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Manoeuvring Mathematical Model of Catamaran Wave Adaptive Modular Vessel (WAM-V) using the System Identification Technique

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Abstract

A successful control system design requires knowledge of the system to be controlled. An accurate model is important to simulate a vehicle's performance and manoeuvring capabilities. In this paper equations of motion to express the manoeuvring behaviour of Wave Adaptive Modular Vessel (WAM-V) is described. The MMG- type modular maneuvering model has been found to be suitable for investigation maneuvering characteristics of catamaran vessel. System Identification Matlab toolbox is used to simulate the manoeuvring motion and to estimate the hydrodynamic derivatives in the dynamic equation. Based on the maneuvering equations and using the collective observations from free running and captive model experiments, the hydrodynamic parameter of WAM-V are estimated and presented in this paper. A nonlinear regression model is used to optimize the hydrodynamic parameters. Therefore, sufficient free running trial data are measured at the experiment pond facility, Osaka University. A parameter identification of the WAM-V is required in order to fully characterize the vehicle for various applications.

Keywords: System Identification, Manoeverability, MMG Mathematical Model, Free Running Trials and Autonomous Surface Vessel (ASV).

1 Introduction

Autonomous WAM-V have great potential to serve as a platform for marine applications. In the last several years there has been a growing interest in designing an autonomous surface vessel (ASV) for competition such as the Maritime Robotx Challenge. The purpose of a competition is to design the complete autonomous system, including sensors, on-board processes, navigation and control. A good mathematical model of the ship dynamic will facilitate the model based design, allowing applications of control design and analysis tools. Free running model tests are often preferred because they confirm manoeuvring properties of a ship configuration in the most direct and convincing way. The method of computer simulation using mathematical models becomes more and more popular due to rapid development of the computer technology. Conducting a captive model experiments are cost consuming. To overcome the drawbacks system identification techniques was developed, which can predict or tune the system parameters in the mathematical model of a dynamic system from measured data of free running experiments. Many of these hydrodynamic coefficients are very difficult to measure empirically and experimentally. In this research, we have attempted to perform system identification based on the data returned by the sensors. The dynamic model of the system is needed in order to simulate the autonomous navigation system.

A system identification approach is useful in providing reliable and accurate models in a short time. In system identification, input and output signals from the experiments are recorded and subjected to data analysis in order to infer the model. "(Abkowits 1980)" developed system identification algorithm using the extended Kalman Filter technique for Esso Osaka ship equations of motion and hydrodynamic coefficient. The results showed good agreement between the simulated motion responses and ship trials. "(Ljung 1987)" explains an introduction in his synopsis about the system identification technique including various parameter estimation method. He also described a system identification by dividing a vehicle modeling techniques into the three Categories: first is a white box model which is based on the principles of physics and empirical knowledge. The Second is a black box model which employs methods that make no assumptions about the system and third is the combination of above two is called grey box. "(Elkaim 2001)" used GPS-based system identification for precision control of wing-sail catamaran 'Atlantis'. "(Naeem et al. 2003)" developed the model of an autonomous underwater vehicle (AUV) with a practical system identification method. In his research, he tested the model with Linear Quadratic Gaussian (LQG) controller. Later on "(Naeem et al. 2006)" presented his study of an autopilot development of USV names Springer for environment monitoring. "(Caccia et al. 2008)" developed the practical model and the corresponding identification procedure for guidance and control of an autonomous surface craft (ASC) name Charlie. "(Elkaim 2008)" used the observation Kalman IDentification (OKID) method for identifying a linear time invariant plant model of a catamaran vessel. With this model Linear quadratic Gaussian (LQG) controllers were designed which demonstrated excellent line tracking performance. "(Oh et al. 2010)" describes a mechatronic system for model ship in order to get the manoeuvring data. The manoeuvring parameters were calculated with the help of the data using system identification technique. "(Wirtensohn et al. 2013)" estimated the parameters of USV CaRoLIME using a weighted least square optimization approach. Several manoeuvre trials were performed to measure the data as an input and output to the system identification toolbox.

This paper presents a description and preliminary findings of a maneuvering parameter of the MMG mathematical model of WAM-V for future autonomous control system development.

2 System Description and Mathematical Model

"(Marine Advance research Inc. 2011)" introduced a new generation vessel WAM-V. The WAM-V is a catamaran designed to provide better sea keeping performance than the conventional boats. It is supported by the two inflatable pontoons attached to a center payload tray using an independent suspension system. The suspension system is configured using springs, shock absorbers and ball joints such the demi-hulls move somewhat independently through the wave field. The vehicle is powered by electric Minn Kota trolling motors, which provide a capability of achieving speeds of about 5 knots. 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.

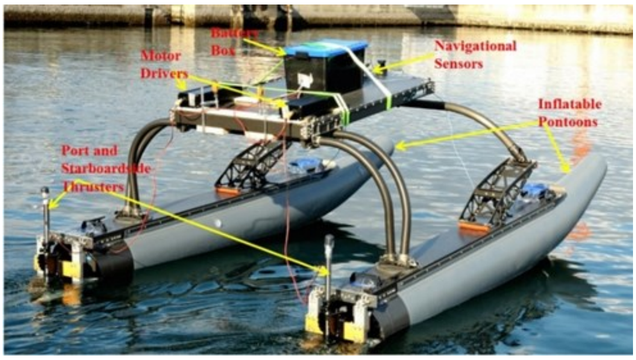

Fig. 1 WAM-V Catamaran robot

The main physical dimension of WAM-V used in this study is shown in Table. I.

Parameters	**Measurements**
Hull Length	3.91 m.
Hull Diameter	4.26 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

The Mathematical Models of Maneuvering Motion Group of Japan proposed MMG mathematical model of ship in the second edition of the Japan Towing Tank Committee. "(Ogawa et al. 1980)" described the concrete methods of MMG model, including hydrodynamic forces acting on the ship. "(Yoshimura et al. 2015)" revised full model with adding some interaction coefficient in the model. The model consists of hull, propeller and rudder characteristics with their interaction effect. The MMG- type modular maneuvering model has been found to be suitable for investigation, such a vessel's maneuvering characteristics of two propeller vessel.). WAM-V movement can be described by 3-degrees of freedom which lies in the plane parallel to the surface of the water, namely surge, sway and yaw. For aquatic applications the system dynamics of WAM-V can be described using equation (1)

$$m(\dot{i} \quad \ldots \quad (U)+X_P$$
$$m(\dot{} \quad \ldots$$
$$+(Y_r+X_{\dot{i}} \ldots r + Y_{vvv}v^3 \qquad (1)$$
$$I_Z \dot{} \quad \ldots \quad N_{vvv}^3\, v+$$

Where *u,v, r* is vehicle's surge velocity, sway velocity and yaw rate respective. *m* is the vehicle's mass and I_Z is the moment of inertia about the *Z* axis. When the WAM-V motion parameters u, v and r is very small, the higher order can be omitted and the derivative of the forces and moments respect to a given variable indicates the change in the fluid forces and moments when the given variables are changed slightly from the equilibrium value, with all other variables remaining at their equilibrium value. "(Jyotsna et al. 2015)" calculated the WAM-V resistance force ($X_u(U)$) with the help of the captive model test. Some parameters Y_v, Y_{vvv}, N_v and N_{vvv} is also calculated with the help of the captive model test. The other hydrodynamic parameters are calculated with the help of system identification method.

The WAM-V relies on differential thrust for steering. So basically in this case when the thrust of two propellers on the portside and starboardside are different, generate turning moment and produce the same effect as a rudder. Where T_P and T_S denote the thrust from the port and starboard propellers, respectively. t_P is the thrust deduction factor and the value taken here is 0.25, d_{NP} is the propeller influence factor is taken here is 25%. y_P is the separation distance between the centerline of each hull. There is no propeller force generated in the Y- direction. Propeller force is X- direction (X_P) and turning moment in Z direction (N_P) are calculated by (2).

$$X_P=(1-t_P)(T_S+T_P)$$
$$N_P=(1+d_{NP})(T_S-T_P)\,y_P \qquad (2)$$

To simulate the motion, the manoeuvring derivatives in the equation should be determined. Using these all the equations the dynamic simulation of the vehicle is created in "(MATLAB/Simulink 2016)" as shown in Fig. 2.

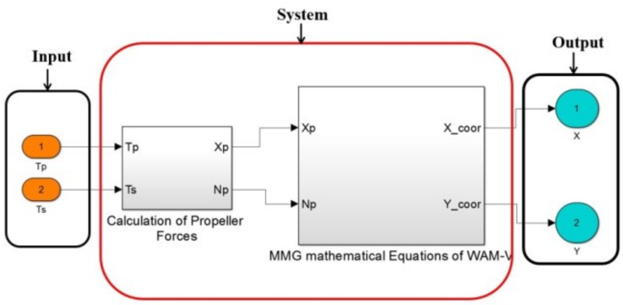

Fig. 2 WAM-V mathematical model in Simulink

3 System Development for Free Running trials and Data Collection:

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. Free running trials are required to characterize a surface vessel's manoeuverability and dynamics. The kind of data collected in terms of inputs is also very important to the success of system identification. The measured data should be accurate enough to simulate the Simulink model.

The system that operates the ship consists of hardware and software module. 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. 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. 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. MATLAB/Simulink is used as a software module.

4 Identification of Parameters and Validation

The simulation data do not match with measured data because the parameters are incorrect. There are some values we are unsure and we couldn't change the manually until the result matches. However, using an optimization algorithm we can automatically tune these parameters until the result of the simulation match the measured data. System identification generally consists of the following four steps. The layout is shown in Fig 3.

1. Data acquisition: First step is to gather input/output data of the system to be identified. The data should be accurate enough to simulate the results.
2. Characterisation: The second step is to define the structure of the system.
3. Identification/estimation: The third step involves identifying the parameters by some initial guesses and define their ranges.
4. Verification: The final step is to identify the model response and cross validate with the other experimental results.

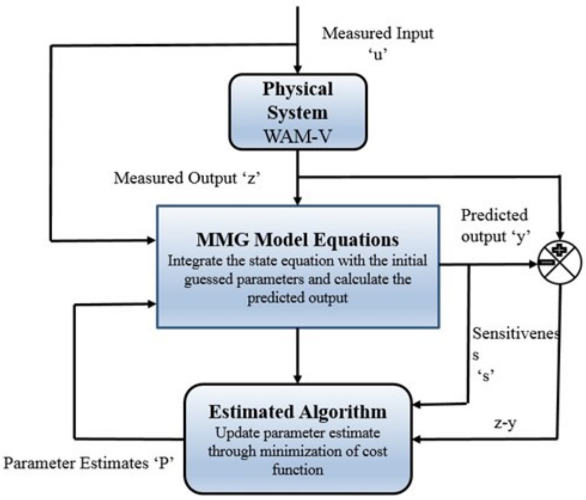

Fig. 3 System Identification Layout

5 Results and Discussion

For the approach to parameter identification, a minimum of two different data sets are required one to determine the unknown parameters and other for the validation or vice versa. Unfortunately, identifying system parameters of the tests is not trivial. In this research several data sets are used to get the best possible set of parameters. Although the current data are sometimes unusable due to low sensor resolution, thus it is necessary to find an alternative to calculated estimated parameters. The alternative way is to generate the data by creating mathematically-based computer simulation model with known parameters determined from the literature. In this research we conducted several speed tests and turning tests.

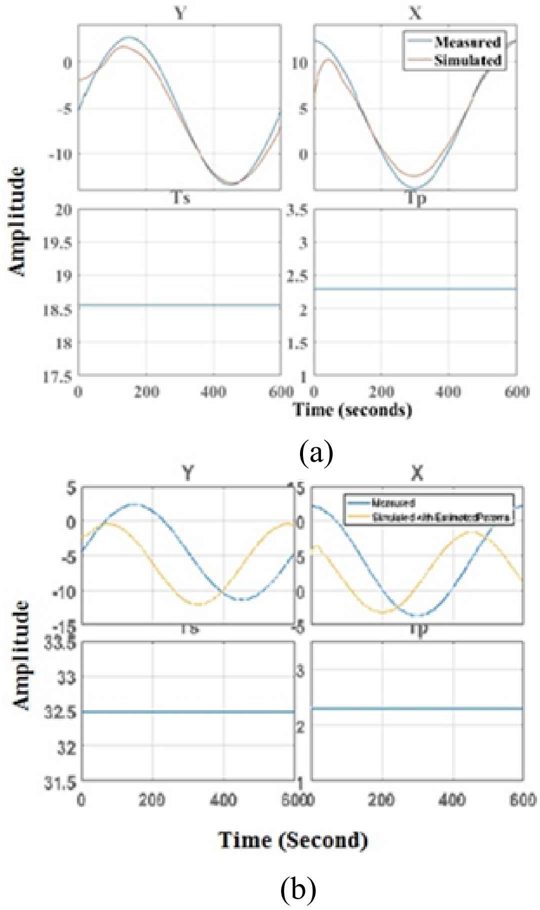

Fig. 4 (a) measured and simulated results of data set 1. (b) Validation of the same parameters with dataset 2

In fig 4 (a) input as a portside thrust (Tp) and starboard side thrust (Ts) is supplied to the 2.3 N and 18.56 N. Simulated trajectory tries to match with measured trajectories by calculating the set of unknown parameters. In fig 5 (b) measured and simulated trajectories are verified with the same set of parameters at different thrust input as Tp =2.3 N and Ts = 32.5N and output X and Y. In this research we performed this simulation with several combinations of different input-output conditions using the same parameter value. Fig. 5 shows the experimental results of two different input conditions and simulation results with the calculated hydrodynamic parameters. The trajectory of simulation results starting trajectory is little different due to different initial conditions.

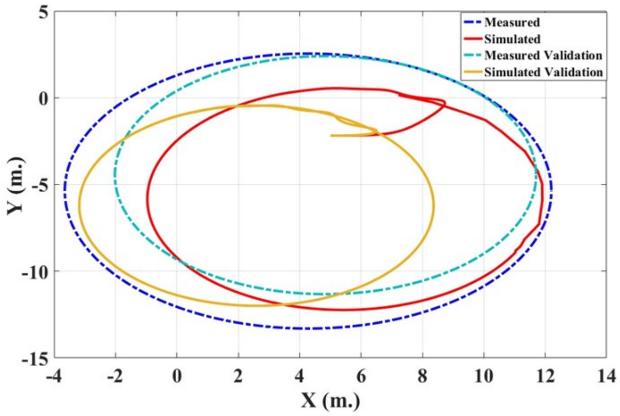

Fig. 5 measured and simulated turning test results with validation results

The dynamic of WAM-V is very complex, so many of the parameters are not so accurately estimated in every simulation, but we tried to make it as close as possible by which maximum results can be verified. Fig. 6 shows the simulation graph of estimated parameters. The calculated values are listed in table 2.

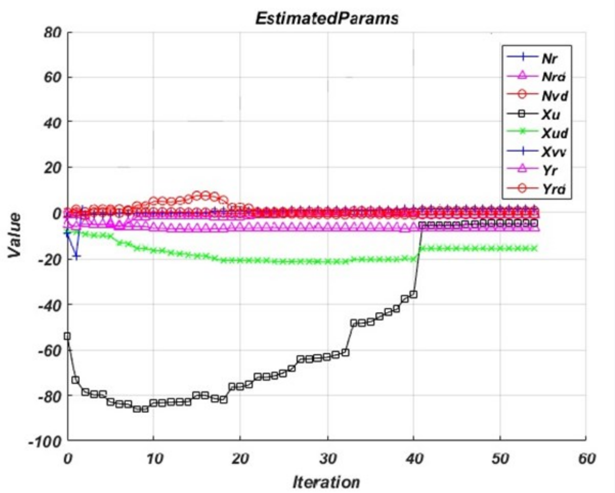

Fig. 6 Estimated parameters iteration

Table 2. Calculated hydrodynamic parameters

Hydrodynamic Derivatives	Magnitude (non-dimensional) *10e-3
$X_{\dot{u}}'$	−18300
X_{vv}'	−880
$Y_{\dot{v}}'$	−1120
$Y_{\dot{r}}'$	−435
Y_v'	−1155
Y_r'	−500
Y_{vvv}'	−0.80
$N_{\dot{v}}'$	25
$N_{\dot{r}}'$	-89
N_v'	-265
N_r'	-177
N_{vvv}'	1659

6 Conclusion and Future Work:

The methodology to calculate the unknown hydrodynamic parameters of MMG model which are difficult to calculate with the help of experiments is discussed in this paper. While it was not possible to conduct the complicated experiments with the WAM-V, the substitution method to calculate those parameters is discussed briefly. The details of the MMG mathematical model of WAM-V is presented in this paper. Straight line and turning circle tests were conducted and sufficient data were collected to use as an input-output in order to perform parameter identification technique. WAM-V is a high speed marine craft with tremendous control and maneuverability in tight, giving its advantage over the other ASV. 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. The knowledge of the maneuvering capabilities of ships has already been required to control the vessel for various marine applications. In near future this research will help to design a controller of WAM-V for waypoint navigation.

References

Abkowitz, M.A. 1980 Measurement of hydrodynamic characteristics from ship maneuvering trails by system identification, SNAME Transaction, vol. 88, pp. 283-318

Caccia, M., Bruzzone, G. and Bono, R. 2008 A practical Approach to Modeling and Identification of Small Autonomous Surface Craft, IEEE J. Ocean. Eng., vol. 33, no. 2, pp 133-145.

Elkaim, G.H. 2001 System Identification for precision control of a wingsailed GPS-guided Catamaran. Ph.D. Thesis, Stanford University, Stanford, CA, December.

Elkaim, G.H. 2008 System identification-based control of an unmanned autonomous wind-propelled catamaran, Control Eng. Practice, vol. 17, pp. 158-169.

Ljung, L. 1999 System Identification: Theory for the user, Prentice-Hall Inc. 2nd ed.., New Jersey

Marine Advanced Research, Inc. (2011) WAM-V: Wave Adaptive Modular Vessels. [Online]. http://wam-v.com/wamv.html

MathWorks. 2016a MathWorks Product Documentation. [Online]. www.mathworks.com

Naeem, W., Sutton, R. and Chudley, J. 2003 System Identification, Modelling and Control of an Autonomous Underwater Vehicle, Proceedings of the MCMC IFAC Conference, Girona, Spain.

Naeem, W., Sutton, R. and Chudley, J. 2006 Modelling and Control of an Unmanned Surface Vehicle for environmental Monitoring, UKACC International Control Conference, Glasgow, Scotland, UK.

Ogawa, A. and Kasai, H. 1978 On the mathematical model of manoeuvring motion of ships, Int. Shipbuild prog 25 (292); 306-319.

Oh, S.R., Sun, J., Li, Z., Celkis, E.A. and Parsons, D. 2010 System Identification of Model Ship Using a Mechatronic System, IEEE/ASME Transaction on Mechatronics, vol. 15, no. 2

Pandey, J., and Hasegawa, K. 2015 Study on Manoeuverability and Control of an Autonomous Wave Adaptive Modular Vessel (WAM-V) for Ocean Observation. IEEE, International Association of Institutes of Navigation (IAIN) World Congress, pp 1-7. Prague, Chez Republic.

Wirtensohn, S., Reuter, J. Blaich, M., Shuster, M. and Hamburger, O. 2013 Modelling and Identification of a Twin Hull-Based Autonomous Surface Craft, IEEE-Methods and Models in Autonomous and Robotics (MMAR), pp 121-126

Yasukawa, H. and Yoshimura, Y. 2015 Introduction of MMG standard method for ship manoeuvrinng predictions. J Mar Sci Technol, vol. 20, pp. 37-52.