Sensors & Transducers, Vol. 187, Issue 4, April 2015, pp. 68-74

Sensors & Transducers

http://www.sensorsportal.com

Using an Autonomous Scale Ship Model for Resistance and Parametric Roll Tests

Fernando LOPEZ PEÑA, Alvaro DEIBE, Marcos MIGUEZ GONZALEZ, Felix ORJALES, Daniel PENA

Integrated Group for Engineering Research, Universidade da Coruña, Mendizabal s.n., 15403 Ferrol, Spain

Tel.: +34 981337400, fax: +34 981337410

E-mail: flop@udc.es, mmiguez@udc.es, adeibe@udc.es, dpagras@udc.es, felix.orjales@udc.es

Received: 16 December 2014 /Accepted: 27 March 2015 /Published: 30 April 2015

Abstract: This work presents the developing of a self-propelled scale ship model aimed to perform resistance and parametric roll tests in towing tanks. The main characteristic of the proposed system is that it doesn't have any material link to a towing device to carry out the tests. This ship model has been fully instrumented in order to acquire all the significant raw data, process them onboard and communicate with an inshore station. This works presents a description of the proposed model as well as some results obtained by its use during a towing tank testing campaign. *Copyright © 2015 IFSA Publishing, S. L.*

Keywords: Ship model testing, Heading control, Parametric roll.

1. Introduction

Ship model testing could be broadly divided into two main families, on one hand there are resistance tests, either in waves or still water, and, on the other, maneuvering and seakeeping tests [1]. The former ones are carried out in towing tanks, which are slender water channels where the model is attached to a carriage that tows it along the center of the tank. On the contrary, the latter tests are usually done in the so-called ocean basins. There the scale model can be either attached to a carriage or radio controlled, with no mechanical connection to it.

However, there exist certain kinds of phenomena in the field of seakeeping that are characterized by showing very large amplitude nonlinear motions that can be better studied in towing tanks, which are cheaper to operate and have more availability than ocean basins. Among these last sort of tests there are the studies of ship parametric roll resonance, also known as parametric rolling. This is a well-known dynamical issue affecting ships, especially containerships, fishing vessels and cruise ships, and it could generate very large amplitude roll motions (rotation around the ship longitudinal axis) in a very sudden way, reaching the largest amplitudes in just a few rolling cycles. Parametric roll is due to the periodic alternation of wave crests and troughs along the ship, which produce the changes in ship transverse stability that lead to the aforementioned roll motions.

This phenomenon is likely to happen when the ship sails in longitudinal seas and when a certain set of conditions are present, which include a wave encounter frequency ranging twice the ship's natural roll frequency, a wavelength of the incident waves almost equal to the ship length and a wave amplitude larger than a given threshold [2].

Traditionally, parametric roll tests in towing tanks have been carried out by using a carriage towed

http://www.sensorsportal.com/HTML/DIGEST/P_2647.htm

model, where the model is free to move in just some of the 6 degrees of freedom restraining the motion on the remaining degrees of. Typically the free degrees are heave –vertical displacement–, roll and pitch –rotation around transversal axis–, which are the ones most heavily influencing the phenomenon [3-4]. However, this arrangement limits the possibility of analyzing the influence of the restrained degrees of freedom [5], which may also be of interest while analyzing parametric roll resonance and, additionally, may also interfere on the development of the phenomenon. Furthermore, space limitations in some towing tanks could also make difficult to handle the model under the carriage if very large motions are present, as it happens in the test case presented in this work [6].

The presented paper is an extended an improved version of the work presented at IDAACS 2013 [7]. The main objective of this work is to develop a system able to overcome the described difficulties for carrying out scale tests where large amplitude motions are involved. This has been done by using an autonomous self-propelled and self-controlled scale ship model, that has no constrains to move in the six degrees of freedom, and has the capability of measure, store and process all the data prescribed for a given test without the direct need of the towing carriage. In addition, the model could be used for any other ship model testing, both in towing tanks or ocean basins, with the advantage of being independent of the aforementioned carriage.

2. Data Acquisition Requirements

The type and amount of data to be collected has been defined taking into account the typology of the tests to be carried out. The speed of the ship model is the most important control parameter in any towing tank tests. For this reason speed data should be undoubtedly include in the acquisition system as it will be used in any test. For the reasons exposed later on, the speed of the model is obtained on the basis of measurements taken by a laser rangefinder (LRF). This device is installed onshore and transmits the measured data through a radio modem to the measurement system onboard the ship model.

As it has been already pointed out, the system presented in this work is conceived to have the capability of being used in any kind of towing tank test, but it is particularly focused towards the analysis of resistance tests, both with or without waves, and parametric roll resonance tests, which falls within the field of seakeeping. The aim of these seakeeping tests is to study the ship dynamic behavior while cruising in waves. In these kind of tests it is necessary to sense and store the data related with the ship motions along the six degrees of freedom (heading related to waves, attitude, rotational speeds and accelerations), together with forward speed. It is usually also recommendable to be able to obtain the ship trajectory in the test basin.

In addition, the proposed system is also intended to be used in resistance tests. The main objective of this kind of tests is to determine the ship resistance in order to improve its hull forms and propeller, or to define its propulsion plant. In conventional carriage-towed facilities, the ship resistance is measured by using a dynamometer installed in the towing device. However, in the presented model no interaction between carriage and model exists, thus the propulsive force is obtained by a direct measure of the thrust generated by the propeller on its shaft. Moreover, the proposed system has been conceived to be additionally capable of analyzing the performance of the propeller itself. For this purpose the propeller speed and shaft torque are also measured onboard.

A full set of sensors has been placed on board to fulfill the aforesaid requirements. In addition, data processing, storage and communication systems have been also implemented aboard in order to ensure the autonomy of the ship model.

3. System Architecture

3.1. General Disposition

The first implementation of the proposed system has been on a scale ship model that has been machined from high-density (250 kg/m^3) polyurethane blocks to a scale of 1/15th, painted and internally covered by reinforced fiberglass. Mobile lead weights have been installed on supporting elements that permit adjust their positions along longitudinal, transverse and vertical axis thus allowing a correct mass arrangement; that is, a correct total mass, a correct position of the center of gravity and correct values of the momentum of inertia around the three axis. Moreover, two small weights have been fitted into a transverse slider for fast and fine-tuning of both the transverse position of the center of gravity and the longitudinal moment of inertia.

The propulsion system consists of a three-phase electric motor and two stage planetary gearbox, which move a four bladed propeller. The rudder is actuated by an electronic servo, which may be controlled either using an external transmitter or by the own model control system.

In order to obtain data of the entire representative parameters mentioned in the preceding section, the following sensors have been installed onboard:

- Inertial Measurement Unit (IMU): A VN-100 IMU by Vectornav has been used in conjunction with its development kit. This IMU has nine MEMS embedded sensors, including 3 axis accelerometers, 3 axis gyros and 3 axis magnetometers. The IMU has an internal processor that provides information of accelerations in the OX, OY and OZ axis, angular rates around these three axis and quaternion based orientation vector (roll, pitch, yaw), both in RAW format and filtered by using Kalman techniques. This sensor has been placed approximately in the center of gravity of the ship with the objective of improving its performance.

• Thrust sensor: a load cell has been installed to measure the thrust generated by the propeller at the thrust bearing. The model used is a SMT 25 N by Interface. This is an overload protected S-type load cell with a capacity of 25 N and an accuracy of less than 01 % FS.

• Revolution and torque sensor: in order to measure the propeller revolutions and the torque generated by the motor, a torque and rpm sensor has been installed between both elements. The sensor used is a ToroqSense RWT321-CF by ST Sensor Technology having a torque range of 0 to 1 Nm and an accuracy of 0.1 % FS. This element is not needed in most tests; it would be used only when performing tests on propeller performance in addition to the standard ship performance tests.

• Sonars: intended to measure the distance to the towing tank walls and feed an automatic heading control system. There are two sonars, each one pointing towards one of the sides of the tank. The model used is a LV-MaxSonar-WR1. This is a high performance weather resistant sonar range finder by MaxBotix. They have a sonar range information from 12-inches out to 254-inches with 1-inch resolution.

The system data acquisition is made through an onboard mounted PC, placed forward on the bottom of the model. The software in charge of the data acquisition and processing and motor speed and rudder control (Matlab based code), is also installed in this PC. However, if needed the system may be controlled from another external workstation by using Wi-Fi connection. Fig. 1 presents an overview of the model where its main components are highlighted.

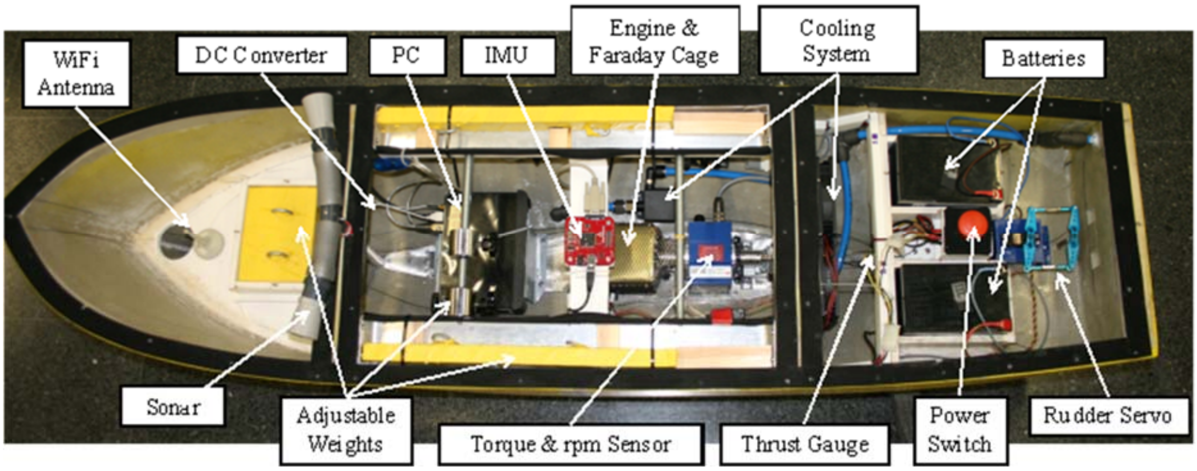

Fig. 1. Ship scale model overview.

The power for all the elements is provided by two 12 V D.C. batteries, placed abaft in the ship, providing room in their locations for longitudinal and transverse mass adjustment. These batteries have enough capacity for a whole day of operation.

Two adjustable weights have been placed in both sides of the model, and another one has been placed forward in the centerline. In both cases, enough room has been left as to allow transversal and vertical mass adjustment. Moreover, two sliders with 0.5 kg weights have been installed for fine tuning of the mass distribution.

3.2. Speed Measurement and Control

The main requirement for the ship model speed measurement system is that it cannot introduce any modification on the drag of the ship model. This constrain lead us to choose a laser range finder (LRF) as a tool to determine the speed of the model. The selected LRF model has been an AccuRange AR1000 by Aquity, and is the only element of the system that is not installed onboard. This LRF is intended to measure distances up to 150 m and has an accuracy of 3 mm. The LRF is installed onshore at one of the ends of the tank and transmits data via a radio-modem to the onboard measurement and control system.

The value of the velocity is obtained indirectly as a derivative of the measured distance values. As this LRF is intended to measure distances and not velocities, it needs to be validated as a speedometer. For this purpose several tests have been made to check its behavior when measuring velocities in real conditions. These tests have been performed on a moving target positioned on a gimbal that is placed on a moving wheeled platform. This set-up is able to replicate the ship motion in extreme conditions and in a controlled and cheap way.

An example of the speed-measured results is presented in Fig. 2. This figure presents the row velocity as it is obtained by direct differentiation of the distances measured by the LRF, as well as the same results but filtered such to neglect spurious measurements. A simple three-sigma filter is applied; this filter takes the average and standard deviation of the last ten valid points and eliminates the point under consideration if its value differs on more than three times the standard deviation from the average value. As it can be seen the filtered measurements are very good. In some test cases under extreme conditions some intervals appear without a valid velocity value, so diminishing the effectiveness of this simple method.

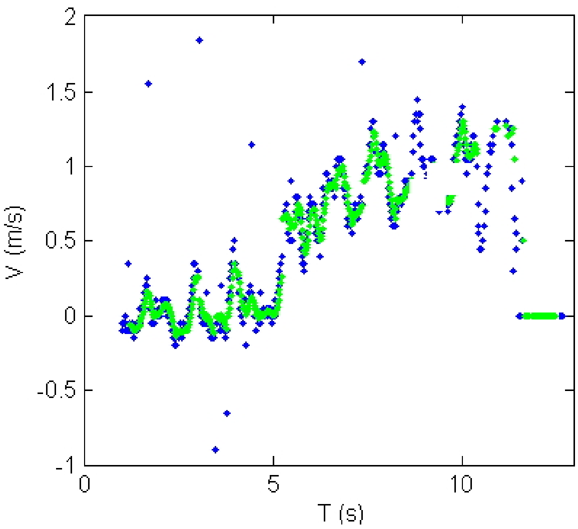

Fig. 2. Raw (blue dots) and filtered (green dots) velocity values obtained by differentiation of the LRF signals.

The speed control of the model is done by setting a command that keeps the revolutions of the motor constant by means of a PID controller programmed within the governing software. Alternatively, a servo command may be used for setting a constant power input for the motor. In calm waters and for a given configuration of the ship model, it exist a relationship between ship speed and propeller revolutions. By performing some preliminary tests at different speeds this relation can be adjusted and used thereafter for testing within a simple controller. However, in case of testing with waves, these waves introduce an additional strong drag component on the ship movement and there is not a practical way of establishing a similar sort of relationship. For these cases, the towing carriage is used as reference and the speed is maintained by keeping the ship model in a steady relative position to the carriage.

The speed control strategy to cope with this composed speed is shown in Fig. 3. It is done by means of a double PID controller; the upper section of the controller tries to match the ship speed with a set point selected by the user, cv. This portion of the controller uses the derivative of the ship position along the tank, x, as an estimation of the ship speed, e_{vx}. The bottom section, on the other hand, uses the integral of the ship acceleration in its local x-axis from the onboard IMU, v_a, as an estimation of the ship speed, e_{va}. Each branch has its own PID controller, and the sum of both outputs is used to command the motor. Both speed estimations come from different sensors, in different coordinate systems, with different noise perturbations and, over all, they have different natures. The estimation based on the derivative of the position along the tank has little or zero drift over time, and its mean value matches the real speed on the tank x axis, and changes slowly. On the other hand, the estimation based on the acceleration along the ship's local x-axis is computed by the onboard IMU, from its MEMS sensors, and is prone to severe noises, drift over time and changes quickly. Furthermore, the former estimation catches the slow behavior of the ship speed, and the latter its quick changes. This is the reason to use different PID controllers with both estimations. The resulting controller follows the user-selected speed setpoint, with the upper branch, eliminating any steady-state speed error, and minimize quick speed changes with the lower branch. Future works in this area would be testing controllers specifically designed to this kind of problems, such as complimentary filters.

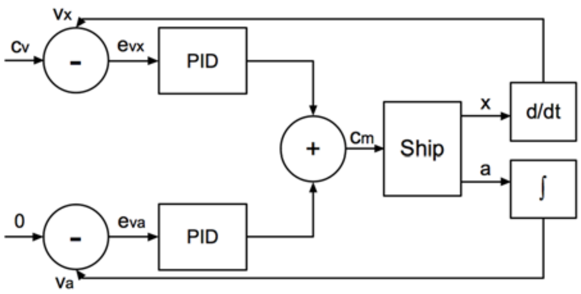

Fig. 3. Speed controller.

The second part of the controller is another PID that has as input the x-axis position of the ship relative to the carriage and finds the difference (error) with the setpoint position. The controller then computes a motor signal so as to minimize this error.

3.3. Course and Track Keeping

Regarding heading control, IMU and sonar data have been used for keeping the model centered and in course along the towing tank. For security reasons and for cases where these values are not accurate enough, heading control could be switched to a manual mode and an external RC transmitter could be used for course keeping. A first attempt was made where the signals from the sonars and a Kalman filter taken data from the IMU were used to keep the course. In this arrangement the IMU magnetometers' signals were of primary importance for the Kalman filter. Nevertheless, during testing, this arrangement manifested to be not very effective because the steel rails of the carriage, placed all along at both sides of the tank, induced a shift in the magnetometer signals when the ship model was not perfectly centered at the tank. In addition, the magnetometers were also very much affected by the electrical power lines coming across the tank. For these reasons only the sonar signals were used to help in keeping both course and position, with the aid of the relative position to the carriage, which have been used to have a reference for keeping the speed constant anyway.

In order to have sonar sensitivity to course variations, and not just to the side displacements from the tank centre line, the sonars have been pointed with an angle *g* towards the sides of the tank. In this way, any course change with respect to the tank orientation will produce a change in the sonar readings even if the model did not move apart from the middle of the tank yet. Some experimental tests have been carried out in the test basin of the School for Naval Arquitects of the Technical University of Madrid. Fig. 4 presents the row and filtered data of the distance measured by both sonars during a test. The filter removes outliers by using a simple "3σ-rule" similar to the one used in the velocity tests.

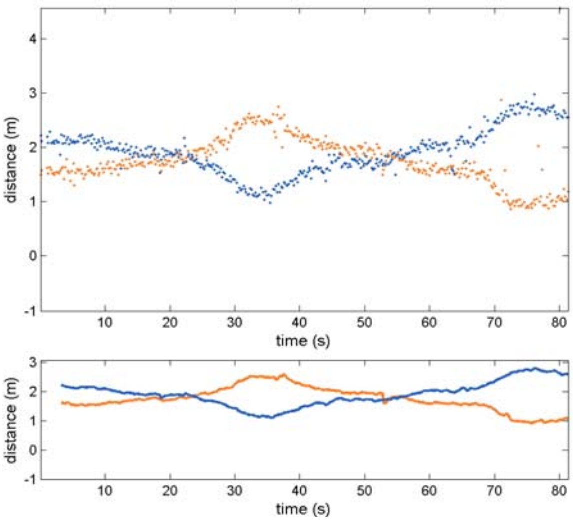

Fig. 4. Raw (top) and filtered (bottom) measurements from the left (red) and right (blue) sonars.

The automatic track control of our system is based on a PID controller that takes as inputs the estimations of course and distance to the tank centerline obtained by processing the sonars outputs. Some tests have been performed as it is explained in the next section.

4. Testing

The proposed system has been used to perform different tests, some of which have been published elsewhere [8]. It is not the purpose of this paper to going into the details of all the tests performed but we want to put as an example some results of a campaign to characterize and forecast the development of parametric roll on a ship. Is in this sort of tests, characterized by large amplitude oscillations in both roll and pitch motions, where the proposed system performs best as it can take information on board without disturbing the free motion of the ship model.

To illustrate the influence of the towing device on the measures obtained in this kind of tests, Fig. 5 is presented. On it, the pitch and roll motions of a conventional carriage-towed model (Fig. 6) in a similar parametric rolling test, are included.

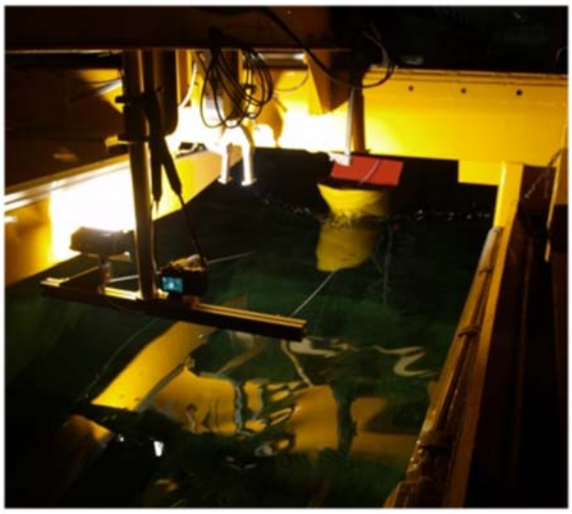

Fig. 5. Conventional carriage-towed model during testing.

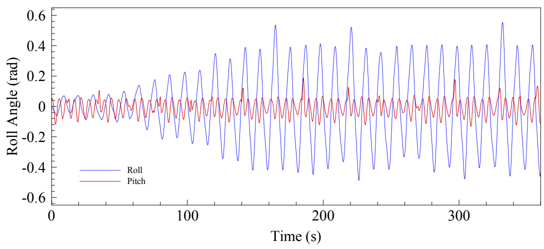

Fig. 6. Roll and pitch motions in parametric roll resonance.

As it can be observed, the ship pitch motion presents a series of peaks (the most relevant in seconds 140, 180, 220 and 300), which are due to the interference of the towing device. These interferences not only influence the model pitch motion, but could also affect the development of parametric roll and so, the reliability of the test.

The test campaign has been carried out in the towing tank of the Technical University of Madrid (Fig. 7). This tank is 100 meters long, 3.8 meters wide and 2.2 meters deep. It is equipped with a screen type wave generator, directed by a wave generation software, capable of generating longitudinal regular and irregular waves according to a broad set of parameters and spectra. The basin is also equipped with a towing carriage able to develop speeds of up to 4.5 m/s.

Fig. 7. Proposed model during testing.

During the experimental campaign, IMU output data was sampled by the onboard computer at a rate of 50 data sets per second. To forecast the onset and development of the parametric roll phenomena some standard perceptron ANN have been used. As for this particular ship model the roll period of oscillation is of few seconds, the data used for training the ANNs was under-sampled to 2 Hz, this data rate results more than enough to capture the events while allowing to reduce the size of the data set used. The tests have been performed on both regular and irregular waves in cases ranging from mild to heavy parametric roll. Several ANN architectures where tested and the overall best results have been obtained with 3 layers of 30 neurons each. In regular waves the RMS error when predicting 10 seconds ahead has been of the order of 10-3 in cases presenting large roll amplitudes and it reduces to 10-4 in cases with small amplitudes.

Fig. 8 presents the forecast obtained by the ANN (dotted line) 10 seconds ahead compared with the real data (full line). This is a typical example of a case presenting large amplitudes and as it can be seen, the results are very good.

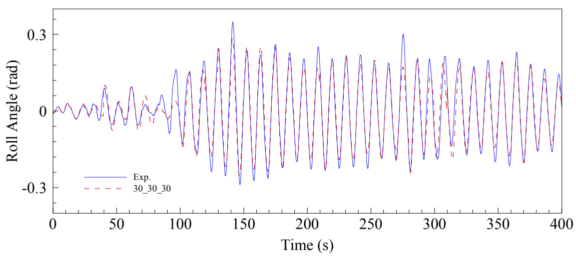

Fig. 8. Measured and forecasted roll motion.

In addition to this, the results of pitch and roll motion obtained with the proposed model are presented in Fig. 9, for the sake of comparison with the results obtained with the conventional model (Fig. 5). As it can be seen, the pitch time series doesn´t present the peaks observed in the conventional model measurements, as no interference between model and carriage occurs in this case.

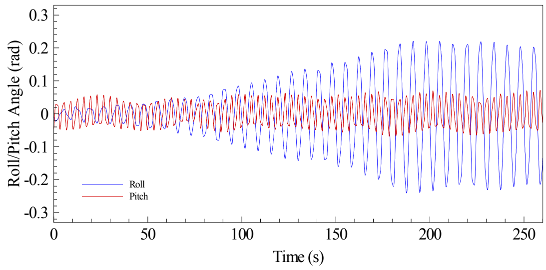

Fig. 9. Roll and pitch motions in parametric roll resonance. Proposed model.

Further details of the characteristics and performance of the forecasting ANN system have been presented by the authors in [8]. There, the forecasting system has been implemented on a ship model instrumented with accelerometers and tested by using standard towing tank methods. The data used for Fig. 4 plots has been obtained during this testing campaign.

During these tests campaigns it has been observed that the sonar based track measurement system performs correctly except in situations where the ship model roll oscillations are larger than 15 degrees. In those cases the number of spurious sonar measurements increases and thus the performance diminishes. Unfortunately, these large roll oscillations frequently appear when performing tests on parametric roll resonance as well as on some other dynamic behavior tests.

Some other tests have been specifically performed to check the performance of the velocity measurement system. These tests manifest that the system performs generally well, but in some occasions the optical target moves out of the LRF laser beam during short time intervals and so the velocity cannot be measured during these intervals. This means that the speed control system would have no input during this periods of time and this could be a potential problem.

5. Conclusions and Future Work

The development and implementation of an autonomous scale ship model for towing tank testing has been presented as well as some of the results obtained with it during some real towing tank test campaigns. The system is aimed to be installed on board of self-propelled models, acting as an autopilot that controls speed, course and maintains the model centered in the tank. It has also an IMU with 3-axis accelerometer, gyroscope and magnetometer and an additional optional module measures the torque, rotational speed and propulsive force at the propeller, thus allowing also to perform propeller tests. A model ship so instrumented would be able to move without any restriction along any of its six degrees of motion, avoiding the interferences between the model and the carriage. Consequently, the system produces optimal measurements even in tests cases presenting motions of large amplitude.

At is present development stage the system only needs to use the towing carriage as a reference for speed and position; and this mainly in situations in which the track positioning and speed measurement modules perform badly as it has been indicated earlier. A most advanced version that could eliminate the use of this carriage is under development. This towing carriage, altogether with its rails, propulsion and instrumentation, is a very costly piece of hardware. The final version of the system could be constructed at a fraction of this cost and it will be a true towless towing tank, as it would allow performing any standard towing tank test without the need of an actual tow.

References

[1]. T. I. Fossen, Handbook of Marine Craft Hydrodynamics and Motion Control, *John Wiley & Sons*, UK, 2011.

[2]. W. N. France, M. Levadou, T. W. Treakle, J. R. Paulling, R. K. Michel, C. Moore, An investigation of head-sea parametric rolling and its influence on container lashing systems, *Marine Technology*, Vol. 40, No. 1, January 2003, pp. 1-19.

[3]. A. Francescutto, An experimental investigation of parametric rolling in head waves, *Journal of Offshore Mechanics and Arctic Engineering*, Vol. 123, May 2001, pp. 65-69.

[4]. I. Drummen, Experimental and numerical investigation of nonlinear wave-induced load effects in containerships considering hydroelasticity, PhD Thesis, *Department of Marine Technology, Norwegian University of Science and Technology*, Trondheim, Norway, 2008.

[5]. Testing and Extrapolation Methods. Loads and Responses, Stability, Model Tests on Intact Stability, in *Proceedings of the International Towing Tank Conference*, Vol. ITTC 7.5-02-07-04.1, 2008.

[6]. M. A. S. Neves, N. Pérez, O. Lorca, Experimental analysis on parametric resonance for two fishing vessels in head seas, in *Proceedings of the 6th International Ship Stability Workshop*, New York, October 2002.

[7]. F. Lopez Peña, M. Miguez Gonzalez, A. Deibe, D. Pena, F. Orjales, An Autonomous Scale Ship Model for Towing Tank Testing, in *Proceedings of the 7th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications*, Berlin, Germany, September 2013, pp. 25-29.

[8]. M. Míguez González, F. López Peña, V. Díaz Casás, L. Pérez Rojas, Experimental Parametric Roll Resonance Characterization of a Stern Trawler in Head Seas, in *Proceedings of the 11th International Conference on the Stability of Ships and Ocean Vehicles,* Athens, September 2012, pp. 1-11.

[9]. F. López Peña, M. Míguez González, V. Díaz Casás, R. J. Duro, D. Pena Agras, An ANN Based System for Forecasting Ship Roll Motion, in *Proceedings of the 2013 IEEE International Conference on Computational Intelligence and Virtual Environments for Measurement Systems and Applications*, Milan, Italy, July 2013, pp. 15-17.