

A SIMULATION TOOL FOR A FAST FERRY CONTROL DESIGN

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Abstract: The research considers a fast ferry with active appendages: a T-foil near the bow and transom flaps. The objective is to attenuate the ship's vertical motions. These appendages are actuators that can move to counteract the effect of each incident wave. There is a problem of control design, to move the actuators in the most effective way. For an easy and safe control study, a simulation tool has been developed. The simulation is based on a previous experimental work to determine the adequate models. The simulation has been developed using MATLAB and SIMULINK: a modular architecture results where it is easy to integrate control strategies to be analysed. Simulated experiments can be run with the tool, to see the behaviour of the important variables: vertical motions of the ship, motions of the actuators, sea-sickness incidence, etc. The paper describes the simulation tool from a functional point of view, and explains some details of the main parts of its internal structure.

1. INTRODUCTION

Our research deals with the attenuation of vertical, heave and pitch, accelerations of fast ferries. For such purpose, the use of a T-foil near the bow and transom flaps is considered. By means of a control system, these appendages must move to counteract the effect of each wave. In consequence, there is a control design problem to be solved.

Direct experimental tests on ships, or scaled down replicas are time consuming and expensive (and maybe dangerous on real ships). To be able to conduct control studies on computer, reducing experiments to a minimum, a simulation environment is welcomed. Therefore a main objective of our research has been to develop a good simulation environment, focusing on the vertical motions of a ship. The behaviour of the ship with actuators, under the control strategy under study, must be predicted with high fidelity.

Using the facilities of CEHIPAR (Canal de Experiencias Hidrodinamicas de El Pardo, Madrid; in English: El Pardo Model Basin) a series of experimental and simulated studies have been accomplished, to establish the models for the simulation environment [De la Cruz, et al., 1998; De Andres, et al., 2000; Aranda, et al., 2000]. As a first step, the research is restricted to head seas.

The simulation environment is designed for an easy study of control design alternatives. Hence a modular structure has been achieved, on the basis of MATLAB and SIMULINK "modus operandi". The results is that, in effect, it is easy to incorporate any control strategy into the environment, to see what happens to the ship's response to waves when this control strategy is applied.

Along the development of the simulation tool, a first version was achieved. Some aspects of this version, in particular those related to actuators modelling, were presented in a previous paper [Esteban (a), et al, 2000]. The recent experiments made by CEHIPAR, to test first control solutions, showed several new aspects that should be considered for a more realistic simulation. For instance there is a mixture of noise and vibrations, so filters must be applied. Also, the interactions of ship and actuators and the non-linear acceleration behaviour recommended to introduce some modifications into the SIMULINK blocks of the simulation. Therefore, in this paper a new, more refined version of the simulation tool, is presented.

The paper begins with a short summary of the research already done to establish the models. Then, the simulation environment is introduced, from a functional perspective. After that, the paper proceeds with a description of the main SIMULINK blocks of the simulation. Finally, the paper covers

some aspects of the use of the simulation tool for control studies.

2. SUMMARY OF THE MODELLING RESEARCH

The particular ship selected for the research is an aluminium-made fast ferry with the following characteristics: deep-V mono-hull, 110m. length, 1250 passengers. The ship is able to get a speed of 40 knots or more.

CEHIPAR built a scaled-down (1/25) replica of the ship without actuators. Experiments have been conducted to measure pitching and heaving motions and accelerations, for regular and irregular waves. The regular waves covered a range of 15 different wavelengths. The irregular waves were generated according to JONSWAP spectra for SSN 4, 5 and 6. The experiments were accomplished for 20, 30 and 40 knots. The experimental data were recorded as computer files.

Using another facility of CEHIPAR, simulated data were obtained for regular waves. This is based on the use of PRECAL: a simulation program based on a CAD description of the hull. This program provides information on motions, forces and moments. The modelling approach was based on a decomposition into waves-to-forces and forces-to-heaving motions, and waves-to-moments and moments-to-pitching motions. Four transfer functions were determined for each speed: 20, 30 and 40 knots. The simulated data were used to determine the models, and the experimental data to validate the models. Some first models were obtained, [De la Cruz, et al., 1998; De Andres, et al., 2000; Aranda, et al., 2000].

The actuators were first designed, and then modelled. The modelling was based on first principles.

The models of the ship and the actuators were integrated to create a first simulation environment, using MATLAB and SIMULINK, [Esteban (a), et al. 2000]. The design of the environment is open to include blocks for control testing. First conventional P.D. controllers were tuned on the environment.

CEHIPAR added scaled-down actuators (a T-foil and transom flaps) to the replica. Experiments were accomplished to set up the control system. This system includes accelerometers, step motors to move the actuators, and an industrial PC with all the needed electronic interfaces. After that, two series of experiments were accomplished. The first one focused on the P.D. tuning for real conditions. During these experiments several problems

appeared, mainly noise and vibrations. Filters were designed and included into the control. The second series experiments were dedicated to evaluate the performances of the improved control.

Figure 1 shows a photograph of the replica with the actuators. Figure 2 a photograph of the experimental set-up in the CEHIPAR towing tank.

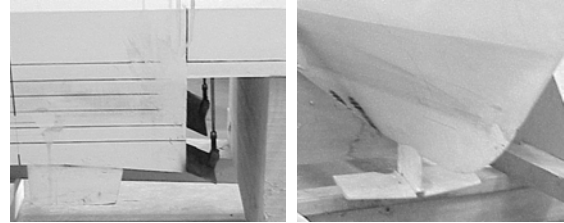


Figure 1: Photographs of the Replica with Actuators

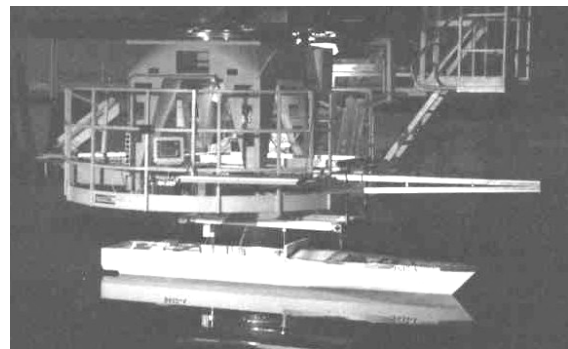


Figure 2: Photograph of the Experimental Set-up

The information obtained during this part of the experimental study, using the replica with the actuators, has been important to refine the simulation environment, for a more realistic control testing.

3. THE SIMULATION TOOL

Taking advantage of the MATLAB and SIMULINK characteristics, the simulation tool runs under MS-Windows. Using the mouse, several windows can be open to inspect the variables of interest during simulations. Figure 3 shows a screen of the simulation.

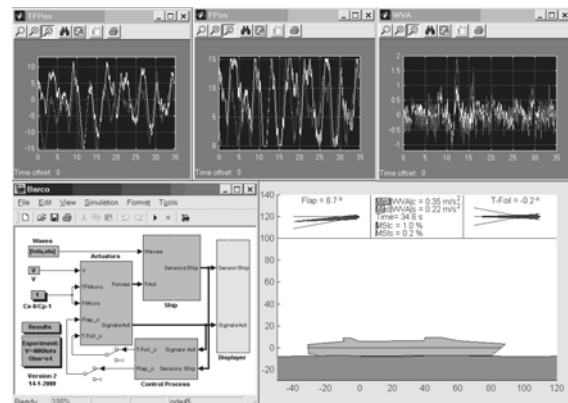


Figure 3: A Screen of the Simulation Tool

When the simulation starts, a window with a SIMULINK diagram and another with a picture of the ship appear. The SIMULINK diagram contains the models of ship and actuators, and a block were the control designer puts the control strategy to be studied.

Figure 3 shows a row of three windows at the top of screen. This is an example of the windows we can open, resize, zoom, close, etc., to observe any variable of interest (for instance, in the figure 3, motions of the T-foil and flaps, WVA acceleration).

The simulation tool is used to run experiments. By clicking on the SIMULINK block labelled "Experiments", a dialog window opens. Figure 4 shows this window. The combo box "Experiment" let us to select the kind of experiment, without appendages, with appendages or controlled. The user specifies the total time of the experiment, "Simulation time". There are also, in the "Speed" line, three possible ship's speeds: 20, 30 and 40 knots. Finally, there is a set of regular and irregular waves (the same studied in the CEHIPAR experiments) that can be used for the experiments. The environment compares the simulated results with the experimental results for the experiment selected.

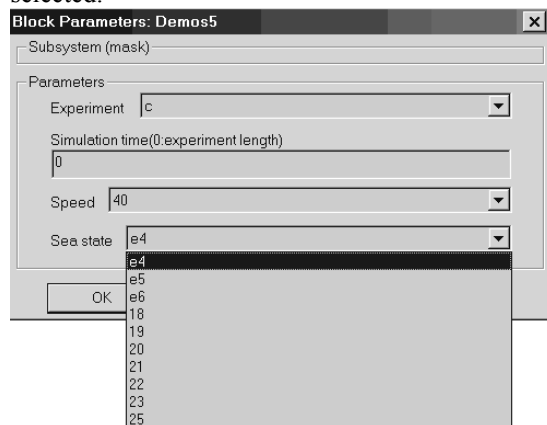


Figure 4: Window for Experiment Specification

When an experiment starts, the picture of the ship moves, in response to incident waves, and data are simultaneously displayed on the windows opened by the user.

When an experiment finishes, all data obtained along time are there, as computer files, together with other information pertaining to a qualification of the results. This information is in the form of numerical indexes, to measure the general effects of the control along the complete experiment. For instance, the MSI (motion sickness incidence) index [O'Hanlon, MacCawley, 1974], and other related to the reduction of vertical accelerations. Therefore we have the means to compare different control solutions.

4. INTERNAL ASPECTS OF THE SIMULATION TOOL

Let us describe some details of the SIMULINK blocks. Figure 5 zooms on the main SIMULINK diagram of the simulation screen.

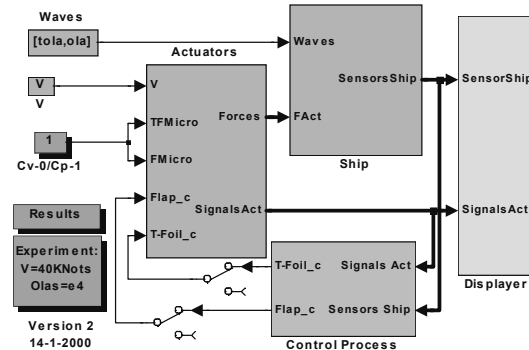


Figure 5: Main SIMULINK Diagram

In this new version the direct feedback from "Ship" block to "Actuators" block [Esteban (a) et al. 2000] has been eliminated using new models of the ship with appendages. This is very important for the simulation because this behaviour is very complex and the feedback in the old version means an algebraic loop, difficult to handle for the integration. With algebraic loops it is necessary to use a very fine integration step: this implies a slower simulation.

The "Control Process" block include different sub blocks, figure 6. There is a sampling block to force the user to employ sampled signals like in the experiments. A filter has been added to eliminate noise in the WVA signal. The "Controller" is the block to be defined by the user, to study on the simulation the performance of a candidate for the control. Since the P.I.D. controller is the conventional solution, our first studies focused on this alternative. The objective is to get results for reference purposes (to confirm whether we can find better solutions).

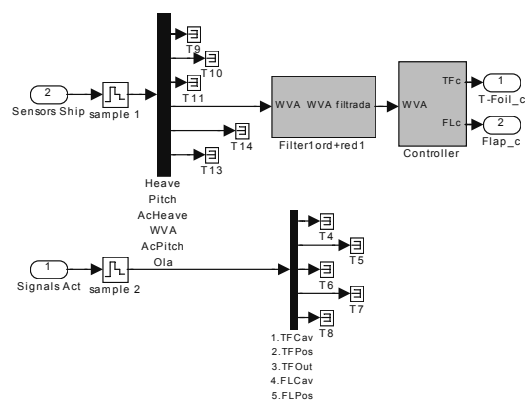


Figure 6: Internal Implementation of the Block "Control Process"

The models included in the blocks at the centre of Figure 5 have been described in previous papers [Esteban (a), et al., 2000; Esteban (b), et al., 2000]. Let us summarize with a short explanation how the models were implemented.

Figure 7 shows the contents of the block labelled "Ship". The left-hand part -the block labelled "Filters"- is a model of the ship's vertical motions. The right-hand part -the block labelled "Sensors"- allows for the inclusion of experimental noises in the simulation.

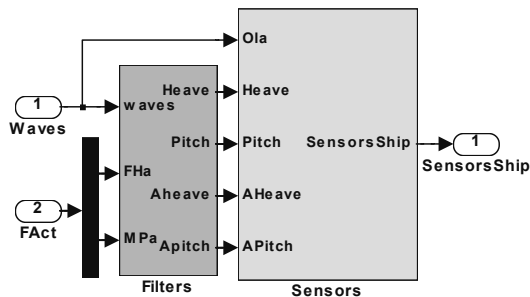


Figure 7: The Contents of the Block "Ship"

The block "Filters", the heart of the environment tool, is made with several blocks (figure 8). Its structure differs from the ship models found in the literature. So this is a novel contribution. Better accelerations modelling has been obtained with this new structure. The model has been decomposed in four state space equations, O2Ah, O2Ap, A2H and A2P. These state equations are very simple, order 2. The crossing of connections means a coupling between heave and pitch motions. There are two conditioning blocks to transform actuators forces an moments to accelerations.

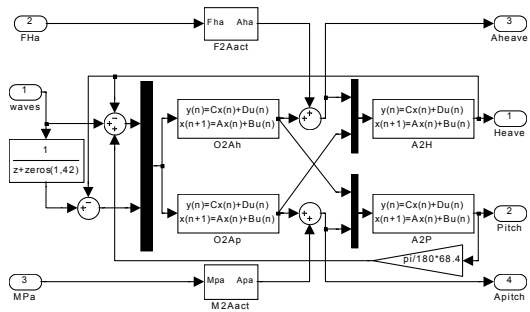


Figure 8: The Contents of Block "Filters"

The block "Actuators" (in figure 5) is made with several blocks: one to model the T-foil's lift force, other to model the flaps' lift force, and other to compute the effect of these forces on heaving force and pitching torque. The output forces and moments of these blocks are connected to inputs in the "Filter" block. Figure 9 shows the internal

structure of block "Actuators". An specification of this block can be found in [Esteban (a) et al, 2000].

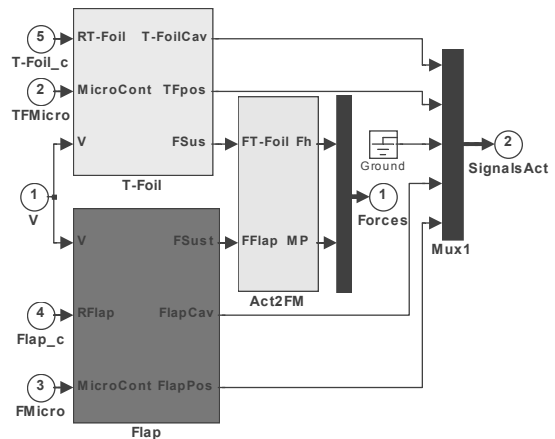


Figure 9: The Contents of Block "Actuators"

In figure 7 there is a block called "Sensors". The noise of the different measured signals has been isolated and is added to the simulated signals to improve the agreement with the real experiments.

Compared to the first version of the simulation tool, the new version involves the following improvements:

- The inclusion of the noise captured by sensors.
- Between ship and actuators there is an intrinsic feedback loop. Starting from a new identification of the ship, now with appendages, the feedback has been embodied in the models of the ship. In this way two algebraic loop of the simulation has been eliminated, and the processing time to run the simulation has been reduced.
- With respect to ship's accelerations the models have been improved for a closer agreement with experimental data.
- The "Controller" now includes filters to eliminate noise from sensors.
- The actuators efficiency has been fitted to the experimental actuators efficiency.

5. THE CONTROL STUDY WITH THE SIMULATION TOOL

Considering several steps of a typical control study, the simulation tool has been developed for several uses.

In the beginning of the study of a particular control strategy, the simulation tool can be used for qualitative analysis. Besides getting information about the effects of control on passenger's comfort, it is also important to see possible emergences of the actuators (it must not happen: they can be destroyed), slamming (if any), and the behaviour of

the actuators (it is convenient to avoid excessive control efforts).

The window with a moving picture of the ship has been developed for a more intuitive display of the ship's behaviour. Figure 10 zooms on this window.

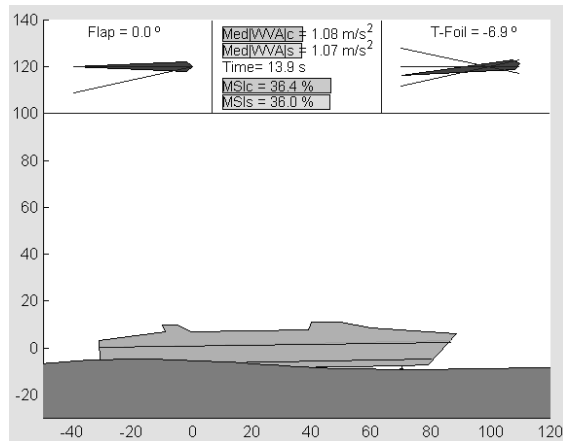


Figure 10: The Window with the Moving Ship

In this window the user can observe, in addition to the ship's response to incident waves, how the actuators will move and the increasing of the motion incidence as the simulated cruise proceeds. In the top centre there are four bars with values, two of them show the MAA for the simulation and for the experiment, and the other two the MSI. Notice how good is the agreement of the simulation and the real behaviour for the MSI percentages.

The results of the simulation are very good. The figure 11 shows the experimental WVA measured by an accelerometer and the WVA simulated, it is very difficult to distinguish the two signals.

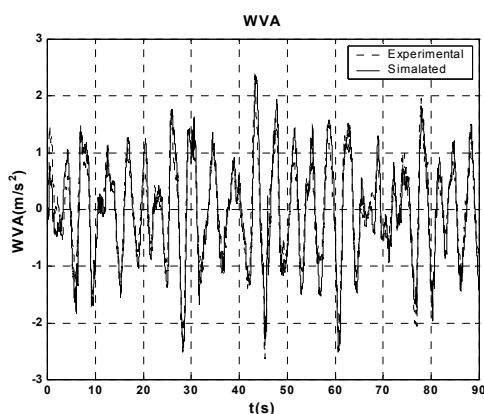


Figure 11: The Window with the Moving Ship

Usually some parameters of the control must be adjusted for optimal results (for instance, tuning a P.D.). Since the complete system is non-linear (there are speed limits and saturations of the actuators) it is difficult to apply analytical methods for optimisation. But the simulation tool can help to

find the optimal by any searching method (for instance with genetic algorithms). In such case, a previous qualitative study can be useful to limit the searching space.

Eliminating the non-necessary functions (such is animated visualization along simulated experiments) and additional signals, a fast version of the simulation has been developed. The result can be used as subroutine of any optimum seeking procedure.

When a good solution has been attained, it is convenient to evaluate it for the complete set of experiments (different sea conditions and ship's speeds). For this purpose, a batch procedure has been implemented, so a set of fast simulations are run and the results (the control qualification indexes) are given as a text table. In this way it is easy to compare different control alternatives.

6. CONCLUSIONS

An important aspect of our research is to get a realistic simulation environment for control studies. The main objective of the research is to attenuate the vertical accelerations of fast ships, by means of moving appendages. The research consider the motions of a fast ferry facing head seas. The motion of appendages must be controlled as best as possible, to counteract each wave. There is a problem of control design. An efficient and safe way of conducting control studies is by using an accurate simulation. In consequence, the research focused on the development of a simulation tool, as a first step before control studies. A series of experiments have been accomplished to determine models of the ship and the actuators. The models have been validated, and are the basis of the simulation. A preliminary version of a simulation tool was developed and used to design a first, conventional controller (a P.D. controller). New experiments, with a replica of the ship with appendages, has been recently performed. With the new experimental information, several aspects of the simulation tool were improved.

The paper presented the new simulation tool: its functions and capabilities, its structure. The simulation has been developed in MATLAB and SIMULINK, it runs under MS-Windows.

First control studies are now under way using the tool. The tool proves to be useful and easy. The modular architecture of the simulation, based on SIMULINK blocks, make easy to integrate and test different control solutions.

Both the modelling methodology and the modular architecture pave the way for the study of other ships.

Our research now is starting to consider a more general context, not only head seas. The simulation will be expanded to other motions of the ship.

Acknowledgements

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