \boldsymbol{e}_k$$

where the state vector consist of both the vessel states and the sensor positions $\boldsymbol{x} = [\boldsymbol{p}_v^T, \boldsymbol{s}^T]^T$.

The vessel dynamics are described with a coordinated turn model

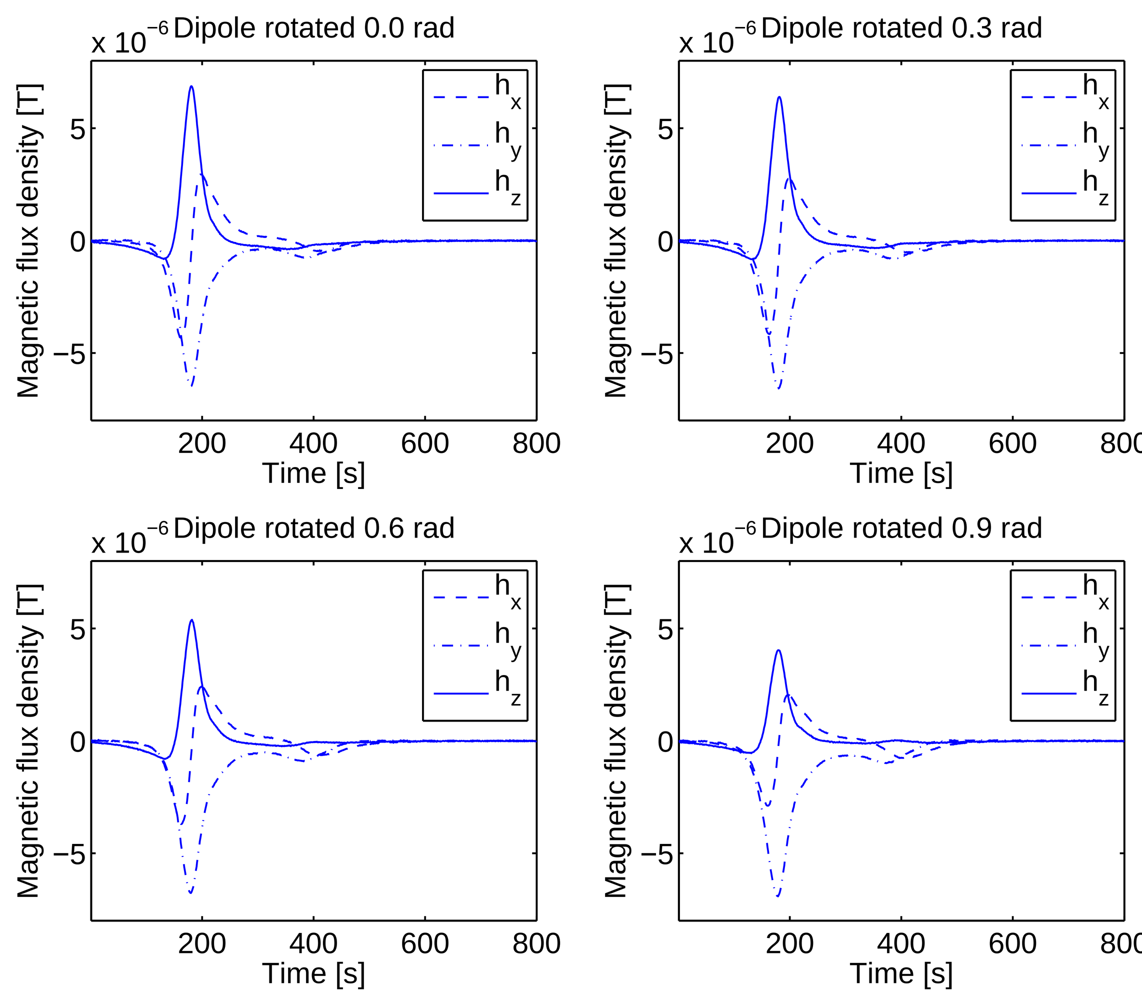
$$\begin{aligned} x_{k+T} &= x_k + \frac{2v_k}{\omega_k}\sin(\omega_k T)\cos(h_k + \frac{\omega_k T}{2}) \\ y_{k+T} &= y_k + \frac{2v_k}{\omega_k}\sin(\omega_k T)\sin(h_k + \frac{\omega_k T}{2}) \\ v_{k+T} &= v_k \\ h_{k+T} &= h_k + \omega_k T \\ \omega_{k+T} &= \omega_k \end{aligned}$$

and the sensors positions are assumed static after some time after deployment

$$s_{x_j,k+T} = s_{x_j,k}$$
$$s_{y_j,k+T} = s_{y_j,k} \qquad j = 1, \dots, M.$$

Triaxial measurements of the magnetic flux density from a single dipole are modeled as

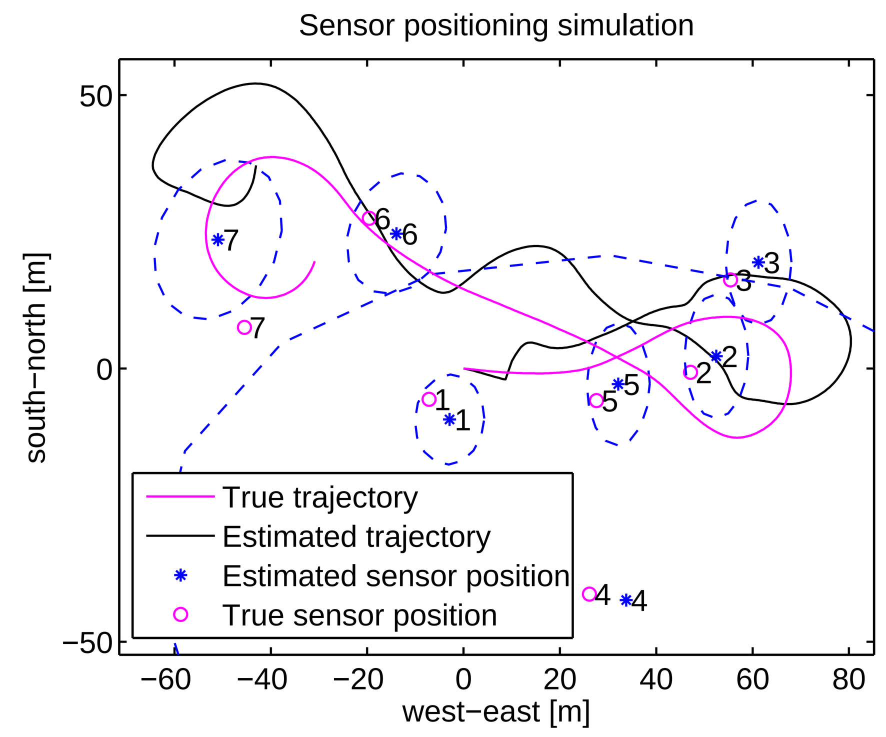
$$h(\boldsymbol{x}_k, \boldsymbol{u}_k) = \frac{\mu_0}{4\pi|\boldsymbol{r}_{j,k}|^5}(3\langle \boldsymbol{r}_{j,k}, \boldsymbol{m}(h_k)\rangle \boldsymbol{r}_{j,k} - |\boldsymbol{r}_{j,k}|^2 \boldsymbol{m}(h_k)).$$



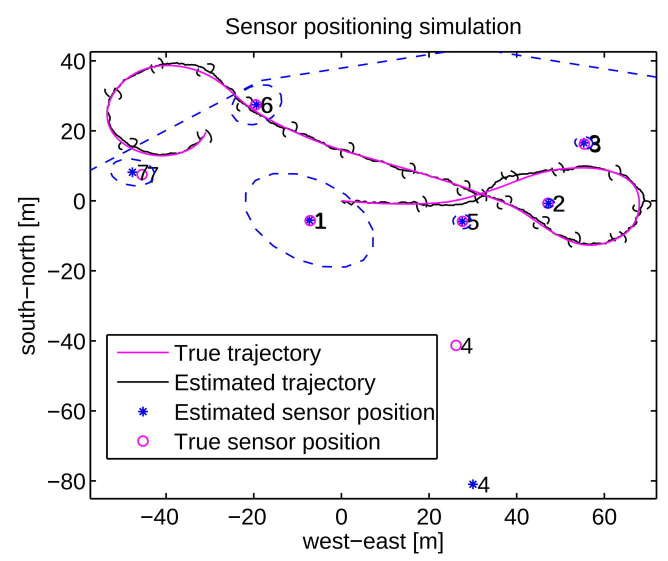
Measured magnetic flux density

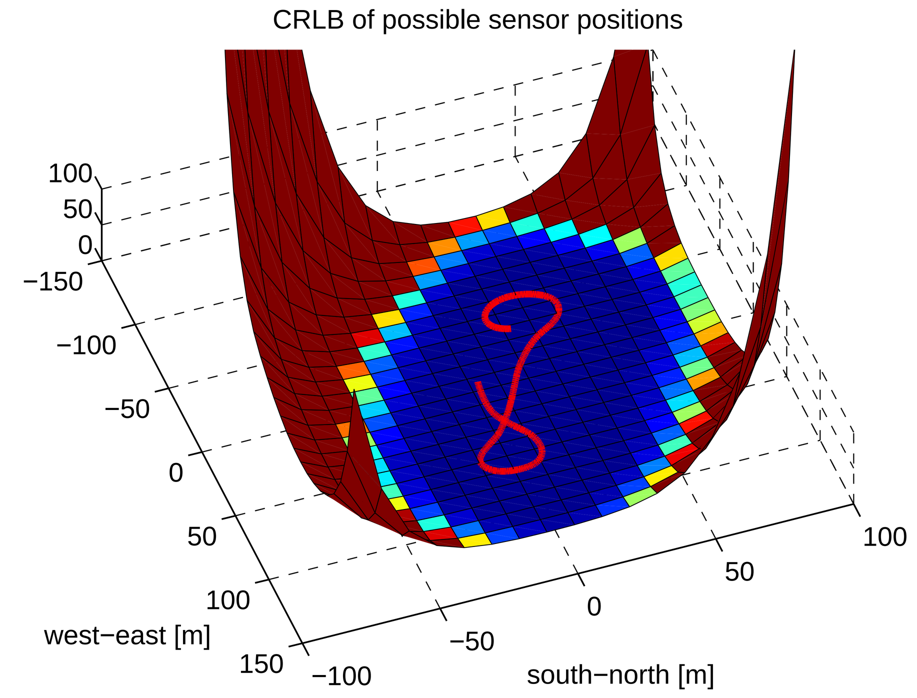
Simulation Results

The sensor positioning problem can, depending on which sensors are available, be solved in different ways. If no accurate global position of the vessel or a sensor is available during the experiment the sensors can only be positioned locally.



Estimated sensor position with 2σ uncertainty and vessel trajectory, magnetometers are used as sensors.





If global position measurements of the vessel are available throughout the trajectory, these measurements are used to improve the trajectory estimate. Given the trajectory of a vessel a lower bound on the covariance of the estimated sensor positions is the Cramér-Rao Lower Bound (CRLB).

Future Work

- Multiple dipole model of vessel
- Model Corrosion Related Magnetics (CRM)
- Evaluate on other network types and different vehicles