## Centralized State Estimation of Distributed Maritime Autonomous Surface Oceanographers

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## Agenda



#### Introduction

Development AAUSHIP.01

Development

Modeling

Ship Model Engine model

Control

State Space Controller Implementation

Test Results Maiden Voyage

Test Results Maiden Voyage

Centralized State Estimation of Distributed Maritime Autonomous Surface Oceanographers

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Ship Model

Engine model

Maiden Voyage

### Introduction

Purpose



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

Centralized State Estimation of Distributed Maritime Autonomous Surface Oceanographers

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#### Introduction

Engine model

Maiden Voyage

#### 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.

Centralized State Estimation of Distributed Maritime Autonomous Surface Oceanographers

12gr730

Introduction

Ship Model

Engine model

Maiden Voyage

### 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

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Introduction

Ship Model

Engine model

Maiden Voyage

#### Introduction Problem Description



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#### Introduction

Ship Model

Engine model

Maiden Voyage

Maiden Voyage



# 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

12gr730

ntroduction

AAUSHIP.01

Development

deling

Ship Model Engine model

ontrol

State Space Controller Implementation

Test Results Maiden Voyage

Maiden Voyage

# Development AAUSHIP.01



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Centralized State Estimation of Distributed Maritime Autonomous Surface Oceanographers

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AAUSHIP.01

Engine model

Maiden Voyage

# Development



- ► The ship is designed as a non-planing deplacement craft (eg. like freight ships).
- ▶ Developed using rapid prototyping techniques.
- ► Developed in Rhinoceros<sup>TM</sup>using a lofting techniques.

Centralized State
Estimation
of Distributed
Maritime Autonomous
Surface
Oceanographers

12gr730

itroduction

AAUSHIP.01

Developmen

Modeling Ship Model

Ship Model Engine model

Control State Space Controller

Implementation

Maiden Voyage

Maiden Voyage

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Centralized State Estimation of Distributed Maritime Autonomous Surface Oceanographers

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AAUSHIP.01

Ship Model

Engine model

Maiden Voyage

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Centralized State
Estimation
of Distributed
Maritime Autonomous
Surface
Oceanographers

12gr730

itroduction

AAUSHIP.01

Developmen

Modeling

Ship Model

Engine model

State Space Controller

Test Results

Maiden Voyage

Maiden Voyage

# Development



Estimation of Distributed Maritime Autonomous Surface Oceanographers 12gr730

Centralized State

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ntroduction

AAUSHIP.01

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Modeling

Ship Model Engine model

Control State Space Control

Implementation

Test Results Maiden Voyage

Asiden Voyage

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

# Development AAUSHIP.01 Hull



Centralized State
Estimation
of Distributed
Maritime Autonomous
Surface
Oceanographers

12gr730

Introduction

AAUSHIP.01

Development

deling

Ship Model Engine model

ntrol

State Space Controller Implementation

Test Results Maiden Voyage

Maiden Voyage

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Pictures of the ship.

# Development AAUSHIP.01 Hull

Pictures of the ship.



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Introduction

AAUSHIP.01

Ship Model Engine model

Maiden Voyage

Maiden Voyage

#### 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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Development

Ship Model

Engine model

Maiden Voyage

# Development Protocol

The designed protocol is given as:



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Introduction

Development

Engine model

Maiden Voyage

Maiden Voyage

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19



# Development



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)

Centralized State
Estimation
of Distributed
Maritime Autonomous
Surface
Oceanographers

12gr730

Introduction

AAUGUDAI

AAUSHIP.01 Development

Modeling Ship Model

Ship Model Engine model

State Space Controlle

Test Results

Maiden Voyage

Test Results

∕laiden Voyage

#### 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

evelopment)

1 Development

Modeling Ship Model

Ship Model Engine model

State Space Controlle

Implementation

Maiden Voyage

Test Results

laiden Voyage

# $\underset{\mathsf{Ship}\ \mathsf{Model}}{\mathsf{Modeling}}$



Centralized State Estimation of Distributed Maritime Autonomous Surface Oceanographers

12gr730

Introduction

Ship Model

Engine model

Maiden Voyage

Maiden Voyage

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19



# 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

Introduction

evelopment

AAUSHIP.01

Modeling

Ship Model

Engine model

Engine model

Control
State Space Control

State Space Controller Implementation

lest Results Maiden Voyage

T .. D ... Iv

Maiden Voyage

## 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.

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

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Ship Model

Engine model

Maiden Voyage

# $\underset{\mathsf{Thrust}/\mathsf{Torque}\ \mathsf{Model}}{\mathsf{Modeling}}$

**Empty Frame** 



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Introduction

Engine model

Maiden Voyage

Maiden Voyage



### Control State Space Controller

**Empty Frame** 



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Introduction

AAUSHIP.01

Ship Model

Engine model

State Space Controller

Maiden Voyage

Maiden Voyage

# Control Implementation

**Empty Frame** 



Centralized State
Estimation
of Distributed
Maritime Autonomous
Surface
Oceanographers

12gr730

Introduction

Development AAUSHIP.01

Developmen

Ship Model Engine model

ntrol

ontrol

Implementation

Implementation

Fort Doculte

Maiden Voyage

Test Result

Maiden Voyage

#### Test Results Maiden Voyage

**Empty Frame** 



Centralized State Estimation of Distributed Maritime Autonomous Surface Oceanographers

12gr730

Introduction

AAUSHIP.01

Ship Model Engine model

Maiden Voyage

Maiden Voyage

#### Test Results Autonomous Sailing

**Empty Frame** 



Centralized State Estimation of Distributed Maritime Autonomous Surface Oceanographers

12gr730

Introduction

AAUSHIP.01

Ship Model Engine model

Maiden Voyage

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19