SMOOTHING FAST FERRY VERTICAL MOTIONS: A SIMULATION ENVIRONMENT FOR THE CONTROL ANALYSIS

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ABSTRACT

Fast ships are of increasing importance. At high speed vertical accelerations can have negative effects. By means of submerged actuators vertical accelerations can be alleviated. A good control must be designed, to move these actuators in the most effective way. It is not easy to optimise this design. A simulation environment has been developed, for an easy study of control alternatives. The simulation has been developed in Matlab and Simulink. It provides a set of windows for the display of the ship's behaviour under several sea states. The heart of the simulation is a set of models of the ship and actuators' dynamics, including non-linear phenomena. The paper describes the simulation parts and the use of the environment for control testing.

KEYWORDS

Ship simulation, marine systems, control systems, non-linear systems, MIMO systems

1 INTRODUCTION

Fast sea transportation has many advantages and is acquiring great importance. But there are difficulties and problems that limit the speed. For instance, vertical motions (heaving and pitching) degrade the comfort of passengers and may have negative consequences for the ship itself. Nowadays there are some alternatives to smooth vertical motions. By means of submerged control surfaces, it is possible to counteract the effect of waves. These surfaces must move in a correct way, taking into account the dynamics of the ship and the phase of the waves. This is a problem of automatic control.

Simulation has many important advantages for testing purposes, especially when real experiments are expensive and potentially dangerous. This is clearly the case with ships. Consider for instance how to safely tune a P.I.D. controller for several ships' speeds and several sea states. Doing this empirically, little by little along cruises, would be unpractical. It is better to obtain a good simulation of the ship's behaviour for a relevant set of speeds and sea states, and test the control systematically with the simulation to get optimal results.

The objective of our research is to devise a suitable control strategy, to smooth vertical motions in an appropriate way. With such purpose, a simulation environment has been developed. The simulation is based on a mathematical model of the system to be controlled. This model has been established after a long experimental work.

The development of the simulation has been done according to the following criteria:

- Different control design alternatives should be easily tested. For instance, the basis for the control could be accelerometers, or gyroscopes; the control may be linear or non-linear, with transfer functions or with state variables, etc.
- Any control solution should be easily and quickly evaluated, with an established set of experiments. In this way, different control solutions can be compared.

- The simulation should visualize the important aspects of the ship's behaviour. That includes the vertical motions of the ship and the motions of the actuators.
- During experiments, the simulation should process data to get quality criteria about motions and control. For instance, an evaluation of the seasickness along the simulated cruise.
- The simulation should be open for model improvements.

Since our research on the control problem involves the efforts of several teams, each one with a different candidate for the solution, an important objective of the simulation is to provide a common field for the design. The simulation environment we developed proved to be also useful for this purpose.

2 SMOOTHING THE VERTICAL MOTIONS OF A FAST FERRY

Modern fast ferries use new technologies to get speed. The advantages are clear, but also new problems arise. Our research is centred on vertical accelerations, which can be important at high speeds. These accelerations originate seasickness. By means of the MSI (Motion Sickness Incidence) formula (O'Hanlon & MacCawley, 1974), this effect can be evaluated in terms of percentage of passengers that get sick.

Our research concerns a particular ship, with the following characteristics: mono-hull aluminium-made, 110 m length and 1250 passengers (Anonymous, 1996). The ship is able to get a speed of 40 knots and more. The research considers only the response of the ship to head seas. A scaled down replica has been built (5m long), to obtain data to establish the mathematical model of the ship dynamics. The replica has been used to conduct experimental studies in a towing tank institution (CEHIPAR, Madrid), with regular and irregular waves. Submerged control surfaces (a T-Foil and two flaps) has been added to the scale replica to counteract the effects of waves.

The experiments with regular waves have been accomplished for 15 different wavelengths, and for three speeds: 20, 30 and 40 knots. The characteristics of the ship change with speed, mainly because the interaction of the ship with the surrounding water. The irregular waves have been generated for sea states SSN 4, 5 and 6, with JONSWAP spectra. The literature on ocean waves offers several statistical models, with probability distributions of wave height against wavelengths (Fossen, 1994; Lloyd, 1998; Esteban (a) et al, 2000). There are several sea states: the highest numbers meaning bigger waves. The JONSWAP spectra are related to coastal waters, which are the pertinent for the ferry we are considering.

The measurement data have been sampled and stored as computer files. Both heaving and pitching displacements and accelerations have been recorded, together with the excitation (the waves). The data about waves are also useful to reproduce in the simulation environment the same excitations.

3 THE MAIN SCREEN OF THE SIMULATION ENVIRONMENT

Simulation can be defined as to experiment with models. In this case, an experiment is to apply a stimulus and measure the response. We developed a simulation environment where the relevant experiments can be accomplished. The simulation has been developed using Matlab and Simulink, for an easy integration of control strategies.

As stimuli, the simulation environment can use both the regular and irregular waves generated by the towing tank institution. The effect of hours of cruising can be studied in seconds. The environment analyses the motions of the ship and, using a model of seasickness, predicts what will be the proportion of passengers that will feel bad.

By means of an interactive procedure, it is easy to apply any control strategy to the ship, and see the effects. The environment presents a window with an animated picture of the ship, to see the vertical motions in an experiment. This window also shows the motions of the actuators, and a statistic of the most important cumulative effects (including seasickness). It is dangerous for the ship to have slamming. This is also detected and considered by the simulation (one of the problems when the bow emerges is that actuators lose control and even can be destroyed). During simulations we can zoom on any part of the experiment, to see waves and responses (heave and pitch) either in position or in acceleration terms.

Figure 1 & 2 show the main screen of the simulation environment. It runs under MS-Windows, making benefit of all the user interface capabilities. The figure 1 displays a SIMULINK block diagram. Figure 2 shows a moving picture of the ship. Other windows can be opened to display all the variables of the simulation.

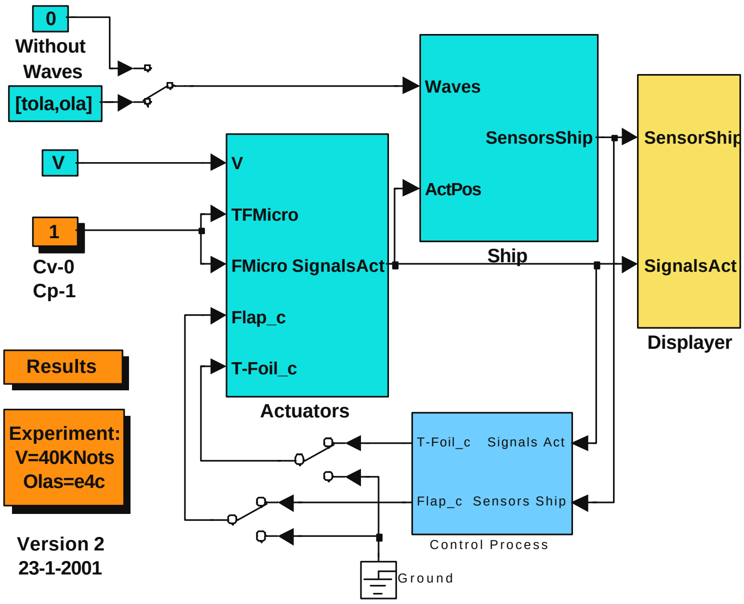


Figure 1. Simulink diagram of the Simulation Environment

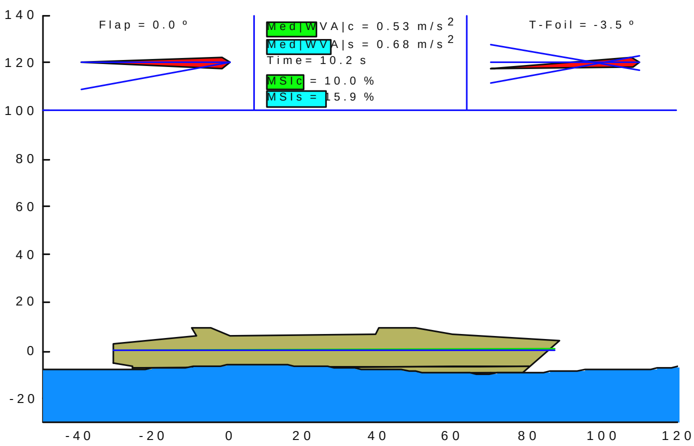


Figure 2. Graphical simulation.

4 THE SIMULINK MODEL

There are three main blocks in the centre of the Simulink diagram in the figure 1. The block labelled "Ship" is an input/output model of the vertical motions of the ship in response to waves. The block labelled "Actuators" is a model of the actuators that can be coupled to the "Ship", such that a model of the ship with actuators is obtained. The block labelled "Controller" takes information from the ship's behaviour, and can compute signals governing the motion of the actuators. This block is where the control designer can put any candidate control strategy to be tested. There are other sub blocks inside these blocks. The contents of the “Actuators” block (Esteban (b) et al, 2000) contains different sub blocks. Figure 3 shows the complexity of the sub block “T-Foil”, one of the actuators sub-blocks. The “Flap” has a similar model. An oriented object methodology has been used.

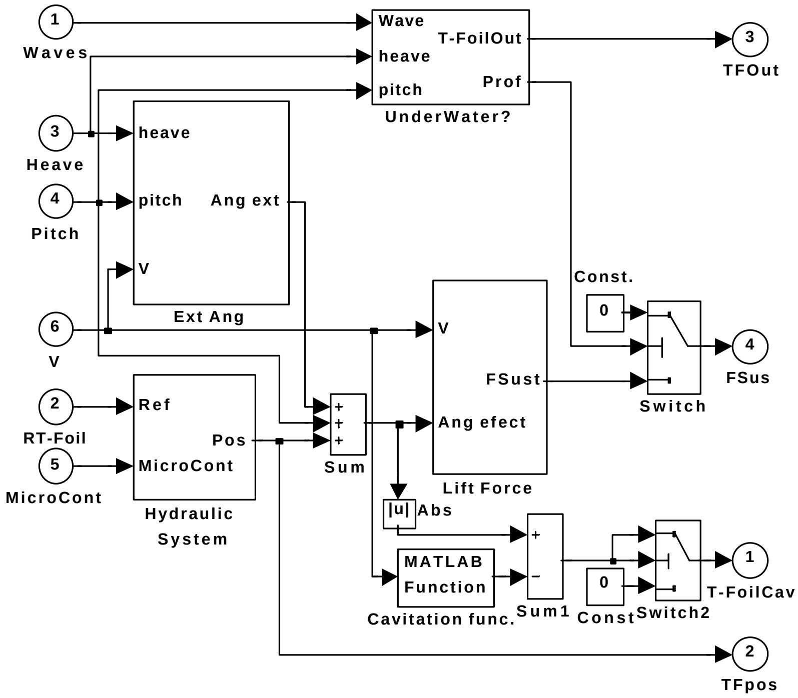


Figure 3. SIMULINK Diagrams of the Actuators model

Looking at the places where passengers can sit during the cruise, there is one (near the bow) with the worst vertical acceleration (we employ the term WVA for this acceleration). The block labelled "WVA", in the Simulink diagram of the figure 1, computes this acceleration (a combination of pitching and heaving vertical accelerations), which can be useful for the "Controller". A plausible objective of the control action can be to reduce as much as possible the WVA.

The block labelled "Displayer” in the Simulink diagram of the figure 1, handles all the visualization tasks: the windows with signals and the moving picture of the ship. Looking at the left-hand side of the figure there are other blocks. The block labelled "Results" is in charge of processing the responses, to obtain some quality indexes, such is the MSI or the attenuation of WVA r.m.s. Clicking the mouse on the block labelled "Experiment", a new window opens (Figure 4).

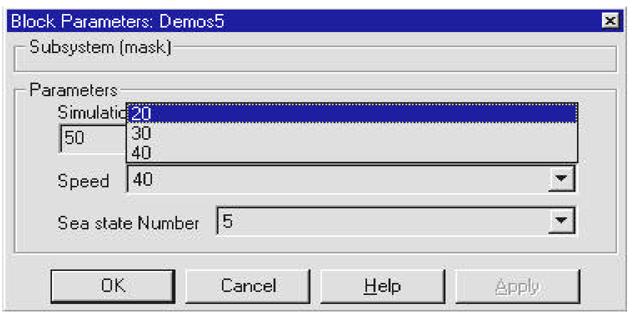
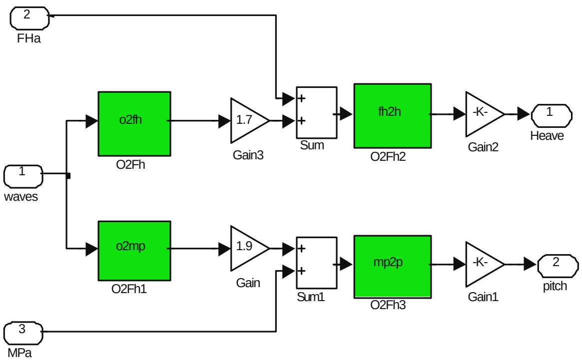


Figure 4. Dialog Window for Simulation Experiment Specification

As Figure 4 shows, the user can specify the experiment to be done by the simulation system. Using the dialog elements of the window, the user selects the ship's speed (20, 30 or 40 knots), the sea state (SSN 4, 5 or 6) and the total time to be simulated. Once the experiment is specified, the block labelled "Experiment" selects the adequate ship models and input data.

Each block of the SIMULINK diagram hides a complete sub-system. Four transfer functions into the block “Ship” are the heart of the model: they simulate the ship behaviour (figure 5). For example for 30 knots and SSN 5, the transfer functions included in the blocks are shown in the equation 1, (Aranda et al, 2000; De la Cruz et al, 1998; De Andres et al, 2000):



$$\begin{aligned} G(waves-force) &= \frac{0.083\cdot s^3+0.011\cdot s^2+0.637\cdot s-0.122}{s^4+1.147\cdot s^3+1.776\cdot s^2+0.616\cdot s+0.122} \\ G(waves-moment) &= \frac{-0.097\cdot s^3+0.093\cdot s^2-0.070\cdot s}{s^4+2.881\cdot s^3+5.251\cdot s^2+5.407\cdot s+2.057} \\ G(force-heave) &= \frac{0.341\cdot s^2-0.496\cdot s+2.841}{s^2+0.456\cdot s+2.841} \\ G(moment-pitch) &= \frac{-2.653\cdot s^3+17.652\cdot s+0.457}{s^3+1.297\cdot s^2+2.964\cdot s+1.118} \end{aligned} \tag{1}$$

Figure 5. Model of the ship

The simulation of ship behaviour is satisfactory indeed. See for instance Figure 6.

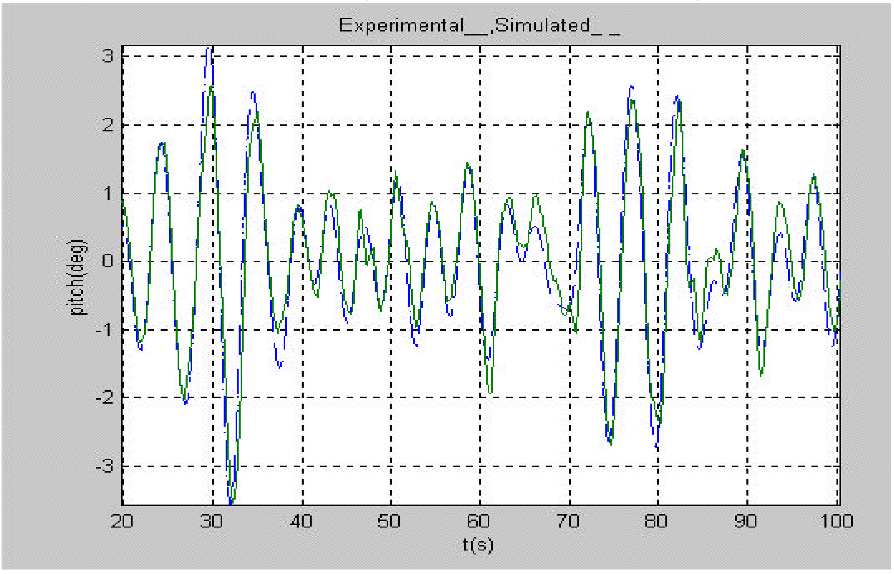


Figure 6. Model Validation: Pitch Motion at 30 Knots & SSN5

5 USING THE SIMULATION ENVIRONMENT

During the development of a control strategy, the simulation environment is useful to observe what happens with a specific controller. It is important to see if there is slamming, emergences of the actuators, excessive cavitation, etc. Also there are synchronicity aspects, between stimuli and control reaction, which are interesting to see (opening the pertinent variable display windows) in order to analyse the performances of control.

In the last steps of the development of a control solution, it is convenient to evaluate it for the complete set of experiments (a matrix of sea states and ship's speeds). For this purpose, the simulation environment provides an operational mode, where every effort has been done for processing speed, offering a batch procedure to automatically run the complete evaluation.

Since the ship with actuators is a non-linear system, it is not easy to find analytically the optimal parameters for any specific control strategy. In consequence, it is opportune to facilitate a systematic searching. This can be done as a version of the batch procedure. For instance, it has been used to tune a P.D. controller for a control based on one accelerometer measuring the WVA. A search for the best Kp and Kd parameters has been run.

6 CONCLUSIONS

By means of actuators, fast ferries can alleviate vertical accelerations due to waves. There is a problem of control, to move the actuators to counteract, as best as possible, the effect of waves. A simulation environment has been developed, where the control designer can easily study solutions for the problem. The developed environment promotes an open modular architecture that makes easy the integration of control alternatives to be studied, it also makes easy to introduce changes (model improvements, other actuators, other windows, etc.).

The target of our research is a fast ferry with specific characteristics; so the models have been determined for this ship, using experimental and simulated (program PRECAL) data. However, it is clear that the architecture of the simulation environment allows for the study of other ships. In particular, the way the model of the ship is formulated draws a neat path for the modelling of other ships.

First studies with conventional P.I.D. controllers are under way. An optimal tuning has been obtained using the simulation environment. The experiments already done in the towing tank confirm that the MSI can be dramatically reduced, see table 1.

Table 1. Reductions obtained with the controllers

Experim.	**V=30,SSN4**	**V=30,SSN5**	**V=40,SSN4**	**V=40,SSN5**
Reduction	76%	16%	59%	18%

In the next future, modern control strategies will be developed and tested, including robust control alternatives.

ACKNOWLEDGMENTS

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