Centralized State Estimation of Distributed Maritime Autonomous Surface Oceanographers

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Agenda

- Little to no research are currently devoted to maritime autonomous crafts.

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Introduction
Purpose

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- During the 2012 Fukushima accident in Japan, no measurements of the spread of radioactivity was available in the coastal zones, thus relying only on estimates.

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- During the 2012 Fukushima accident in Japan, no measurements of the spread of radioactivity was available in the coastal zones, thus relying only on estimates.
- The coastal area around Greenland has no up-to-date baymethric maps available, and with the growing interest in Greenland (both industrially and commercially) this poses a threat to the ships going in and out of the fjords.

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Empty frame

Development
AAUSHIP.01

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- Vaccumformed by DD-plast in Randers and assembled in the machine shop at Aalborg University.

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Development
AAUSHIP.01 Hull

Pictures of the ship.

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Pictures of the ship.

Development
Hardware

- Fitted with 2 x 1200W engines (totally producing around 3 HP at full thrust).
- Fitted with 6 x 3200mAh batteries (results in a mission time of around 5 hours).
- 2 counter rotating 60mm propellers.
- Inertial Measurement Unit.
- Global Positioning System.
- A 20mW 19.2 kbps radio link @470 MHz
- Arduino Mega with a custom made shield board mounted.
- Retrofitted with a hydrofoil to reduce the wake and pitch of the ship.

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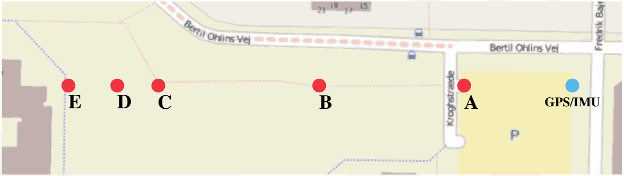
The designed protocol is given as:

Development
Distributed Control

As the protocol takes care of packet verification, the channel can be estimated by a bernoulli variable, with outcomes of a received package either a succes or a failure.



The measurements make for the following distribution of the GPS with a distance of 189 metres:

$$\lambda_{\text{gps,E}} = \begin{cases} 0.8643 & \text{for } \lambda = 1 \\ 0.1357 & \text{for } \lambda = 0 \end{cases} \tag{1}$$

And for the IMU also at 189 metres.

$$\lambda_{\text{imu,E}} = \begin{cases} 0.8689 & \text{for } \lambda = 1 \\ 0.1311 & \text{for } \lambda = 0 \end{cases} \tag{2}$$

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Development
Kalman Filter

The derivation of the Kalman filter is based around the position being equal to the last position, the change due to velocity and the change due to acceleration:

$$x[n] = x[n-1] + \dot{x}[n-1] \cdot ts + \ddot{x}[n-1] \cdot \frac{ts^2}{2} \tag{3}$$

$$\dot{x}[n] = \dot{x}[n-1] + \ddot{x}[n-1] \cdot ts \tag{4}$$

$$\ddot{x}[n] = -\beta \cdot \dot{x}[n-1] + \ddot{x}[n] \tag{5}$$

Which can be put on matrix form:

$$\begin{bmatrix} x[n] \\ \dot{x}[n] \\ \ddot{x}[n] \end{bmatrix} = \begin{bmatrix} 1 & ts & \frac{ts^2}{2} \\ 0 & 1 & ts \\ 0 & -\beta & 0 \end{bmatrix} \begin{bmatrix} x[n-1] \\ \dot{x}[n-1] \\ \ddot{x}[n-1] \end{bmatrix} \tag{6}$$

This goes for the y-axis and the rotation about the z-axis as well.

The thrust generated by the engines are modeled using equation 7 which is a function of the RPS of the propellers:

$$F_{\text{stbd,port}} = \rho \cdot K_{\text{T}} \cdot D^4 \cdot |n_{\text{stbd,port}}| \cdot n_{\text{stbd,port}} \tag{7}$$

As the engines are mounted on the starboard and port side the total thrust forward is a sum of the two engines $F_{\text{total}} = F_{\text{stbd.}} + F_{\text{port}}$ and the difference between them generates a torque around the centre of rotation

$$\tau = (F_{\text{stbd.}} - F_{\text{port}}) \cdot l \tag{8}$$

Where l denotes the distance from the centre of rotation to the top of the propellers.

Modeling
Thrust/Torque Model

Using Newtons 2nd law, the force and torque can be converted to an acceleration and an angular acceleration:

$$\ddot{x} = \frac{F_{\text{total}}}{m} \quad \ddot{\theta} = \frac{\tau}{I} \tag{9}$$

Thus allowing for the input $\mathbf{u}$ to the system to be given as:

$$\mathbf{u} = \begin{bmatrix} F_{\text{total}} & \tau \end{bmatrix}^T \tag{10}$$

And the $\mathbf{B}$ is given as the conversion from the force and torque to an acceleration and an angular acceleration respectively.

$$\mathbf{B} = \begin{bmatrix} \frac{1}{m} & \frac{1}{I} \end{bmatrix}^T \tag{11}$$

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The Dynamics of the system are given by the drag the ship experiences when moving through the water. The drag is given as:

$$F_{\text{Drag}}(\dot{x}, \dot{y}) = \frac{1}{2} \cdot \rho \cdot C_{\text{D}} \cdot \dot{x}^2 \cdot A \tag{12}$$

The formula changes when the ship is turning, as the drag then is converted into a torque - which is defined as:

$$\tau_{\text{Drag}}(\omega) = \frac{1}{2} \cdot \rho \cdot C_{\text{D}} \cdot (d \cdot (r_f^4 + r_b^4)) \cdot \omega^2 \tag{13}$$

The above can be put an matrix form as:

$$\mathbf{Ax} = \begin{bmatrix} -\beta_X & 0 & 0 \\ 0 & -\beta_Y & 0 \\ 0 & 0 & -\beta_\omega \end{bmatrix} \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} \tag{14}$$

As the motion in the y-direction is uncontrollable, and the thing to be controlled is the velocity and the angle, the combined system becomes:

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}\mathbf{u} \tag{15}$$

$$\begin{bmatrix} \ddot{x} \\ \dot{\theta} \\ \dot{\omega} \end{bmatrix} = \begin{bmatrix} \frac{-\beta_x}{m} & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & \frac{-\beta_\omega}{I} \end{bmatrix} \begin{bmatrix} \dot{x} \\ \theta \\ \omega \end{bmatrix} + \begin{bmatrix} \frac{1}{m} & 0 \\ 0 & 0 \\ 0 & \frac{1}{I} \end{bmatrix} \begin{bmatrix} F_{\text{total}} \\ \tau \end{bmatrix} \tag{16}$$

And the output of the system $\mathbf{y}$ becomes:

$$\mathbf{y} = \mathbf{C}\mathbf{x} + D\mathbf{u} \tag{17}$$

$$\begin{bmatrix} \dot{x} \\ \theta \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \dot{x} \\ \theta \\ \omega \end{bmatrix} + \mathbf{0} \begin{bmatrix} F_{\text{total}} \\ \tau \end{bmatrix} \tag{18}$$

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- Optimal Control
- Reference Tracking

Empty Frame

Test Results
Kalman Filter

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