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An Autonomous Scale Ship Model for Towing Tank Testing

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Abstract—**This paper presents the work done for developing a self-propelled scale ship model for towing tank testing, with the main characteristic of not having any material link to a towing device to carry out the tests. This model has been fully instrumented in order to acquire all the significant raw data, process them onboard and communicate with an inshore station, and all this for both seakeeping and resistance tests. In order to illustrate the applicability and advantages of the proposed model, some results obtained by its application on a towing tank test campaign, aimed at developing a parametric roll detection system, are also presented.**

Keywords—model testing; heading control; parametric roll

I. 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 and have more availability than ocean basins.

Among these 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 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. Further more, 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].

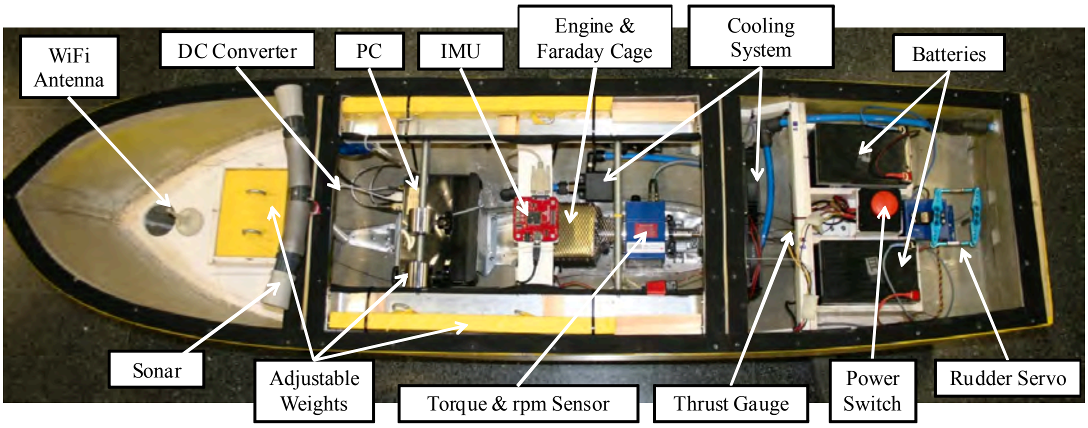

Figure 1. Ship scale model overview.

The main objective of the presented 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 a self propelled and self controlled scale model, capable to freely move in the six degrees of freedom, as well as to measure, store and process all the necessary data 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.

II. 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 system presented in this work is conceived to be used in any kind of towing tank test, but it is particularly focused towards the analysis of parametric roll resonance, which falls within the field of seakeeping. The aim of seakeeping tests is to study the ship dynamic behavior while sailing in waves. In these 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.

III. System Architecture

The first implementation of the proposed system has been on a scale ship model that has been machined from high density (250 kg/m3) 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. 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 all the representative parameters mentioned in the preceding section, the following sensors have been installed onboard:

- Inertial Measurement Unit (IMU): it 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 thrust gauge has been installed to measure the thrust generated by the propeller at the thrust bearing.
- 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.
- Sonars: intended to measure the distance to the towing tank walls and feed an automatic heading control 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.

Figure 1 presents an overview of the model where its main components are highlighted.

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 Figure 2. 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, c_v. 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

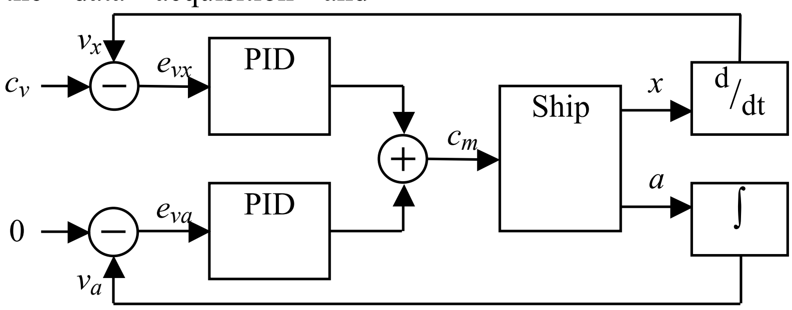

Figure 2: Speed controller

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.

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.

Regarding heading control, IMU and sonar data are used for keeping the model centered and in course along the towing tank. In case these values are not accurate enough, heading control may be switched to a manual mode and an external RC transmitter could be used for course keeping. At first, the signals of the sonars to maintain the model centered on the tank and a Kalman filter taken data from the IMU were used to keep the course, the magnetometers' signals being of primary importance in this Kalman filter. 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.

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.

IV. TESTING

The proposed system has been used to perform different tests, some of which have been published elsewhere [7]. 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, Figure 3 is presented. On it, the pitch and roll motions of a conventional carriage-towed model (Figure 4) in a similar parametric rolling test, are included.

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.

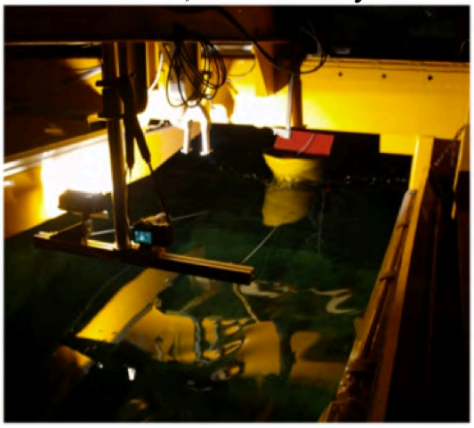

Figure 3. Conventional carriage-towed model during testing.

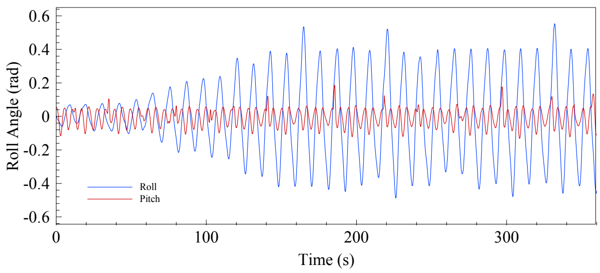

Figure 4. Roll and pitch motions in parametric roll resonance. Conventional carriage-towed model.

The test campaign has been carried out in the towing tank of the Technical University of Madrid (Fig. 5). 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.

Figure 5. 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.

Figure 6 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.

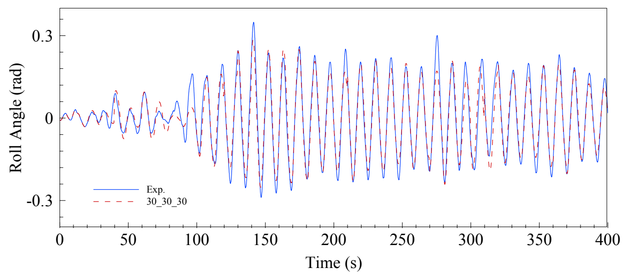

Figure 6. Measured and forecasted roll motion.

In addition to this, the results of pitch and roll motion obtained with the proposed model are presented in Figure 7, for the sake of comparison with the results obtained with the conventional model (Figure 4). 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.

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 figure 4 plots has been obtained during this testing campaign.

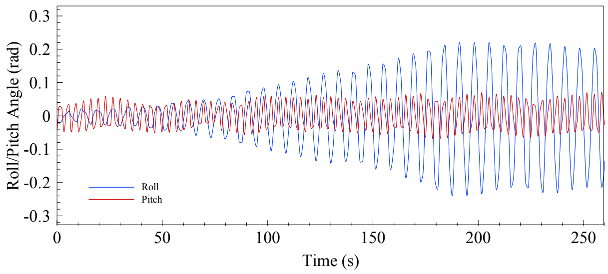

Figure 7. Roll and pitch motions in parametric roll resonance. Proposed model.

V. 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 a real towing tank test campaign. 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, in addition, it 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 reference for speed and position. 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.

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References

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

[2] W. N. France, M. Levadou, T. W. Treakle, J. R. Paulling, R. K. Michel and C. Moore, "An investigation of head-sea parametric rolling and its influence on container lashing systems", *Marine Technology*, *vol.* 40(1), pp. 1-19, 2003.

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

[4] I. Drummen, *Experimental and Numerical Investigation of Nonlinear Wave-Induced Load Effects in Containerships considering Hydroelasticity*, PhD Thesis. Trondheim: Norwegian University of Science and Technology, 2008.

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

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

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

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