A COMPUTER-BASED TESTBED FOR DESIGNING THE CONTROL OF VERTICAL MOTIONS OF A FAST FERRY

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Introduction

Vertical motions (heaving and pitching) of fast ships can cause serious inconveniences. There are some alternatives to alleviate this problem: for instance, to use active control surfaces. In our case, the ship has two flaps below the transom that we can move under control. Our research deals with automatic control. We want to determine a good control strategy, to move the flaps in the best way to counteract the effect of waves.

The first step of an automatic control study is to determine a suitable mathematical model of the system to be controlled. With this model, we can analyze on a computer the dynamic behavior of the ship, under several simulated conditions. If we can include in the model the actuators, then we have a testbed to probe the efficacy of any control strategy. In order to compare results, the study must establish a set of seakeeping scenarios, to test the modelled system.

An extensive review of the pertinent literature has been done, to get useful information for our work. The essential concepts are found in the books [1][2][3]. There are also important articles dealing with the dynamic response to waves [4][5], and others about control surfaces [6] and vertical motions control [7].

The paper is organized as follows. First, the description of the ship and the research done to get a mathematical model. Second, a model of the actuators, that can be included in the ship's model. Third, how the testbed is established. And to close the paper, some results with PID conventional control, and final conclusions.

Obtaining the Model of Vertical Motions of the Ship.

The ship is called "Silvia-Ana": a fast ferry acquainted to the waters of La Plata and also the Baltic Sea. The articles [8][9] present technical descriptions of this aluminium-made ship. The main characteristics are the following: mono-hull deep V form, 110m. length, 14.696m. beam, 2.405m. draught, 475 tons. deadweight, 1250 passengers. Figure 1 shows a photograph of her.

Figure1. Photograph of "Silvia Ana"

A scaled down replica has been built, to conduct experimental studies in a towing tank institution (CEIHPAR, Madrid, Spain). Vertical motions have been measured under regular and irregular heading waves, towing the replica at several speeds. The experiments with regular waves have been accomplished for 15 different wavelengths. The irregular waves have been generated according with STANAG 4194, for sea states 4, 5 and 6, with JONSWAP spectra. The measurement data have been sampled, and saved as computer files.

Using a geometrical model of the ship, by means of the program PRECAL, CEIPHAR generated another set of data, reproducing the same conditions of the experiments done with regular waves. This set is also useful to build the model, as it has no noise and can be easily processed for visualization in the format of RAO and phase diagrams.

The model has been obtained by considering first principles, decomposing into parts: relationship between waves and forces on the ship, and relationship between forces and motions. By means of MATLAB and SIMULINK, the model can be represented as a block diagram. Figure 2 depicts this diagram. The relationships just mentioned, can be described as Transfer Functions (this requires an identification [10] and curve-fitting study), and represented as the blocks of the diagram. An important cross coupling between heaving and pitching has been noticed, and represented in the diagram. SIMULINK is used to draw the diagram, and then to automatically generate MATLAB code. The MATLAB code can be employed to run simulations of the ship, to display and study her dynamic behavior (vertical motions).

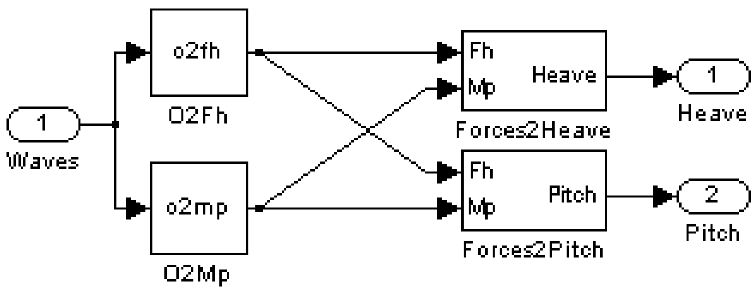

Figure 2. SIMULINK Model of Vertical Motions of the Ship

The model obtained shows a good agreement with the experimental data. For instance, figure 3 shows the data predicted by the model, and the data measured experimentally, about heaving and pitching at 30 knots with regular waves.

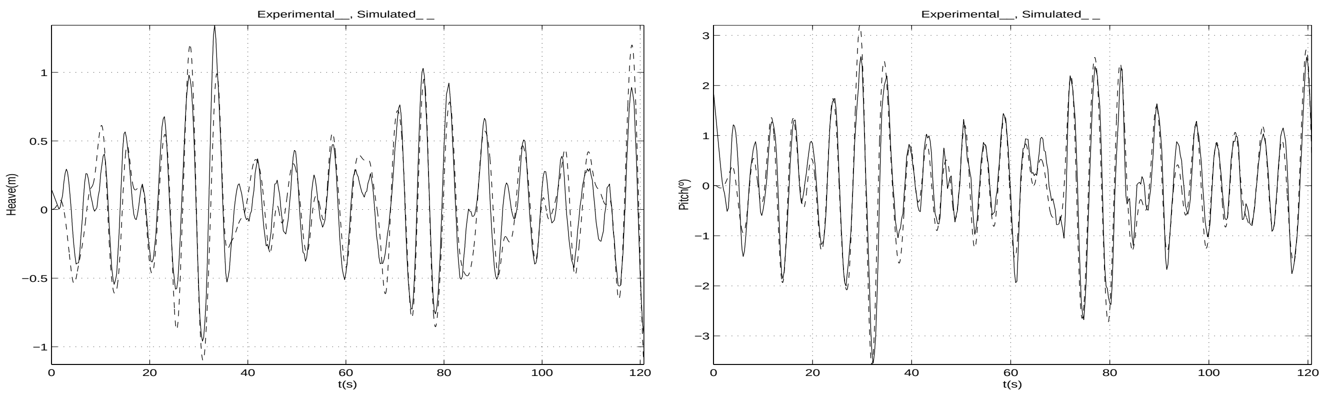

Figure 3. Comparison between Experimental Data (—) and Model (- -)

Augmented Model (Actuators)

From the point of view of automatic control, there are two aspects to be considered for modelling: magnitude of forces, and transient phenomena. In the case of the flaps, forces can be analyzed considering a wing moving into water. Concerning transients, the flaps are moved by hydraulic cylinders with a constant speed (not very fast).

Again, SIMULINK can be used for an easy building of models. Representing systems by means of blocks is much in the spirit of modern object-oriented modeling methodologies [11]. The outputs of the actuators model are heaving force and pitching torque. These outputs can be connected (through sum blocks) to the ship's model. Figure 4 shows how easily the model of the ship is augmented, to include the effect of the flaps.

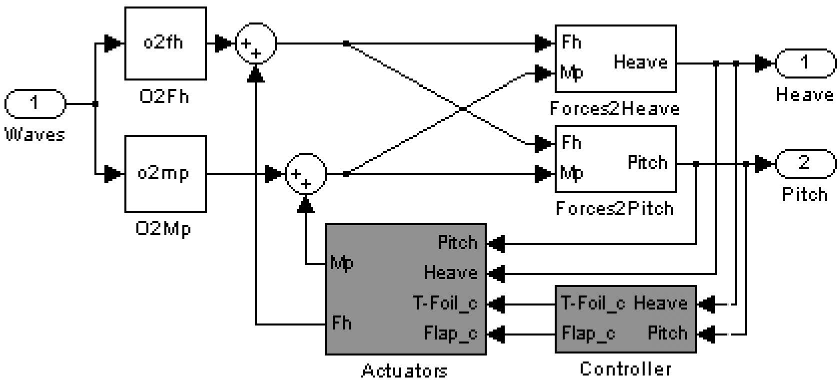

Figure 4. SIMULINK Augmented Model of the Ship with Actuators and Controller

Set-up for Testing

Simulation can be defined as to experiment with models. In this case, an experiment is to apply an stimulus, and measure the response. The experimental design, to carry on a suitable set of experiments, involves several constituents: stimuli, measurements, and ways to express and analyze the results.

It is important to take advantage of all the possibilities we have. Thus, we employ as stimuli the following:

- Regular waves (15 different wavelengths) generated by CEHIPAR, sampled and registered as computer data files.
- Regular waves generated using MATLAB, for any wavelength of interest.
- Irregular waves generated by CEHIPAR (also registered as computer data files), for sea states 4, 5 and 6 with JONSWAP spectra.

All the experiments are done with the computer. The effect of hours of cruising can be deduced in seconds. The model we developed is able (by changing Transfer Functions) to represent the behavior of the ship at 20, 30 and 40 knots. We have experimental data of heaving and pitching of the ship for these speeds.

Thinking about passenger comfort, the main problem is related with the amplitude of vertical accelerations. So, the main objective of flaps control should be to decrease these accelerations. Also, the chief objective of the simulation experiments is to measure vertical accelerations. We focus on peak values.

Using the SIMULINK model is easy to test the behavior of the ship with any control strategy. The conventional way is by means of a PID controller. This could be taken as reference, to confirm the advantages that can be expected from the flaps, and to see whether any other control procedure can be still better.

We studied the effect of a PID controller. Figure. 4 shows the SIMULINK diagram, with the ship and the PID controller applied to the flaps.

We first defined as the aim of the control to decrease heaving peak acceleration. The results obtained for ideal conditions (perfect action of the actuators), are on the left part of figure 5. Second, we defined as the aim of the control, the decrease of pitching peak acceleration. Again for ideal conditions, the results obtained are on the right part of figure 5. In both extreme cases, the predicted behavior of the ship, moving the flaps, is really better than having no flaps. In figure 5, each pie displays the decrease of the peak acceleration (in %), for sea states 4, 5 and 6, at 30 knots.

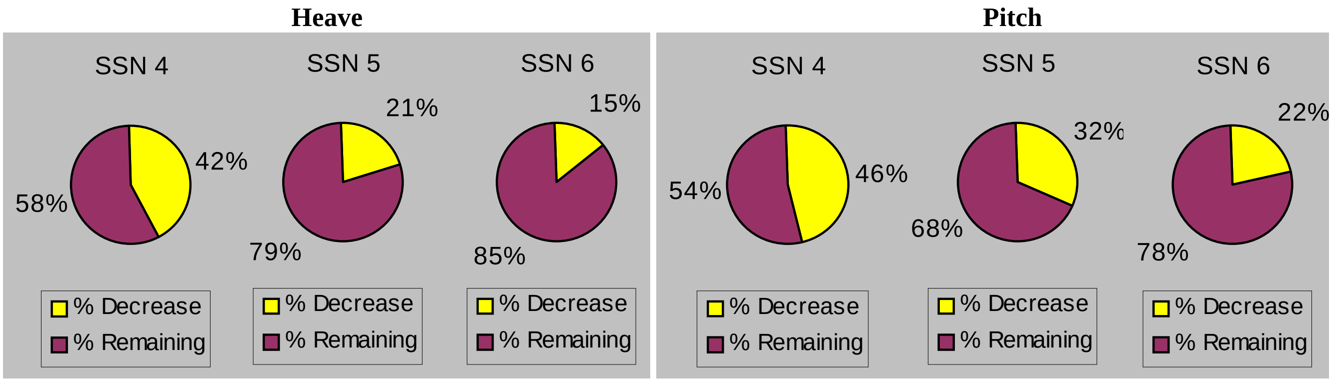

Figure 5. Effect of Moving Flaps on Vertical Motions of the Ship

During simulations we can zoom on any part of an experiment, to see waves and responses (heave and pitch) both in position and in acceleration terms. Figure 6 shows an example, at 30 knots, with and without PID. Our initial control design put focus mainly on the attenuation of the pitching accelerations (which is the most important part of the total vertical acceleration).

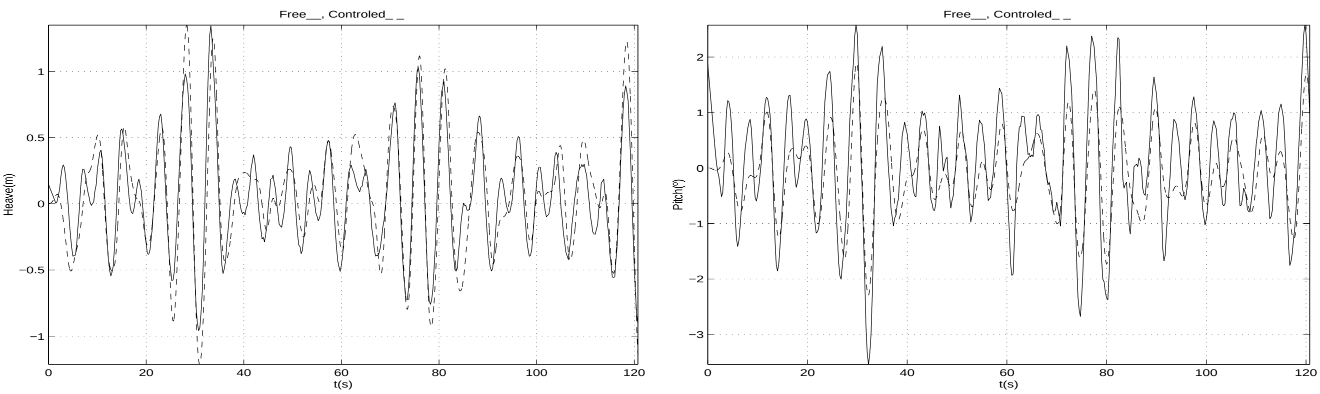

Figure 6. Heaving and Pitching Motions at 30 Knots, Without Flaps (—), and With Flaps (- -)

Conclusions

The paper briefly describes a computer-based testbed, that can be used to design a good controller for the flaps of a fast ferry. The heart of the testbed is a SIMULINK model, including the actuators. Different sea conditions can be studied, using both experimental sampled waves or computer generated waves.

Some initial studies have been conducted using the testbed, to get information about the advantages of the flaps. A conventional PID controller has been used, and good results have been obtained, compared with having no flaps. The SIMULINK model showed to be very useful for control design purposes, as it is inherently open to connect different controllers blocks.

Our research focuses on heaving and pitching with head seas. In the future we want to enlarge our view with other bearings and motions. Also, using the testbed already developed, we want to find better control procedures to move the flaps.

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