Master thesis

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December 2024

Contents

1 Abstract

2 Introduction

Container ships are growing in size at a pace that outstrips the development of supporting infrastructure. The primary driver of this increase in size is economic efficiency, as larger ships reduce per-container transportation costs. One potential alternative to these massive vessels is a system based on small, modular robotics.

Transitioning from large containerships to a modular system presents significant challenges that must be addressed. A key challenge, and likely the greatest barrier to widespread adoption, is the reduction in sailing efficiency. In a modular system, the combined frontal area of multiple small vessels is larger than that of a single large ship, leading to increased hydrodynamic drag.

Another major challenge in modular shipping is the dynamic nature of the maritime environment. Unlike solid ground, water is constantly shifting, making precise alignment and connection of modules difficult. The motion of waves, currents, and wind introduces continuous relative movement between vessels. Additionally, as one module approaches another, the hydrodynamic wake it generates can create forces that push the ships apart, further complicating the docking and attachment process.

In this project, we will quantify the efficiency loss of a modular swarm system compared to traditional large containerships. To achieve this, we will develop a mathematical model to scale modular systems to the size of current container vessels and validate our model through small-scale real-world experiments using a custom-designed boat module. Additionally, we will explore solutions to the challenge of reliably attaching and stabilizing modular boats in dynamic maritime conditions.

3 Related Work

3.1 Modular robotics

3.1.1 Concept of modularity

- Slot Architecture
- Bus Architecture
- Sectional Architecture

3.1.2 Definition and Classification of Modular Robots

The three levels are:

- *Reconfigurable* - Modules can be connected in several different ways to form different robots in terms of size and shape.
- *Dynamically reconfigurable* - Modules can be disconnected and connected while the robot is active.
- *Self reconfigurable* - The robot can change the way modules are connected by itself.

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3.2 Effeciency

3.2.1 Different effeciencies based on position

3.3 Global and relative positioning

3.4 ??Working in water??

4 Our work

4.1 Efficiency

4.1.1 Experimental setup

To validate our mathematical model, we conducted real-world experiments using our custom-designed boat module.

1. Find the given formation that needs to be tested.
2. Calculate the expected energy usage (Wh) for this formation using the mathematical model
3. Measure the amperage (or state of charge) of the batteries before starting.
4. Attach the custom-designed boat modules in the same configuration.
5. Sail the attached boats for a given distance
6. If we can only measure amperage: At regular intervals, measure the amperage of the batteries (including voltage if possible)
7. Use the measured current to calculate energy consumption in Wh using the formula:
$$\text{Energy Used (Wh)} = \sum (V \times I \times \Delta t) \tag{1}$$
where:
   - V is the voltage (V),
   - I is the current (A),
   - Δt is the time step in hours (h).

To improve accuracy, we repeated steps 3–7 five times and calculated the average energy consumption.

4.1.2 Experimental Results

The mathematical model showed that we would use X Wh for sailing X meters in the GIVEN configuration. In our real-world experiments, we saw the energy usage was X Wh. All experiment results can be found in A

5 Discussion

6 Future Work

7 Conclusion

A Experiment results