Research on the Influence of the Deformable Trimaran Expansion and Contraction on the Speed and Stability of the Ship in Wave Waters Based on PID Algorithm

Minzhe Yang

Culver Academies, Culver, Indiana, USA
Minzhe.Yang@culver.org

Abstract: *This article studied on whether transforming from a mono-hull vessel to a trimaran surface vessel increases the stability of the vessel. Based on testing results from different levels of waves, a system of algorithm was developed to maximize the speed and stability of the vessel. Automation of the width of the tamarin with respect to the strength of the wave was made possible with a program in Arduino. The data for this particular trimaran vessel have significant value to the optimization of speed and stability and can be generalized for other in trimaran vessels. The application of transformable trimaran can save energy and protect the environment.*

Keywords: *Trimaran vessel, Mono-hull, Transformable, Arduino, Sampling, Automation, Algorithm*

1. Introduction

In shipbuilding, water resistance and stability are the two most crucial factors. But they are always conflicting each other. A thinner hull provides fewer resistance, thus a higher speed; a thicker hull provides greater stability but causes higher resistance at the same time. In water areas with medium and large waves, the balance between stability and water resistance becomes the priority.

When the task of a vessel is water sampling or surveillance, the stability of the vessel needs to be seriously considered. There are previous studies on trimaran vessel, which is multihull boat that comprises a main hull and two smaller outrigger hulls or amas. Numerous advantages are demonstrated by the trimaran vessel. First, the slender main hull reduces the wave resistance for the vessel, while the two lateral hulls provide stability. This solves the problem regarding resistance and stability. Second, the wide deck allows a greater capacity for equipment and storage. Third, unmanned trimaran vessel is achievable. This reduces human risks and allows the vessel to reach places that humans cannot. Some potential implements of the trimaran vessel are water sampling, surveillance, animal protection, and military usage[1-2].

Figure 1: A trimaran vessel with a thin main hull and two lateral hulls

The transformable trimaran has several advantages in protecting the environment and save energy. First of all, it can conduct water sampling to detect water containment and ensure a safe and healthy

ecosystem. By sampling the water, we can measure the concentration of different chemicals that can be a potential threat. Second, it can help researchers and zoologists to study the population and habit of animals in order to protect them and balance the ecosystem. More importantly, transformable trimaran is environmentally friendly. By optimizing the balance between speed and stability, it can save energy. When the water surface is relatively stable, the vessel will contract the lateral hulls and decrease water resistance, which provides a greater speed at the same horsepower. As is shown in Fig.1.

2. System Overview

The vessel was designed in a way to minimize water resistance. Since vessel was built from PMMA boards, we could not avoid corners and edges. We made tilted bow to decrease the areas that directly touch water. According to basic formula for resistance which the ship's hull surface experiences by moving against a viscous fluid, resistance = resistance coefficient x pressure x surface area. Resistance coefficient is determined by the viscosity of the fluid. In this case, assuming the pressure and resistance coefficient are constant, the water resistance on the vessel is directly proportional to the area of vessel that are in contact with the water. Thus, cutting the PMMA boards into a slide to decrease the surface area of the bottom of the vessel lowers the water resistance. The expansion and condensation of the transformable vessel also influence water resistance. By opening the lateral hulls, greater areas of the vessel are in touch with the water, which generates greater water resistance. Those water resistance cancels out some of the forward velocity and slow down the vessel. If we condense the vessel into a mono-hull, fewer parts of the vessel would contact the water and the vessel could move faster.   As is shown in Fig.2.
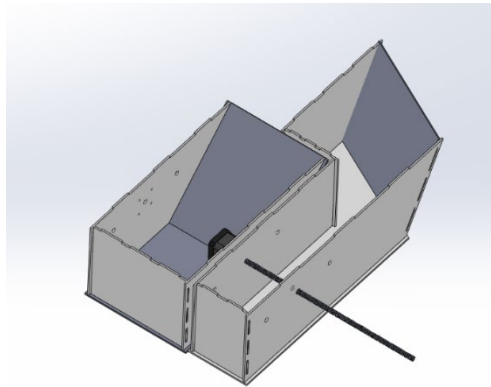

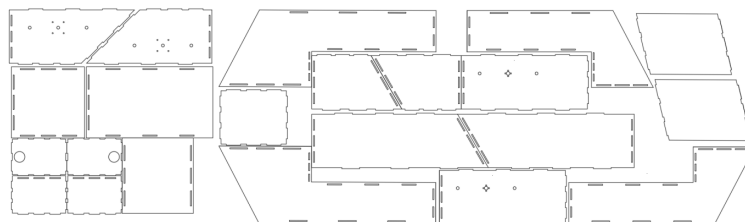
Figure 2: Vessel design

3. Design Overview

Figure 3: CAD drawing

The vessel is separated into three sections, the right lateral hull, the middle hull, and the left lateral hull. The framework of the vessel is made up of PMMA boards. We used SolidWorks and AutoCAD to design the boards into desired shapes. We cut the PMMA boards by laser machine according to the blueprint. Then, the PMMA boards were assembled together, and areas of conjunction were waterproofed by super glue. We had to make grooves and bulges that are the same size on the edges of the boards. They We made one hole on the back of each lateral vessel to allow the brushless direct current motor (propeller) to pass through. They were waterproofed after the motors were installed in the back holes. Besides, there are three more holes on each side of the lateral hulls that is closer to the middle hull[3-5].

They were not waterproof and located above the water surface to avoid leakage. If they were glued, the lateral hulls could not slide on the smooth screw anymore. As is shown in Fig.3.

4. Hardware Overview

Two stepping motor in the middle hull control the opening and closing of the two lateral hulls. One lead screw from the stepping motor and two smooth screws were connected from the middle hull to each lateral hulls. The two smooth screws made sure the lateral hulls were balanced when expanding or condensing. Two screws were attached to the end of each side of the lead screw to the lateral hulls. This allows the stepping to push and pull the lateral hulls sideways in order to expand and condense the vessel. The two stepping motors were connected to a driver module that is used to regulate the current entering into the motors.   As is shown in Fig.4.

Figure 4: Transform part

The brushless direct current motors on the bottom of each lateral hull have their own driver module and were powered from the motherboard. Then, the driver module was connected to the motherboard which was also connected to a Bluetooth module, a battery, a switch, and a gyro. The Bluetooth module allowed me to control the motherboard on my phone and better maneuver the vessel. The gyro measured the acceleration and angular velocity of the vessel to calculate the angle of tilt. To elaborate, it measures how tilt the vessel is. It was set flat on the middle hull so that the default value is zero. A program that was made on Arduino will be imported into the motherboard and provide all the instructions and algorithm for the vessel. As is shown in Fig.5.
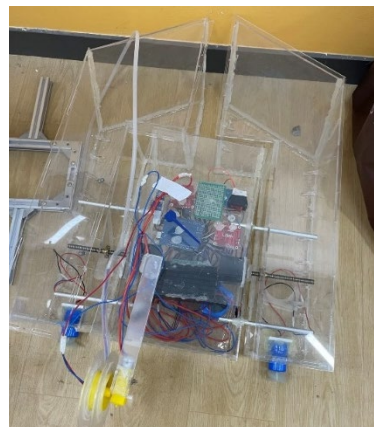
Figure 5: Overall structure

We created a small water sampling machine that is attached at the end of the middle hull. It was controlled by a brushless direct current motor. A tube that was used to extract water was attached to the motor and passed through a wheel. By activating the motor, the tube could be lowered into the water or coiled around the wheel. There was a pump at the end of the tube. It sucks water and transport them into a container in the middle vessel[6-7].   We also designed a machine that is connected to the edge of the pool to stimulate waves. It had a wide and flat surface close to the water. It could produce waves by moving up and down on the surface. The machine can be adjusted to produce different sizes of waves.
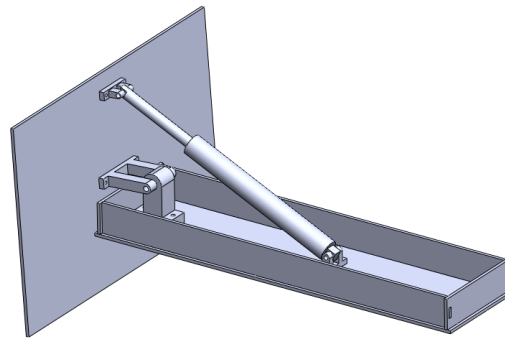
As is shown in Fig.6.

Figure 6: Wave machine

5. Program

5.1. Overall control flow

This project sends signals through the mobile phone Bluetooth, communicates with the hull Arduino UNO through the Bluetooth serial port, and judges the corresponding action by the received characters. As is shown in Fig.7.
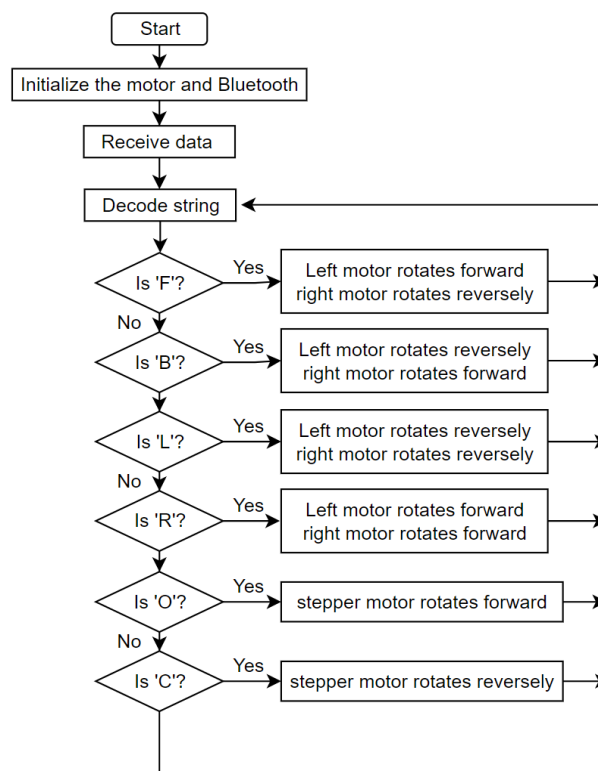

Figure 7: Program flow chart

5.2. Stability System Control

In this project, in order to enable the sampling boat to obtain high traffic efficiency and maintain good stability, the sensor carried by the hull is used to detect the degree of wind and waves on the water surface, and the extension state of the hull is adjusted according to the size of the wind and waves on the water surface during the hull traveling. The PID is used to control the extension width of the entire hull, the attitude data collected by the MPU6050 is used as the feedback input, and the screw motor that controls

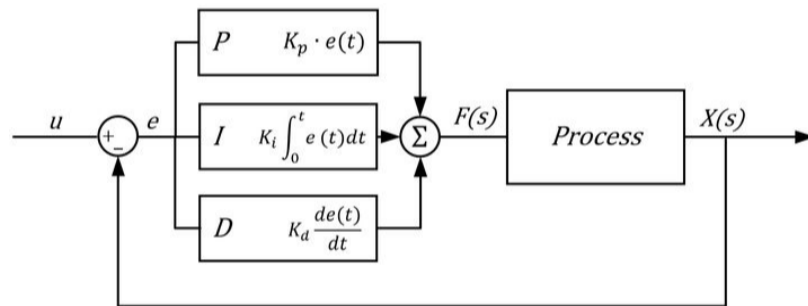the extension of the hull is used as the output. As is shown in Fig.8 and Fig.9.

Figure 8: PID control process

Since the controlled object is a stepping motor, the incremental control method is adopted, and the sampling period is set to 50ms.

$$\Delta u(n) = u(n) - u(n-1)$$

$$= K_P\left[e(n) - e(n-1)\right] + K_P\frac{T}{T_I}e(n) + K_P\frac{T_D}{T}\left[e(n) - 2e(n-1) + e(n-2)\right]$$

Figure 9: PID control process

6. Experiment

The purpose of this experiment is to determine whether an expanded trimaran can provide stability at the presence of measurable waves. We used a machine to stimulate different sizes of waves that might be encountered in cruise.

Two stepping motor in the middle hull control the opening and closing of the two lateral hulls. One lead screw from the stepping motor and two smooth screws were connected from the middle hull to each lateral hulls. The two smooth screws made sure the lateral hulls were balanced when expanding or condensing. Two screws were attached to the end of each side of the lead screw to the lateral hulls. This allows the stepping to push and pull the lateral hulls sideways in order to expand and condense the vessel. The two stepping motors were connected to a driver module that is used to regulate the current entering into the motors[8-10].
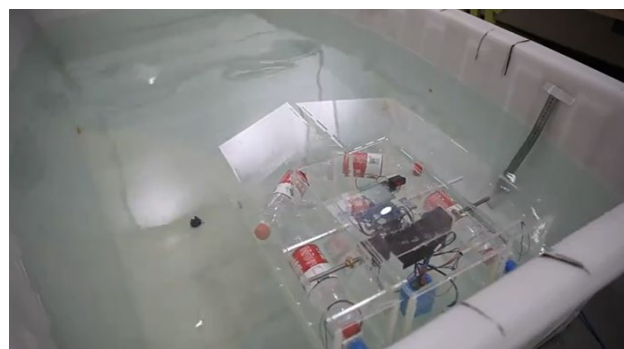
6.1. Material List

Figure 10: Experiment

Waves generation machine

A relatively large pool

The transformable vessel

A phone to control the vessel

Ruler

We conducted two separate experiments to determine the impact of the structure of the transformable trimaran on the vessel's speed and stability in water areas with waves. The water is simulated by a 1.5m x 2m pool with a wave maker. As is shown in Fig.10.

Experiment One was to compare the speed the trimaran when the lateral hulls are expanded and when they are folded in waveless water. We chose two forms to compare, completely expanded and completely contracted, to emphasize the difference. The trimaran started from one side of the pool and travelled to the other side while the time was recorded. Then, we switch the form of the trimaran and ran for another trail. We have 5 trials in total and the results are in Table 1.

Table 1: Experiment Data

	Expend (s)	Shrink (s)
1	16	32
2	17	25
3	14	36
4	16	39
5	18	35

Experiment Two was to determine whether an expanded trimaran can provide stability at the presence of measurable waves. We used a machine to stimulate different sizes of waves that might be encountered in cruise. We tested the stability of the vessel under three levels of waves: large, medium, and small. They were based on the height of the crest and trough of the wave above the bottom of the pool. The pool was 39.3cm deep under no waves. The crest of large waves is 41.0cm high, and trough is 37.5cm high; the crest of medium waves is 40.2cm high, and trough is 38.0cm high; the crest of small waves is 39.6cm high, and trough is 38.8cm high. We used three forms of trimaran: not expanded, each hull expanded 5 cm, and completely expanded. We measured the angle acceleration using the gyro when different forms of trimaran are encountered with different levels of waves. The angle acceleration was used to find out the angle of tilt of the vessel. The vessel was not driving so that waves created by the vessel itself can be prevented. The results are as following Fig.11..
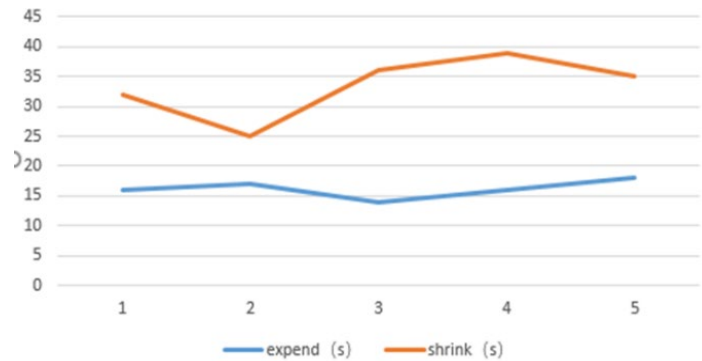

Figure 11: Experiment data chart

6.2. Analyze

According to the data obtained from the experiment, it can be clearly seen that the speed is slower in the unfolded state, and the traveling speed is faster in the retracted state, and the change of the speed amplitude is smaller.

From the results of Experiment One and Two, we concluded that the trimaran moves faster than when the lateral hulls are folded, and the trimaran is more stable when the lateral hulls are expanded. In Experiment One, the time that a trimaran with lateral hulls expanded needs to travel though the 2m polo is more than doubled the time that a trimaran with lateral hulls folded needs to travel through the 2m polo under the same power. We presume it was due to higher water resistance when the lateral hulls were expanded. In Experiment Two, no matter under small, medium, or large waves, the angle acceleration (tilt) of the trimaran with lateral hulls completely expanded is the smallest. A trend is shown that the more the lateral hulls are expanded the small the angle acceleration becomes. By contracting the lateral hulls when the vessel is stable, it can decrease the amount of energy to power the vessel.

7. Future research and constrain

Something constraining this research is the production of the trimaran. The usage of PMMA boards created corners on the trimaran, which increased water resistance. If I could have better method of production, the model of the transformable trimaran could be more resembled to a real vessel and produce more convincing results. Furthermore, I am developing a system that can achieve full automation of the expansion and contraction of the lateral hulls based on the size of waves. The gyro measures the angular acceleration and converts it into angle of tilt, which is how much the vessel deviate from its default state. When the angle of tilt is higher than a certain number, it means the waves are large and the lateral hulls will expand. When the angle of tilt is within a range of certain numbers, it means the speed and stability of trimaran are optimized and the lateral hulls will stop contracting or expanding. When the angle of tilt is below a certain number, it means the waves are too small and the lateral hulls will contract to increase velocity. This program allows the speed and stability of the trimaran to be optimized spontaneously. I am still trying to find the best angle of tilt which the lateral hulls should expand, contract, or stop their movement. It requires multiple experiments, calculations, and data analysis.

References

[1] Molland, A. F., J. F. Wellicome, and P. R. Couser. "Resistance experiments on a systematic series of high speed displacement catamaran forms: variation of length-displacement ratio and breadth-draught ratio." (1994).

[2] Sahoo, Prasanta K., Marcos Salas, and Adam Schwetz. "Practical evaluation of resistance of high-speed catamaran hull forms—Part I." Ships and offshore structures 2.4 (2007): 307-324.

[3] Castiglione, Teresa, et al. "Numerical investigation of the seakeeping behavior of a catamaran advancing in regular head waves." Ocean Engineering 38.16 (2011): 1806-1822.

[4] Bouscasse, Benjamin, Riccardo Broglia, and Frederick Stern. "Experimental investigation of a fast catamaran in head waves." Ocean engineering 72 (2013): 318-330.

[5] Johnston, Thomas A., and Richard A. Cunjak. "Dry mass–length relationships for benthic insects: a review with new data from Catamaran Brook, New Brunswick, Canada." Freshwater Biology 41.4 (1999): 653-674.

[6] Imre, I., J. W. A. Grant, and R. A. Cunjak. "Density‐dependent growth of young‐of‐the‐year Atlantic salmon Salmo salar in Catamaran Brook, New Brunswick." Journal of Animal Ecology 74.3 (2005): 508-516.

[7] Souto-Iglesias, A., et al. "Analysis of the wave system of a catamaran for CFD validation." Experiments in fluids 42.2 (2007): 321-332.、

[8] Papanikolaou, Apostolos, et al. "Numerical and Experimental Optimization Study on a Fast, Zero Emission Catamaran." Journal of Marine Science and Engineering 8.9 (2020): 657.

[9] Xu Shuangxi, et al. "Experimental and numerical analysis of ultimate strength of inland catamaran subjected to vertical bending moment." Ocean Engineering 188 (2019): 106320.

[10] Tarafder, Md Shahjada, and Kazuo Suzuki. "Computation of wave-making resistance of a catamaran in deep water using a potential-based panel method." Ocean Engineering 34.13 (2007): 1892-1900.