Estimation Problems in Distributed Systems with Marine Applications

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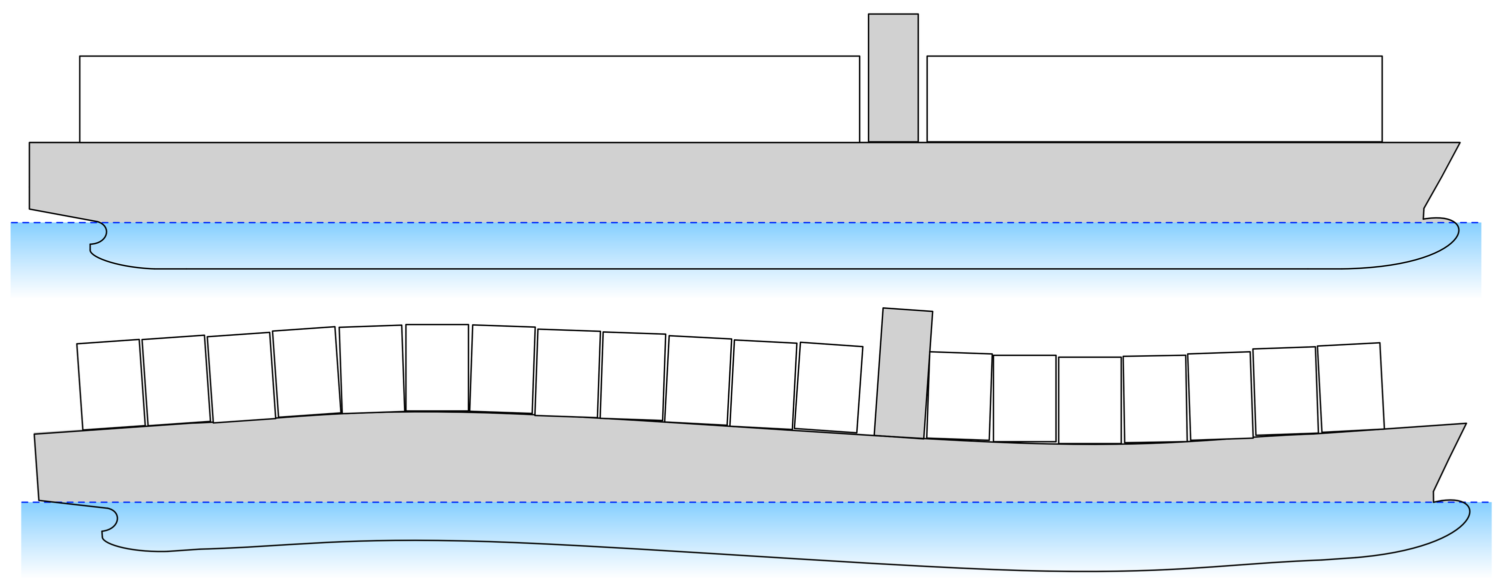
Background

For ships, dynamics will change over time. For instance, the roll dynamics of a ship is very sensitive to changes in the loading condition. Furthermore, for large vehicles, such as container ships, the sensors will move relative to each other because of the flexibility in the structure. This means that the output of the sensor is dependent not only on time, but also on the spatial position. With today's competitive markets, advanced simulations and control strategies are applied in order to, for example:

- Increase performance
- Reduce operational cost
- Improve operational safety

If the spatial and temporal variations of the ship dynamics are considered, this can be used to improve the estimation of the ship state which can improve the previous model-based solutions.



Given a flexible mechanical structure, this work focuses on identifiability and observability for parameters and states, respectively. Interesting problems that are being considered are:

- Which sensor setup is needed if we are interested in estimating a certain set of parameters or states?
- Which parameters and states can be estimated given a sensor configuration?

Examples of model-based control & supervision

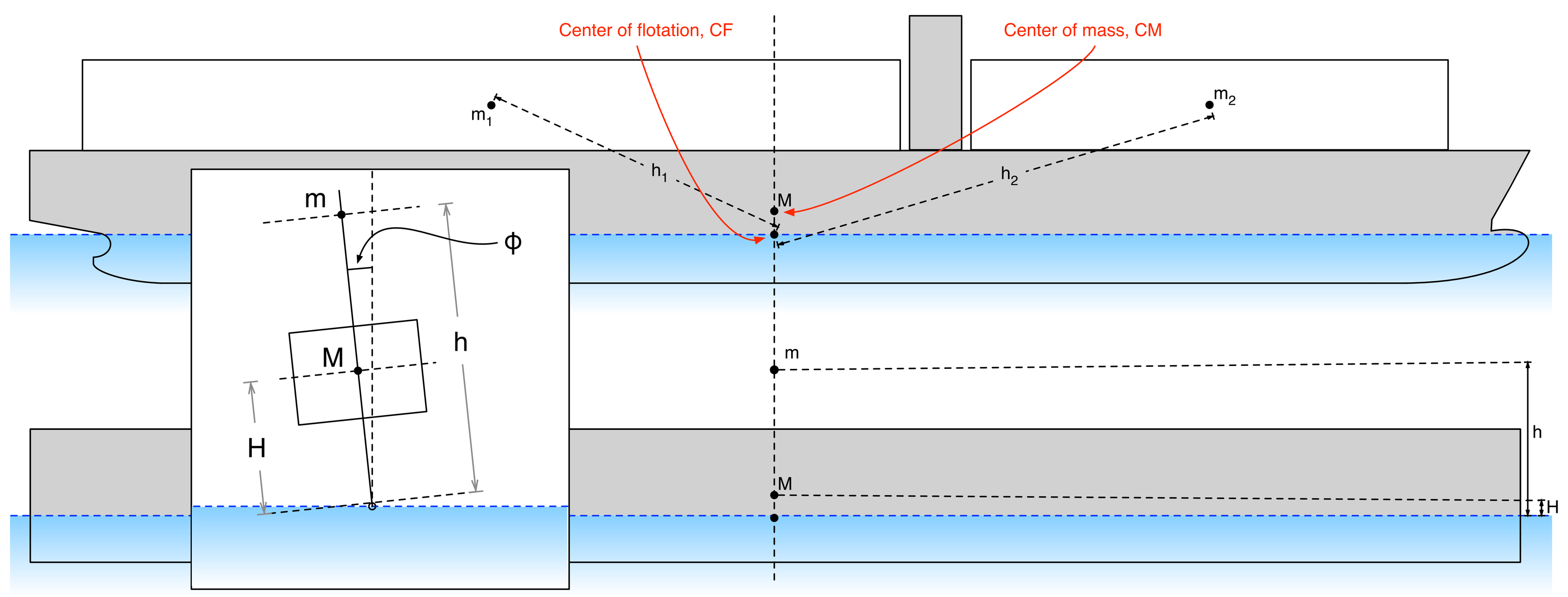
- **Trim optimization** – Minimization of fuel consumption.
- **Dynamic positioning** – Keeping the position and pose in relation to a moving or stationary point.
- **Ship response simulations** – For example used in advisory systems to aid the crew to operate the ship in a more efficient or safe way.

Initial study

To understand the difficulties with mass and *center of mass* (CM) estimation, the simplest case possible is studied. The basic idea is to collect measurements from two different load cases and then compare these to detect and estimate the change in load, using a simple and fast algorithm.

Assumptions

- The ship is geometrically symmetric around the roll axis
- The ship does a pure pitching movement
- The load is a point mass (this will give an "equivalent height" if the load has additional inertia)
- The acceleration is measured without any measurement noise



Model

The model is derived using a pure pitching model with rotation around the *center of flotation* (CF) and assuming ϕ to be small. The model is

$$(I_x + MH^2)\ddot{\phi} = MHa_y + (MHg - k)\phi - c\dot{\phi} + v \tag{1}$$

This equation can be used to derive a relation between the angular velocity measurement and the acceleration. The discretized relation is given by

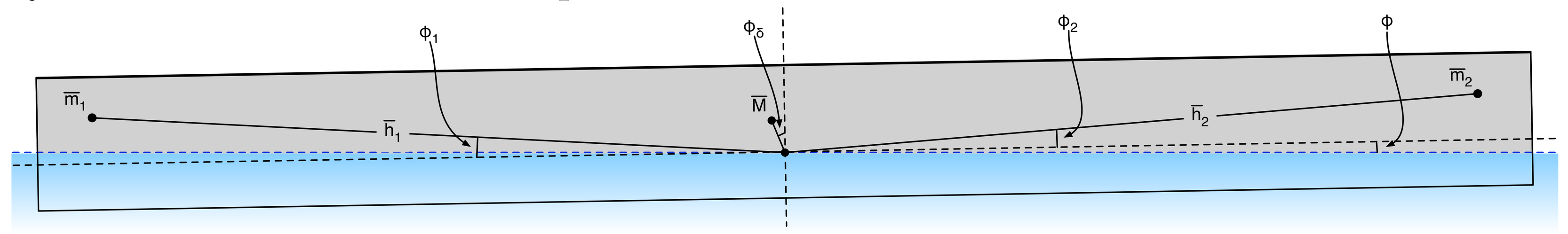
$$y_{k,i} = \frac{\theta_{3,i} + \theta_{3,i}q^{-1}}{1 + \theta_{1,i}q^{-1} + \theta_{2,i}q^{-2}}(u_{k,i} + v_{k,i}) = \frac{B_i(q)}{A_i(q)}u_{k,i} + \frac{C_i(q)}{A_i(q)}v_{k,i} \tag{2}$$

This discrete ARMAX model can be identified using an appropriate method and the resulting parameters from the two sets of measurement can be used to give a nonlinear estimator of h.

$$\hat{h} \approx T^2 \frac{(\theta_{1,l} + 2\theta_{2,l} + gT\theta_{3,l})^{-1} - (\theta_{1,n} + 2\theta_{2,n} + gT\theta_{3,n})^{-1}}{\theta_{3,n} - \theta_{3,l}} \tag{3}$$

Greybox model for load mass estimation

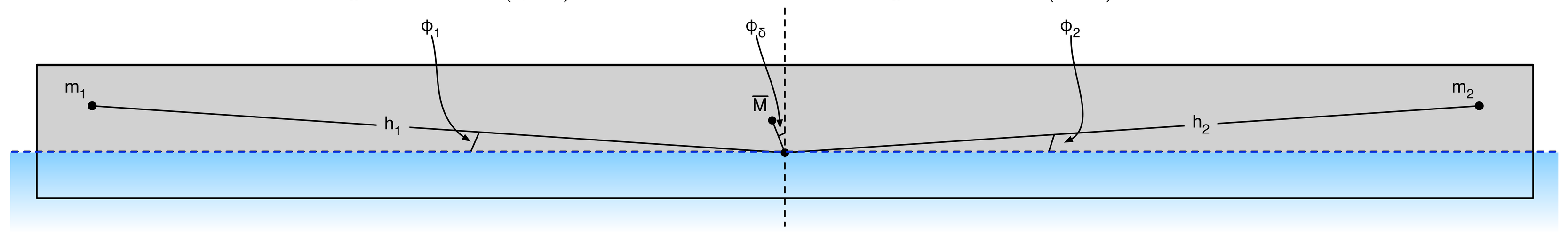
In the harbor, pressure sensors can be used to get the draught and angle of the ship. Using the ballast system which has tanks with known weight and position, the CM and the mass can be found using the fact that the system is in mechanical equilibrium.



$$\bar{M}g\bar{H}\sin(\phi + \phi_\delta) - \bar{M}_2 + \bar{M}_1 - \rho g \nabla \overline{GM}_L \sin(\phi)\cos(\phi) = 0 \tag{4}$$

$$(\bar{M} + \bar{m}_1 + \bar{m}_2)g - \rho g \nabla = 0 \tag{5}$$

where $\bar{M}_1 = \bar{m}_1 g \bar{h}_1 \cos(\bar{\phi}_1)$ and $\bar{M}_2 = \bar{m}_2 g \bar{h}_2 \cos(\bar{\phi}_2)$.



$$\bar{M}g\bar{H}\sin(\phi_\delta) - M_2 + M_1 = 0 \tag{6}$$

where $M_1 = m_1 g h_1 \cos(\phi_1)$ and $M_2 = m_2 g h_2 \cos(\phi_2)$. A suitable greybox method can now be used with

$$\dot{x}_1 = x_2 \tag{7}$$

$$\dot{x}_2 = \frac{MHu_1 + (MHg - k)x_1 - cx_2}{I_x + MH^2} \tag{8}$$

$$\dot{x}_3 = x_4 \tag{9}$$

$$\dot{x}_4 = \frac{(MH + mh)u_2 + (MHg + mhg - k)x_3 - cx_4}{I_x + MH^2 + mh^2} \tag{10}$$

$$y = [x_2\ x_4]^T \tag{11}$$

where I_x, c, k, m and h are unknowns. The model has the two acceleration measurements as inputs and the two angular velocity measurements as outputs.

Conclusions

This work focuses on sensor configuration for a mechanical system that has a flexible structure and identifiability of models for such a system. The initial study shows one possible approach to estimate the mass and the center of mass for the pure pitch rigid case.
Future work includes generalizing the approach to:

- Additional degrees of freedom
- The flexible case