Centralized State Estimation of Distributed Maritime Autonomous Surface Oceanographers

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Agenda



Introduction

Development AAUSHIP.01 Development

Modeling Engine model Ship Model

Control State Space Controller Implementation

Test Results Kalman Filter Open water tests

Centralized State Estimation of Distributed Maritime Autonomous Surface Oceanographers

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Engine model

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Introduction

Purpose



Centralized State
Estimation
of Distributed
Maritime Autonomous
Surface
Oceanographers

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

) Introduction

Development AAUSHIP.01 Development

Development Modeling

Engine model Ship Model

ontrol

State Space Controller Implementation

Test Results Kalman Filter

Open water tests

Dept. of Electronic Systems, Aalborg University, Denmark

Introduction

Purpose



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

Centralized State
Estimation
of Distributed
Maritime Autonomous
Surface
Oceanographers

12gr730

) Introduction

, introduction

AAUSHIP.01

Modeling

Engine model

Ship Model

ntrol

State Space Controller mplementation

Test Results

Kalman Filter

Introduction

Purpose



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

- 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.

Centralized State
Estimation
of Distributed
Maritime Autonomous
Surface
Oceanographers

12gr730

Introduction

Development

Development

Vlodeling Engine model

Ship Model

ontrol

Implementation

Kalman Filter

Introduction Problem Description



Centralized State Estimation of Distributed Maritime Autonomous Surface Oceanographers

12gr730

Introduction

Engine model Ship Model

Dept. of Electronic Systems. Aalborg University, Denmark

20

Empty frame

Development AAUSHIP.01



▶ The ship is designed as a non-planing deplacement craft (eg. like freight ships).

Centralized State Estimation of Distributed Maritime Autonomous Surface Oceanographers

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AAUSHIP.01

Engine model

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Development AAUSHIP.01



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AAUSHIP.01

Engine model

▶ The ship is designed as a non-planing deplacement craft (eg. like freight ships).

Developed using rapid prototyping techniques.

Development



► The ship is designed as a non-planing deplacement craft (eg. like freight ships).

- ▶ Developed using rapid prototyping techniques.
- ► Developed in RhinocerosTMusing a lofting techniques.

Centralized State
Estimation
of Distributed
Maritime Autonomous
Surface
Oceanographers

12gr730

ntroduction

AAUSHIP.01

Developmen

Modeling

Engine model Ship Model

Ship Model
Control

itate Space Contro

Implementation
Test Posults

Kalman Filter

Development AAUSHIP 01



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AAUSHIP.01

Engine model

Development



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- ▶ Examined and the process iterated.

Centralized State
Estimation
of Distributed
Maritime Autonomous
Surface
Oceanographers

12gr730

itroduction

AAUSHIP.01

Developmen

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Modeling Engine model

Ship Model

Control State Space Controll

Implementation

Kalman Filter

Development



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

Centralized State
Estimation
of Distributed
Maritime Autonomous
Surface
Oceanographers

12gr730 troduction

itroduction

AAUSHIP.01

Developmen

Modeling

Engine model

Control
State Space Controlle

State Space Controller Implementation

Test Results Kalman Filter

Development AAUSHIP.01 Hull

Pictures of the ship.



Centralized State
Estimation
of Distributed
Maritime Autonomous
Surface
Oceanographers

12gr730

Introduction

Development

AAUSHIP.01

Development

Engine model
Ship Model

ontrol

State Space Controller Implementation

Test Results Kalman Filter

Open water tests

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Denmark

Development AAUSHIP.01 Hull



Centralized State
Estimation
of Distributed
Maritime Autonomous
Surface
Oceanographers

12gr730

Introduction

AAUSHIP.01

Development

Engine model

Ship Model

State Space Controller Implementation

Test Results
Kalman Filter

Open water tests

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Pictures of the ship.

Development



► 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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Estimation
of Distributed
Maritime Autonomous
Surface
Oceanographers
12gr730

Introductio

Development

AAUSHIP.01 Development

Madalla

Modeling Engine model

Ship Model

Control

State Space Controller Implementation

Kalman Filter

Open water tests

Development Protocol



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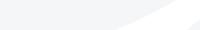
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Development

Engine model

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20



The designed protocol is given as:

Development

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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:

$$\lambda_{\mathsf{gps},\mathsf{E}} = \left\{ \begin{array}{ll} 0.8643 & \text{for } \lambda = 1\\ 0.1357 & \text{for } \lambda = 0 \end{array} \right. \tag{1}$$

And for the IMU also at 189 metres.

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

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Estimation
of Distributed
Maritime Autonomous
Surface
Oceanographers

12gr730

Introduction

Danielania

AAUSHIP.01

Development

Modeling Engine model

Ship Model

Control
State Space Controll

Implementation

Kalman Filter

Open water tests

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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:

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

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

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

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Estimation
of Distributed
Maritime Autonomous
Surface
Oceanographers
12gr730

ntroductio

Development

Development

Modeling

Engine model Ship Model

State Space Controlle

Implementation

Kalman Filter

Modeling Thrust/Torque Model



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

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

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

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

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

Centralized State
Estimation
of Distributed
Maritime Autonomous
Surface
Oceanographers

12gr730

troduction

Development

Developmen

Modeling

Ship Model

hip Model

ontrol

State Space Controlle Implementation

est Results

Kalman Filter

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 **B** is given as the conversion from the force and torque to an acceleration and an angular acceleration respectively.

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

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Engine model Ship Model

Modeling System Dynamics



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

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

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

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

The above can be put an matrix form as:

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

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Modeling System Dynamics



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:

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

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

And the output of the system **y** becomes:

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

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

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Control State Space Control

► Optimal Control ► Reference Tracking

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Introduction

Engine model

Ship Model



Kalman Filter

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Control Implementation

Empty Frame



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12gr730

Introduction

AAUSHIP.01

Modeling Engine model

Ship Model

Implementation

Open water tests

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Test Results Kalman Filter



Centralized State
Estimation
of Distributed
Maritime Autonomous
Surface
Oceanographers

12gr730

Introduction

Development

AAUSHIP.01 Development

Modeling

Engine model Ship Model

ontrol

State Space Controller Implementation

Test Resi

B) Kalman Filter

20

Open water tests

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Empty Frame

Test Results Maiden Voyage



Centralized State Estimation of Distributed Maritime Autonomous Surface Oceanographers

12gr730

Introduction

AAUSHIP.01

Modeling

Engine model Ship Model

Open water tests

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20

Empty Frame

Test Results Autonomous Sailing



Centralized State Estimation of Distributed Maritime Autonomous Surface Oceanographers

12gr730

Introduction

AAUSHIP.01

Engine model

Ship Model

Open water tests

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20

Empty Frame