Master thesis

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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

Often modularity comes in complex system and is dividing it into pieces in order to better understand the simpler elements and parallelize the design efforts. [3] define modular to be: "The robot is built from several physically independent units that encapsulate some of the complexity of their functionality" [2] Describe 3 concepts of modularity robotics, by mean of different architecture types.

- Slot Architecture
- Bus Architecture
- Sectional Architecture

Slut architecture Each of the of the interfaces between the components is of different type from the others, that the various components in the product can not be interchanged.

Bus architecture There is a common bus to which the other physicals can connect via the same type of interface.

sectional architecture All interfaces are the same type and there is no single element to which all the other components attach, there is no base component.

If a robot system adopts a bus- and sectional-modularity design approach for its internal structure and external configuration, it can be called a modular robot. Users can reconfigure the compartmentalization and interchange functional modules with some levels of efforts.

Our work is based on the modular principles. Therefore will we in the next section describe the different types of modular robots.

3.1.2 Definition and Classification of Modular Robots

[2] define 3 types 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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This is the overview of the three types, we will now describe the different types in greater details.

3.1.3 reconfigurable robots

The background of modular manipulation comes in the form of automatic tool changers also called quick-change end-effectors. These are tools that can e attach to the end of a robot arm, like milling machines. which enable the machines to drill holes of different size.

The problem with reconfigurable robots, is that the modular manipulator can be optimal at the component level, but not at the system level. task-driven robot configuration optimization becomes necessary to establish locally optimal performance for the overall robotics system. [2].

3.2 Self-reconfigurable modular

Grew out of the concept of self-evolution and self-configuration of biological cells. Self-reconfigurable robots can rearrange their own topology. These system are characterized by many identical modules that can be rearranged into a variations of shapes and configurations and by being highly scalable. These systems have 3 promises:

1. Low cost
2. highly robustness
3. Very versatile from the ability to reconfigure and adapt to changing situations

There are 3 types of self-reconfigurable modular robots which is:

1. chain
2. lattice
3. mobile

Chain types robots are reconfigure by using chains of modules that form and break loops. They are often well suited for work the environment, because articulated limbs. Several studies has been publish about chain like robots examples are [1] and [4] and later improved version in[5]

Lattice The lattice systems hace modules have nominal positions sittings on a regular lattice and tend to be better at self-reconfiguration as moving to neighboring lattice positions makes colliision checking easy.

Mobile

4 Multirobot system

4.1 Swarm robotics

4.2 Effeciency

4.2.1 Different effeciencies based on position

4.3 Global and relative positioning

When dealing with cargo, people want to know where there stuff is located, both for a sense of security but also to estimate arrival times and so on. For this, we need a global positioning system that can place our modules in the world. Since our boats are modular, we also need a way to do relative positioning so they can know where they are in relation to each other, to not crash, and to be able to assemble correctly.

4.4 ??Working in water??

5 Our work

5.1 Efficiency

5.1.1 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.

5.1.2 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

6 Discussion

7 Future Work

8 Conclusion

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A Experiment results