Study on Navigation and Control of the Propelling Manoevre of Wave Adaptive Modular Vessel (WAM-V)

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ABSTRACT

Wave Adaptive Modular Vessel (WAM-V) is an entirely new class of vessels and it contains a huge amount of potential in various applications. WAM-V Catamaran water vehicle is a kind of unmanned boat with twin hull which can be autonomously guided to the water and have relevant applications in numerous fields. WAM-V includes four main elements a body (2hull), a propulsion system, a navigation system and a data collection and transmission system. The catamaran boat is equipped with two sets of propellers installed on each hull which is symmetric in shape. The catamaran must have ability to cruise on the water with a robust propulsion system which determines its propulsion capability and maneuverability. In this paper, WAM-V will be introduced and its manoeuvring performance is studied with the help of free running open loop trails in the Osaka University pond facility. Several manoeuvring tests were conducted in order to access the control fix straight line and turning ability, which tests the response of the boat to a RPM change of the propellers. The test results that: in control separately the port and starboard thrusters working at different speed, the flexible manoeuverability of the catamaran is satisfied. The principal challenge to perform outdoor experiments is navigational systems because of limitations in satellite signal reception. Demand for catamaran is justified to a point for improved manoeuverability and the motion of the robot is affected by environmental disturbances such as wind, wave and current. In this paper, we are analyzing the maneuverability and controllability of two propellers in order to establish an autonomous system for oceanography or as a complimentary observing system.

1. Introduction

According to research only 5% oceans, is known and it is one of the most demanding environments and a vast frontier for discovery. Japan is surrounded by the sea; the coastline measures approximately 29751km and contains 22 major international commercial ports. Recent studies indicated that global warming and ocean acidification have worsened, and extreme climate changes increased frequently in recent years. Additionally, due to increased pollution has caused changes to the marine ecosystem and reduced fishery resources. Currently oceanography or ocean environmental sensing (meteorological survey) is performed using satellites, buoys, research vessels or ships. However, remote surveillance of oceanography data using satellites and aeroplanes is restricted due to cloud cover, temporal/geographical coverage as well as spatial resolution. Meanwhile, manned research vessels are expensive for ocean surveillance. Whereas the use of moored buoy, due to lack of controllability and self deployability is not so attractive option for spatial sampling purposes. Due to all of the above mentioned reasons autonomous surface vehicles (ASV) & autonomous underwater vehicles (AUV), due to their various capabilities for payload, communication, and autonomy, have emerged as the best option for in situ measurement of oceanography data as well as a complimentary observing system (port protection, mine countermeasures, and surveillance missions). To access those immense areas unmanned we need in order to nurture the next generation techniques. Nowadays, several designs of autonomous surface craft like mono hull, catamaran, trimaran, streamlined, troller mono hull and swath is developed to maximize the surreptitious capabilities of performing marine operations. While autonomous surface vehicles are in their popularity, we believe that the astounding opportunity exists for modular and customized WAM-V to tackle this kind of situation. Capacity of WAM-V to be used for environmental monitoring and ocean task performance will serve to improve our understanding of the oceans, which will in turn benefit from the interaction between society and the environment. WAM-V type of unmanned surface vessel (USV) has been developed to autonomously launch and recover an autonomous underwater vehicle (AUV) (Pearson, 2014). A small sized autonomous catamaran surface vehicle is developed for monitoring the coastal water quality (Ferri, 2015). ASV has been developed for ocean observation can work under the rough ocean and observe the environment on coastal beaches also oil polluting sampling in the harbor basin (Jianxin, 2008). These types of ASV'S are propeller driven, whereas some of the catamaran ASV's are wind-propelled which can provide unmanned coastal cruising capabilities with energy efficient (Elkaim, 2006). An ASV should be appropriate instruments with hardware and software to provide high-quality records of kinematic parameters measured during self-running test (Perera, 2012). Free running open water model test data is not readily available for high speed crafts such as WAM-V. The summaries of some case histories are described in the literature (Phillips, 2011). The structure and concept of MMU free running model ship were introduced with some experimental results (Im, 2010). Simulation of turning circle maneuver of a catamaran is also studied (Honaryar, 2014). In this paper firstly configuration of WAM-V is described. After that structure of the open loop trail in the form of hardware and software details are explained with schematic diagrams is explained. Finally the result of the straight running test, speed test and turning test are analyzed followed by conclusion and future work.

2. WAM-V Boat Configuration

The WAM-V is a catamaran type of vehicle and the behavior of the vehicle is different from a conventional ship. There are several modified designs like Proteus was the first generation design and then two 12' and a 33' WAM-V, was the second and third generation respectively (Conti, 2011). It has been designed to adapt to the shape of the water surface. WAM-V is equipped with springs, shock absorbers, and ball joints, giving enough agility to the vessel and damping stresses to the structure and payload as shown in Fig.1. Two propellers attached to the aft part of each pontoon with special hinges that keep the propeller in the water all the time. High frequency waves are absorbed by the air filled pontoons. The 2:1 length-to-beam ratio, in addition to ball joint and suspension system, makes the WAM-V a stable platform. The main physical dimension of WAM-V used in this study is shown in "Table.1".

TABLE: I.

Parameters	*Measurements*
Hull Length	3.91 m.
Hull Diameter	4.2.6 m.
Overall Vehicle Height	1.27 m.
Overall Vehicle Width	2.44 m.
Payload	136 Kg. (Maximum)
Full Load Displacement	255 Kg.
Draft	0.165 m.
Primary Sensors	GPS, Camera, LRF, INS, Hydrophone- Pinger

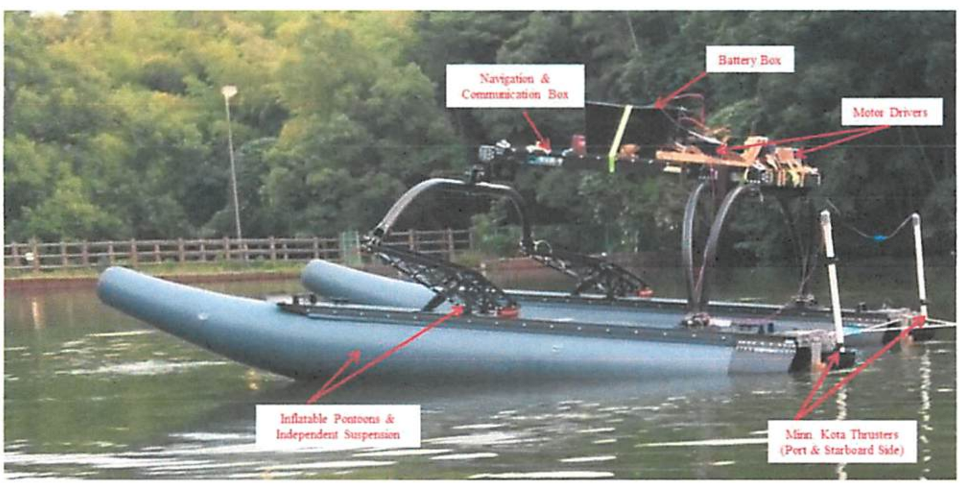

Fig. 1 Configuration of WAM-V

3. The Structure of a free running open loop trail
The WAM-V free running model experiment consists of hardware and software modules.

3.1 Hardware Module

3.1.1 Propulsion Module
A free running experiment usually requires high capacity of power because it operates in open water with a heavy payload. The propulsion module and powering modules need to be designed with an assessment involving an in depth failure mode analysis influence by the vessel's operational requirement. The Propulsion system of the vehicle consists of a pair of Minn. Kota transom mount trolling motors. The two motors are installed on the port and starboard of the WAM-V. In this configuration, steering the vehicle is achieved by setting different RPM on each motor. In the original state of Riptide Motor, the RPM of the motor and its orientation are controlled by a foot pedal. We modified the setup according to our application. This motor is designed around 12 V, to take the advantage of the availability of 12 V deep cycle battery designs specifically for marine use. The motor itself is sealed inside the compartment and it is submerged during the experiment which prevents overheating. The motor is controlled by Mbed NXP LPC 1768 microcontroller with H-Bridge module using RS 232 Serial port communication. The Mbed type of microcontrollers provides fast and flexible type of platform and its online compiler is used to create motor control program. Minn. Kota thruster's specifications are given in table. II

TABLE II. Minn. Kota Thruster Specification

Parameters	*Measurements*
Thrust of the motor	244 N (max.)
Armature Shaft Diameter	0.00488m
Propeller	2 Blade Weedless Wedge
Minimum Depth Inside the Water	0.3 m

3.1.2 Sensor (GPS)
The vehicle features a global positioning system receiver WINTEC G- Rays 2+. Using the GPS satellite constellation, it provides the system with an estimate of its latitude and Longitude. Those values are used to calculate X and Y position of the vehicle. G-Ray 2+ is the Bluetooth GOS receiver with internal antenna. USB connector and Bluetooth interface ensures easy linking with computer and other electronic devices. The specification is given in table. III

TABLE III. GPS Specification

Parameters	*Measurements*
Frequency	L1, 1575.42 MHz Channels 32 Channel for acquisition
Protocol	NMEA 0183
Operating Distance	10 m
Accuracy	2.5m CEP (stand-alone, S/A off) 2.0m CEP (SBAS)
Dimension	64*40*17 mm
Weight	55 g (With Battery)
Operating Temperature	10°C ~ 60°C
Dynamics Signal levels	Strong: type. 4g; Weak: type. 1g

3.1.3 On Board Computer
The hardware components comprising the GNC are located in the center of the hull. The main computer and various peripheral devices, such as serial-to-USB interfacing hardware, voltage regulator, DC to AC converter and the wireless LAN hub, are housed in a sealed plastic fiber box.
3.1.4 Communication
WAM-V uses various sensors and actuators for its localization and actuation, each took in different communication protocols depending on firmware implementation, RS-232, CAN, and USB protocols. Manual control of WAM-V was also possible via a wireless link, using a remote computer

3.1.5 Power Supply

The vehicle is powered by 3 G & Yu battery, SMF 27MS-730 (105Ah/20 hour rate capacity) batteries.

3.2 Software Module

All software was written in Borland C++. This software operates a shared memory and thus provides communication between the individual sensor programs. For example, sensor drivers read the sensor data from the detector hardware and write it to the shared memory. Other programs are requiring sensor data for processing can read data directly from the shared storage.
WAM-V navigation system is layout is shown in Fig. 2.

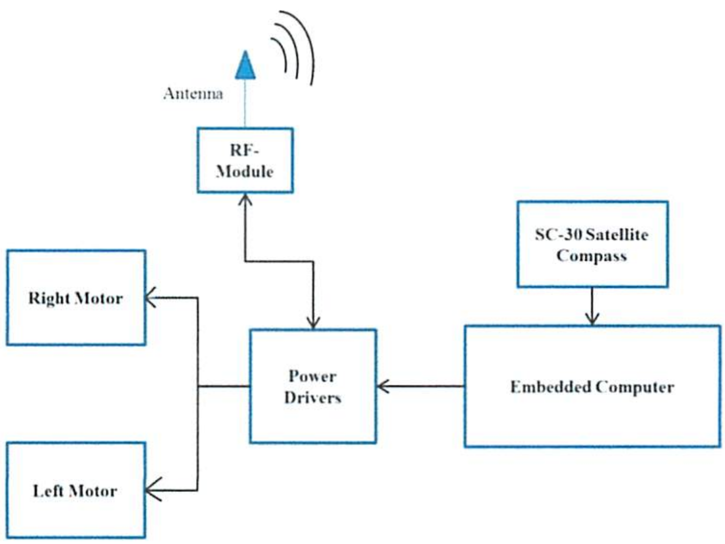

Fig. 2 WAM-V Navigation System

4. Free Running Open Loop Trails of WAM-V

The open water trial is required to characterize a WAM-V maneuverability and dynamics. Numerous international organizations like IMO (International Maritime Organization), ITTC (International Towing Tank Conference) and SNAME (Society of Naval Architecture and Marine Engineering) have developed to give recommendations about the test and assess the maneuverability and performance of the ship. In this open loop-trial, a self propelled WAM-V is steered by radio control on the water by giving some control commands and motion trajectories. Time histories of motion variables etc. are measured. In this test, the WAM-V is stable in motion so there is no unstable coupled heave and pitch motion.
In order to calculate specific model parameters specific tests were chosen to excite certain modes of the vehicle dynamics. The tests are as follows

4.1 Straight Line Test

Straight line tests were performed with the goal of identifying the relation between vehicle speed and percentage of voltage supply in order to measure the speed of the vehicle. The GPS location and heading was recorded. For one such run the measured vehicle track is given in Fig.3. Open loop type of test is not typically expected to be stable because of the inherent nonlinearity of the system and this is why with the open loop speed commands the vehicle's track is unstable and doesn't naturally follow the track.
The Speed test was conducted at different voltage supply in order to determine the speed of WAM-V. Fig.4. shows the graph between velocity of WAM-V at 50%, 60%, 70%, 80% and 90% of total voltage supply which is analyzed by experimental data. At 90% of the total voltage vehicle speed reached to 1.169 m/sec which is quite sufficient.

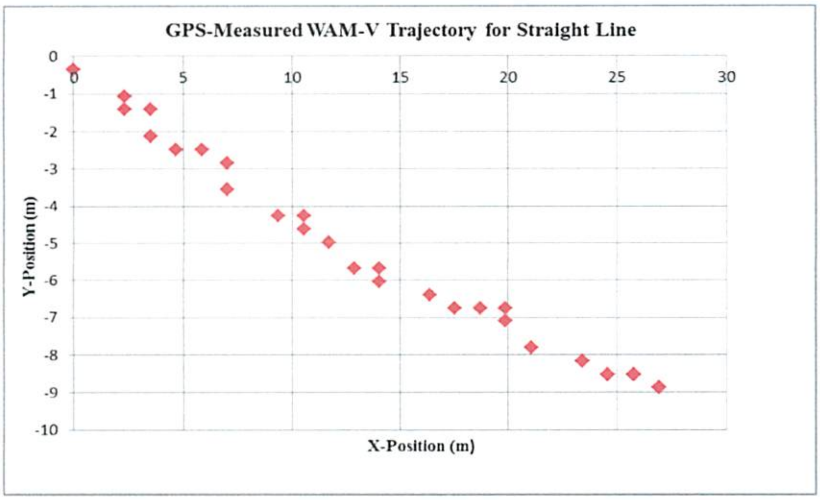

Fig. 3 GPS-Measured WAM-V Trajectory for Straight Line

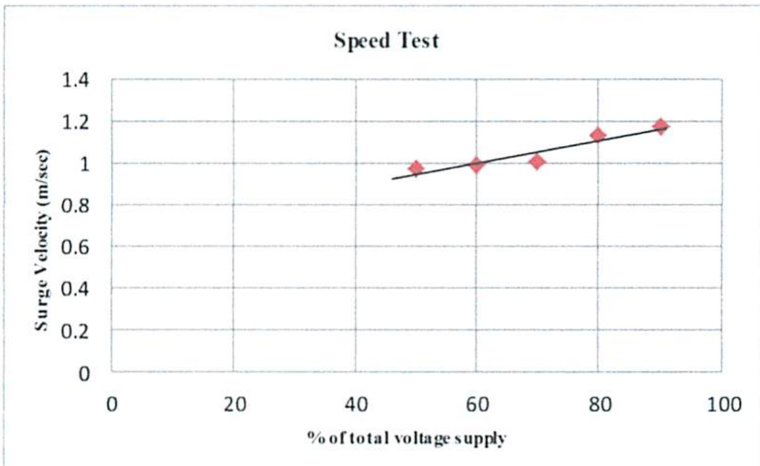

Fig.4 Speed Test of WAM-V

4.2 Turning Test

The motion of WAM-V is controlled by the revolution speed of two propellers installed on the two hulls and when the revolution speed of the two propellers on the portside and starboardside are different turning moment is generated which produce the same effect as a rudder. Thruster rotation speed governs the motion trajectory of the WAM-V. A differential thrust force can be generated by controlling the rotation of the individual thruster for applying a turning moment to turn the WAM-V in the required direction. Hence, the controlled rotation speed of the portside and the starboard side thruster can produce similar maneuvering forces as that of conventional rudder. In the turning test experiment for WAM-V, port and the starboard thruster were rotated at different speed. During the experiment the GPS data was stored and analyzed offline to see the turning response of the WAM-V, with change in rotational speed of port and starboard thruster. Figure 5 shows the turning trajectories with change of % of total voltage supply. For turning left the portside thruster is provided 50% and starboardside is provided 80% of total voltage supply and turning right is vice versa. The turning ability of WAM-V greatly varies depending on the approach speed that is caused by speed effects on the hull forces. In this experiment the wind condition was not measured. The left hand side and right hand side trajectories may have some effect of different wind conditions.

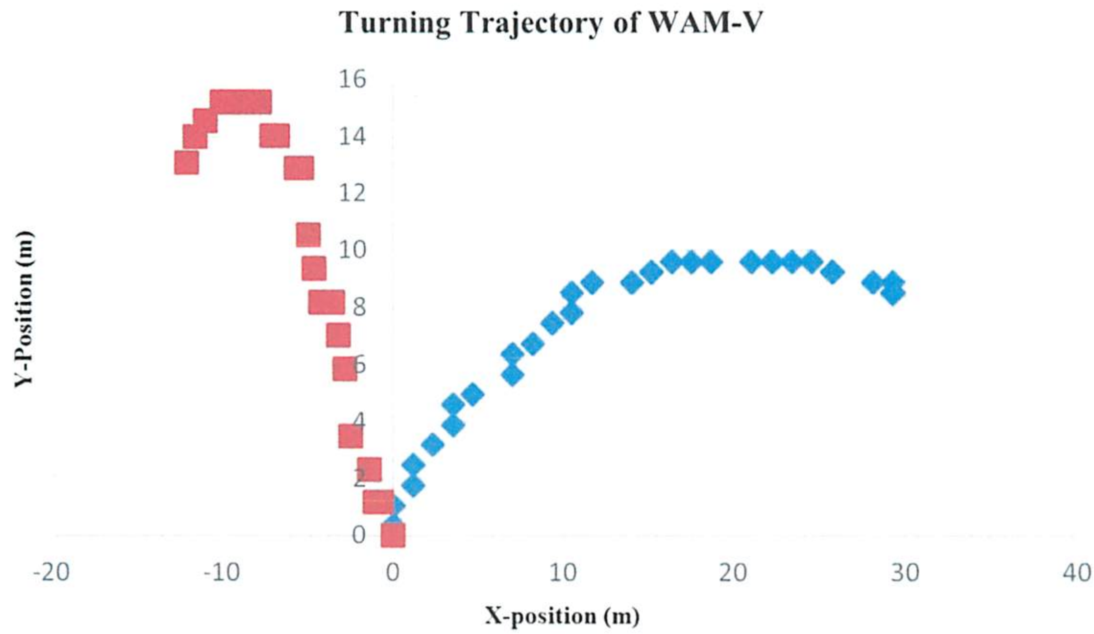

Fig. 5 Left and Right side turning trajectories of WAM-V

5. Conclusion and Future Work

In this paper, a 3.91 m Wave Adaptive Modular vessel (WAM-V) is introduced with its navigational and manoeuvring performance using free running open loop trail. In order to better quantify the vehicle dynamics with respect to autonomous control free running open loop model test has enabled significant advances made in the understanding of high speed vehicles like WAM-V. The use of free running models also provides the opportunity to test in open water conditions, which not only reduces reliance on high cost test facilities but is also of particular importance for high speed crafts. The assessment of system failure conditions in practical situations on WAM-V designs has also been the feature of the free running open loop model test. The first task was to design and integrate as sensors and electronics to make it capable of recording actuator input commands and the resulting vehicle response which is successfully accomplished. The straight line test was conducted in order to understand the relation between WAM-V speed and voltage supply to the propellers. Turning ability of WAM-V is studied by changing the voltage difference supplied to the portside and starboardside propellers. Control design for high speed autonomous vehicles such as WAM-V is challenging due to uncertainty in dynamic models, significant sea disturbances, underactuated dynamics and overestimated or underestimated of hydrodynamic parameters. Future work includes modeling the system dynamics accurately and designing a suitable controller for marine applications. We believe that tremendous opportunity exists for modular and customized WAM- V.

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