# Autonomous Control of the WAM-V Catamaran Type Unmanned Surface Vehicle: Propulsion System Design

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## 1. Introduction

Recently, the field of unmanned vehicle has bloomed for the purposes of conducting in dangerous environment for human, such as rescue and exploration. It can be intuitively classified to 4 categories with respect to where the unmanned vehicle is performed, including Unmanned Ground Vehicle (UGV), Unmanned Aerial Vehicle (UAV), Unmanned Surface Vehicle (USV) and autonomous underwater vehicle (AUV).

**Fig.**1 16 WAM-V USV, with the length of 4 m and the weight of 100 kg without payload.

USV is defined as the vehicle that can operate on the surface of the water without a crew. Usually, a small-scale USV is more often studied because of the easily-built platform and relatively low cost. In this paper, a scientific research is conducted for the application of the real-scale USV shown in Fig. 1, which can be further classified as catamaran for that it is equipped with two separate hulls. The catamaran was provided as a standard platform for the participating teams of an international competition named Maritime RobotX Challenge [1]. Besides the standard platform, each team has to develop their own propulsion systems and on-board sensors to achieve multiple missions such as obstacle avoidance and docking. The competition will be held in Singapore, October 2014. 15 teams from 5 countries are invited.

In this paper, the design of the propulsion system of this USV is presented, including the two driving configurations considered, the dynamical model derivation, the performance test through simulation and the power system setup.

## 2. Design of the Propulsion System

In order to propose a high performance propulsion system, a prototype is first built with several experiments conducted to test two different type of driving configurations. After the most effective driving configuration is chosen, the dynamic model derivation of the USV is presented and used for an analysis of the USV's performance with different outboard motor configurations. Finally, the power system with the concern of real application is proposed.

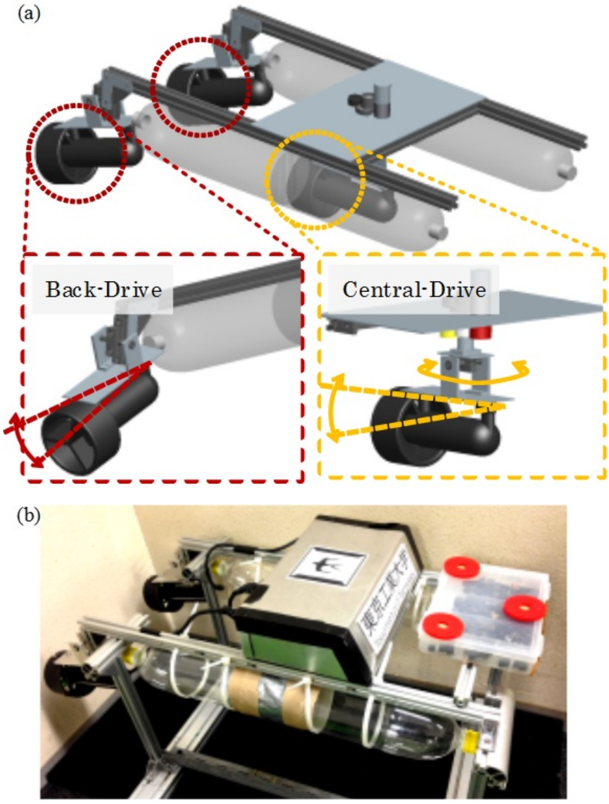

**Fig.**2 (a) CAD design of two different driving configurations of propulsion system, each one having a passive degree of freedom to make the propulsion system adaptive to wave disturbance. (b) Photo of the real prototype.

### 2·1 Tests with Two Driving Configurations

For the tests, two driving configurations with propulsion systems are considered; the "back-drive", composed by two propulsion units placed at the back of each hull, and the central-drive, composed by only one propulsion unit placed at the center of gravity (CG) and another motor controlling the direction of the propeller (yaw angle). The CAD design of each drive configuration is shown in Fig. 2(a). The back-drive had the advantage of being more easily-implemented, but there is the possibility of having a relatively larger rotational radius. The central-drive has the advantage of allowing a side-way motion, which might be useful for mission such as docking. However, the controllability and maneuverability is not easy to imagine, being possibly of too much complexity.

To verify our assumptions, a small-scale prototype is built and shown in Fig. 2(b). Several experiments with remote controller are then conducted in a swimming pool (2m*3m). Contrary to what it was expected, the back-drive presented a small rotation radius allowing the prototype to successfully accomplish tasks such as docking, while the central-drive presented a complicated controllability and maneuverability even when performing the side-way motion, which was expected to be one of its advantages compared to the first driving configuration. Therefore, the back-driving configuration was chosen for our propulsion system.

### 2·2 Dynamic Model Derivation

After deciding to use back-drive propulsion system, next concern rises with the choices of motors. In order to do so, a comparison between motors should be conducted through performance analysis in the USV, which can be conducted through simulations. As the simulation demands a dynamical model of the boat, the schematic diagram of the USV represented in Fig. 3 was obtained and the following dynamic equations of motion in the local frame of reference was derived:

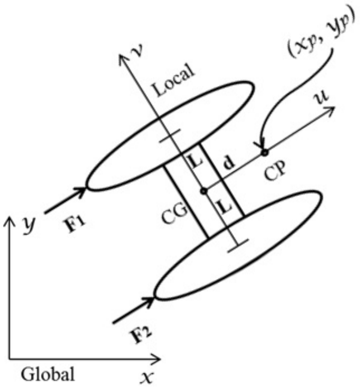

**Fig.**3 Schematic diagram of the surface vessel showing the control point (CP) and the centre-of-gravity (CG).

$$m_{11}\dot{u} - m_{22}vr + d_{11}u = F_1 + F_2 \quad (1)$$

$$m_{22}\dot{v} - m_{11}ur + d_{22}v = 0 \quad (2)$$

$$I_{33}\dot{r} + (m_{22} - m_(11))uv + d_{33}r = (F_2 - F_2)L \quad (3)$$

The parameters u, v, and r represent surge, sway and yaw speeds, respectively, and the vectors $F_1$ and $F_2$ represent the propellers forces produced by each motor. The propellers forces are modeled as $F_{1,2} = An_{1,2}^{c}$ where A is a constant, C is an dimensionless parameter and $n_{1,2} \geq 0$ are the propellers speed [2].

### 2·3 Performance Analysis of Motors

To conduct the performance analysis of the motors, equation 1 was used. Considering that the boat does not move laterally, the surge $v$ is zero, eliminating then the second term of the equation. As the thrust force can be obtained in the motor specifications, the only parameters that need to be defined are $m_{11}$ and the $d_{11}$. Those were obtained through the equations obtained in [3] with $m_{11}$ being 1.18 of the whole system weight and $d_{11}$ being function of $m_{11}$ and the length of the boat. The final values used in the simulation are represented in table 1.

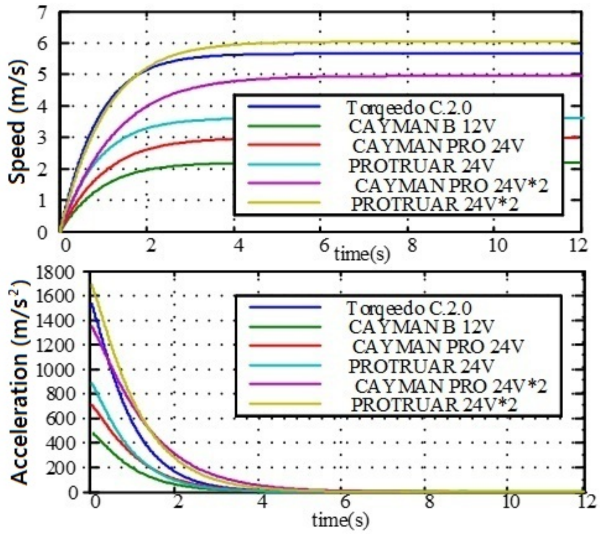

**Fig.**4 The results of the performance analysis with different configuration of motors.

As it can be seen in table 1, it was made a comparison between 4 different motors in 6 different configurations once it includes the use of 4 motors for propulsion instead of just 2. The method used in this comparison is to use the 24V Torqeedo Cruise 2.0 outboard motor as a reference and find a propulsion system which can reach beyond its performance. This motor was chosen as the reference since it is an expensive commercial outboard motor recommended by the catamaran cooperation. With all this information available, the performance tests were conducted with Simulink and the simulation results are shown in the Fig. 4, where the final speed and the acceleration are compared.

Further detail results are shown in Table 2. In this table, we could clearly observe that among a total of 5 proposed choices, using 4 24V Protruar motors could successfully power our catamaran with higher thrust force and therefore higher final speed, with a relatively smaller but acceptable acceleration, and with a considerably lower cost compared with

| Simulation Parameters | | | | | | |
|---|---|---|---|---|---|---|
| Model | Torqeedo C.2.0 | Cayman B12V | Cayman Pro12V | | Protruar 24V | |
| F ($F_1$+$F_2$) [N] | 1534 | 489 | 711 | 1351 | 889 | 1689 |
| $m_{11}$[kg] | 267.39 | 267.15 | 331.11 | 402.62 | 303.26 | 346.92 |
| $d_{11}$ | 121.77 | 121.76 | 125.37 | 129.41 | 123.8 | 126.27 |

**Table** 1 Simulation Parameters

| | Reference | Choices Considered for the Propulsion System | | | | |
|---|---|---|---|---|---|---|
| Model | Torqeedo C.2.0 | Cayman B12V | Cayman Pro12V | | Protruar 24V | |
| Number of Motors | 2 | 2 | 2 | 4 | 2 | 4 |
| Final Speed[m/s] | 5.66 | 2.2 | 2.99 | 4.95 | 3.62 | 6.05 |
| Final Speed[%] | 100 | 38.86 | 52.78 | 87.47 | 63.85 | 106.76 |
| Time to reach 90% of Final Speed[s] | 1.93 | 2.09 | 2.24 | 2.79 | 1.94 | 2.32 |
| Time to reach 90% of Final Speed[%] | 100 | 108.29 | 116.06 | 144.56 | 100.52 | 120.21 |

**Table** 2 Comparison between different configurations of propulsion system

the Torqeedo motors. Furthermore, using 4 outboard motors can make the propulsion system redundant, which could ensure that even if one motor unfortunately fails in the competition, the catamaran can still complete the mission with the remaining motors.

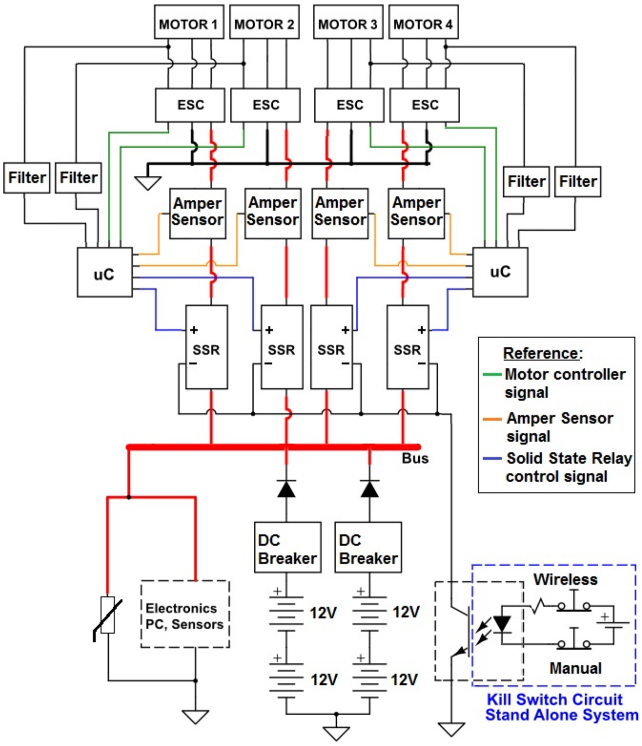

**Fig.**5 Real setup of the power system.

## 2·4 Setup for the power system

The real setup of power system is proposed and shown in Fig. 5. We consider using four 12V sealed lead-acid batteries with the capacity of 100Ah since they are common-used in the application of marine leisure. Each pair of power unit consists of two series-connected batteries. Then two pairs of power units are connected in parallel to generate the total power system of 24V with the capacity of 200Ah. With such power system, the catamaran is estimated to be able to perform a continuous speed of 3 m/s for at least 2.5 hours based on the results of simulation. Moreover, to guarantee the safety of the real setup on the catamaran, breakers, diodes are SSR's will be included. This system will prevent the batteries from charging each other, will cut the power in case of over current caused by a motor stuck and will disconnect the power line of one of the motors in case another motor in the other side of the catamaran stops working. In this system it is also included a isolated and standalone Kill Switch, which can be activated either mechanically with a emergency button or electronically with a remote control. When activated the kill switch will instantaneously cut the power of the four motors and will maintain this status until the system is restarted. This circuit will be placed in a waterproof case, easily detachable for maintenance purposes.

## 3. Conclusion

The study of real-scale surface vehicle, specifically referred to the catamaran type, has been conducted. The propulsion system is designed through the experiments of the prototype, the dynamic model derivation, the performance analysis in Simulink and the setup for the power system.

The next step for this project is to design the attachment of the motors to the catamaran boat, conduct tests to verify the results obtained through simulation and the finish developing the sensor system to compete in this year competition.

## References

[1] "Maritime RobotX Challenge website" `http://robotx.org/`

[2] Y. Siramdasu, and F. Fahimi: "Nonlinear dynamic model identification methodology for real robotic surface vessels,"International Journal of Control, vol. 86, Jun 2013.

[3] H. Ashrafiuon, and L. C. McNinch,: "Sliding-Mode Tracking Control of Surface Vessels,"Transaction on Industrial Electronics, Vol. 55, No. 11, Nov 2008.