A RESEARCH ON MOTION SMOOTHING OF FAST FERRIES

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Abstract

This paper is about a research on the use of active appendages to smooth the motions of fast ferries. According to Bazan specifications, the research focused on a fast ferry with a T-foil and transom flaps. A collaboration of three research groups, with he experimental support of CEHIPAR was established to accomplish the objectives. The research was scheduled as two main steps. A first step of control-oriented modelling has successfully been achieved. The second step is dedicated to control design and experimental evaluation, seeking for the best solution. First experimental results confirm good expectations with the use of the active controlled appendages. This paper describes the main aspects of the research: the problem to be solved, the methodology and fulfilment of the research project, and the most relevant results obtained.

1. INTRODUCTION

Fast ships are acquiring great importance. New technologies are applied for more speed and better performances. Also, new control systems and appendages are added for several uses. One of the problems with high speed is that considerable vertical accelerations, due to waves, can appear. These accelerations can originate sea-sickness [O'Hanlon, MacCawley, 1974], degrading the comfort of passengers.

Our research deals with the use of active appendages to smooth the motions of fast ferries. There are important reasons for smoothing the motions: to improve the comfort of passengers, to avoid negative effects on the ship, to increase the operational capabilities of the ship. The origin of the research is the proposal from the company BAZAN to start working on this topic. A collaboration of three investigation groups, from three universities, was established to embark on a research project. To have a solid experimental basis, the services of CEHIPAR (Canal de Experiencias Hidrodinamicas de El Pardo, Madrid), a prestigious towing tank institution, have been of particular importance.

The research project was defined and submitted to CICYT (Comit, Interministerial de Ciencia y Tecnolog¡a), the most important government entity for research promotion and support. The project obtained the approval and financial support from CICYT, and started in 1997.

It is interesting, to give an idea of the kind of problems to be treated, to look at a graphical representation of the impact of vertical accelerations on passenger's sea-sickness. There is an index, computed with a formula, denoted "MSI" (motion sickness incidence) that can be used as a statistical measure of the rate of passengers that get sick. Figure 1 shows that there is a frequency band (waves originate changing vertical accelerations) with a negative effect of passengers comfort. For the type of ships we are considering, usually the motions of the ship fall into this band.

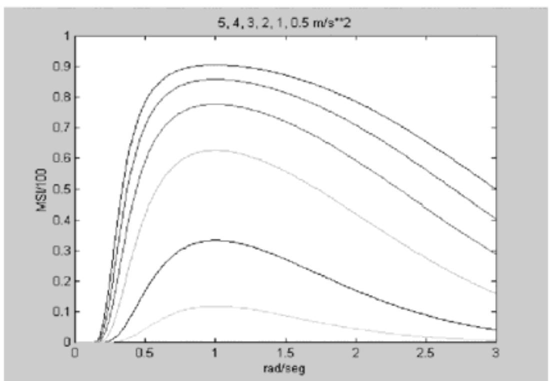

Figure 1: Model of Sea-sickness

It was clearly noticed, from the beginning, that the research involved several novel aspects. Fortunately, the difficulties found along the research, related to the experimental and the modelling tasks, were successfully solved.

The paper describes the main traits of the research. It begins dealing with the methodology and realization of the project. Next, the main results are presented. These results are satisfactory and promising.

2. STATEMENT OF THE RESEARCH

In order to have a specific ship, to centre the research, Bazan selected a particular example belonging to a series of fast ferries recently built by this company. The research was restricted to head seas. Bazan determined also the use of a T-foil near the bow and transom flaps, to smooth vertical motions. Figure 2 shows a photograph of the fast ferry. Figure 3 shows a lateral view of the ship, with a zoom on the actuators.

Figure 2: Photograph of the Fast Ferry

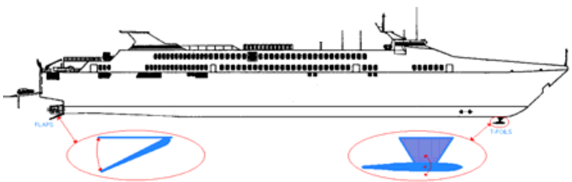

Figure 3: Lateral View of the Ship with Actuators

The T-foil and the flaps can move, to counteract the effect of each incident wave. By means of a control system, these appendages should move in the most effective way: that means a problem of control design. The objective of the research is to solve this problem, following some important steps:

- To obtain a dynamic, control-oriented model of the ship

- To define the criteria and specifications the control designs should obey.

- To develop an evaluation system for the control designs.

In view of the main objective and the necessary aspects, a time scheduling and an operational methodology was established for the complete research team. The experience with control investigations says that the first step, devoted to modelling, usually means the longest effort, since it requires an experimental basis. This modelling step is important because:

- When resorting to first principles analysis, it promotes a study in depth of the system to be controlled.

- On the basis of good models, reliable simulation environments can be created. The study of control on simulation environments is more flexible and fast, and less dangerous, than the direct experimental study.

- A simulation tool allows for a quick and easy evaluation of different control alternatives. Furthermore, it favours the development of more sophisticated and powerful control designs.

The main support for the physics analysis is given by [Fossen, 1994; Lloyd, 1998; Lewis, 1994].

To obtain the experimental data for modelling, CEHIPAR built a scaled-down (1/25) replica of the fast ferry. With the replica, CEHIPAR, using its facilities, performed a set of experiments at 20, 30 and 40 knots. In addition, CEHIPAR, using the program PRECAL, obtained simulation data about heaving and pitching motions, heaving force and pitching moment, for a set of regular waves and ship's speeds of 20, 30 and 40 knots. The program PRECAL computes motions, forces and moments, using a CAD description of the hull.

Figure 4 shows the replica in the basin, ready to the experiments with waves.

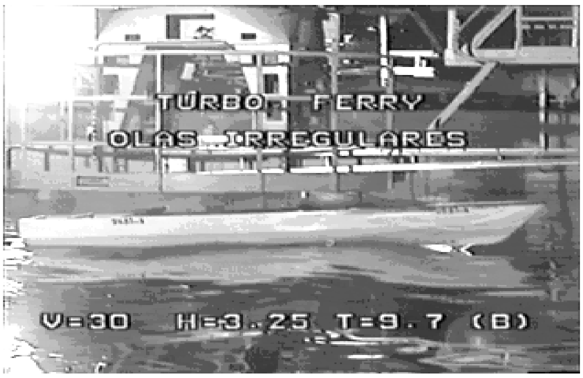

Figure 4: The Replica Ready to Experimental Study with Waves

Among the experimental data obtained, there are some related to the vertical accelerations measured in several places of the ship that are very illustrative, since our research tries to attenuate these accelerations. Figure 5 displays the measures obtained for the three speeds. Notice how big the acceleration can be near the bow.

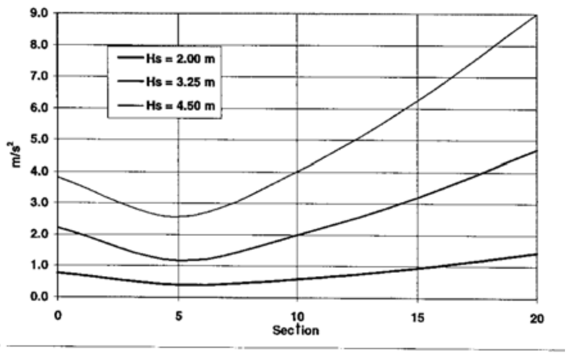

Figure 5: Vertical Accelerations Along the Hull

Figure 6 displays a block diagram that summarizes the statement of the research about modelling.

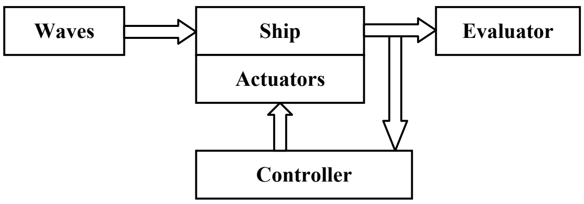

Figure 6: Block Diagram for the Modelling

According to this block diagram, the main tasks to tackle are the following:

- Modelling of the ship's dynamics. By using first principles and the experimental data with the replica.

- Wave generator. A program should be developed for generating waves for the simulation of cruises, according to several sea states.

- Modelling of the actuators. This implied a design of the T-foil and the transom flaps. The modelling approach is also first principles.

- Analysis and design of different control alternatives. Implementation and test with the replica.

3. METHODOLOGY AND REALIZATION OF THE PROJECT

From start it was decided that all programming was done with MATLAB- SIMULINK. In this way an easy coupling of blocks, and developing of control solutions, was fostered.

Figure 7 shows the relationships between the main tasks of the project.

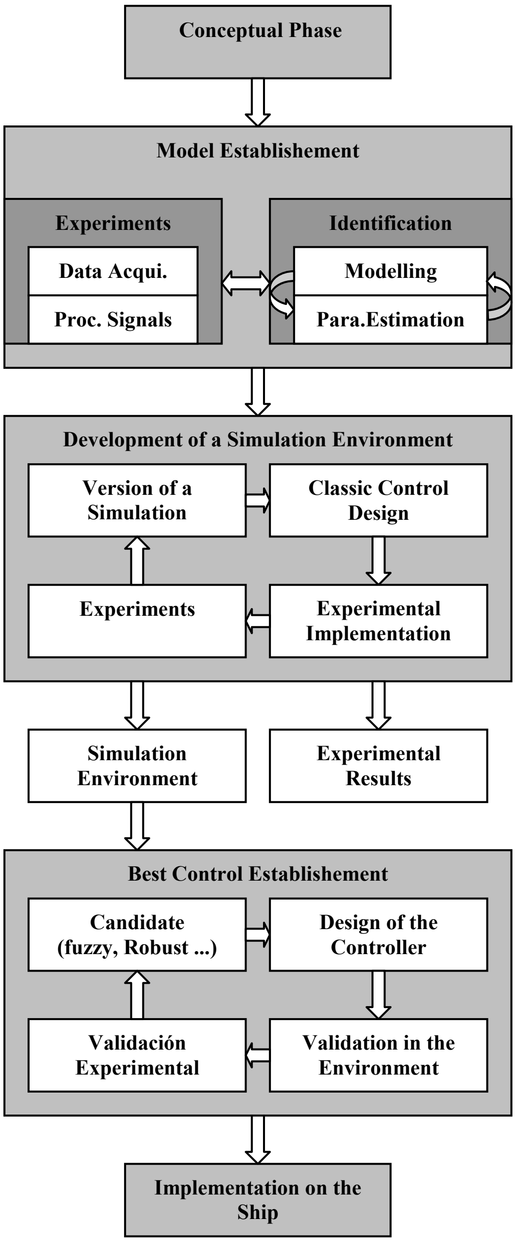

Figure 7: Block Diagram of the Research Tasks

Part of the research scheduling was to define the assignment of tasks to research groups. Also, a timing was specified. Every four months a general meeting (in Santander, or in Madrid) was done to confirm the timing accomplishment and to share results and experiences. The research groups came to the meetings with written contributions. A set of reports has been elaborated.

A web site has been created (ctb.dia.uned.es/cribav). Figure 8 shows the main page of the web site. In this page there are reports, experimental data and results of the research. This page has been useful for the consults from Bazan, CEHIPAR and the members of the three universities participating in the research.

Figure 8. Main Page of the Research Web.

To obtain the models, an experimental design was specified, with regular waves (15 different wavelengths) and irregular waves (SSN 4, 5 and 6), at ship's speeds of 20, 30 and 40 knots.

An analysis based on physics principles, confirmed by the experimental data obtained by CEHIPAR, showed the system is non-linear. Once first experiments, with the scaled down replica, were performed, an arduous work of data processing and analysis was achieved, previous to the application of several model identification techniques.

The following identification alternatives were used:

- Discrete-time identification

- Genetic algorithms

- Non linear least squares method with constraints

- Interval modelling

- Fuzzy modelling

The scientific literature remarks the convenience of hybridising methods for optimisation, beginning with an heuristic search and, when near the optimum, refining with a local optimisation method. In effect, in this case we found useful to start the identification with a genetic algorithm, ending with a non linear least squares method with constraints, determining the tightest intervals around each coefficient of the transfer functions that satisfy the membership and frequency response requirements. In this way, a set of linear time invariant models have been obtained (for each speed: 20, 30 and 40 knots).

The scientific literature also coincide about the convenience of taking into account every piece of "a priori" knowledge, to guide and confine the searching for the optimum. This knowledge can be included in the identification methods as constraints. In our case, the following must be taken into account:

- The models must be stable.

- The gain of the pitch transfer functions must tend to zero at low frequencies.

- The gain of the heave transfer functions must tend to one at low frequencies.

The results of the identification were several models, that were validated using the experimental data obtained by CEHIPAR [De la Cruz, et al., 1998; Aranda, et al, 2000; De Andres Toro, et al., 2000; Esteban (a), et al., 2000; Esteban (b), et al., 2000].

A simulation environment has been developed, based on the models obtained. The environment is specifically oriented to provide the best conditions for the study of control designs.

Concerning the part of the research devoted to control, the goal is to decrease (or eliminate) the vertical acceleration, therefore reducing the motion sickness incidence on passengers.

Several experimental studies have been accomplished by CEHIPAR to check the performances of the replica with the T-foil and the transom flaps. The replica has been equipped with sensors and motors, being connected to an industrial PC in charge of real-time control.

In real practice, most of the control solutions are based on P.I.D. controllers. Any other control alternative must demonstrate really better results, to be accepted for substitution of the P.I.D. For this reason, our first studies of control were centred on the P.I.D.

The simulation environment has been used to determine an optimal tuning of a digital P.I.D.

One of the research groups has developed a software tool for the automatic generation of real-time control code. This tool has been useful for a fast generation of control code for experimental testing with the replica. Therefore, we have been able for a soon start of the first experimental studies focusing on control. The data and experiences obtained were useful for research feedback: to improve the accuracy of the simulation environment, to refine the control.

At present, several different control design alternatives are under development. They will be evaluated in the simulation environment. If there are better solutions than the P.I.D., they will become candidates for experimental testing.

4. RESULTS

Many times the investigators involved in control problems pointed up that most of the time and efforts during a research, are invested in modelling the system or process to be controlled. This is also the case with our research. Hence, the most interesting and important results are reached in the last steps of the project.

The most important and recent result of our research is the confirmation that is possible, by means of actuators and adequate control, to obtain a significant attenuation of vertical accelerations. This is highly positive for passenger's comfort and to increase the operational capabilities of the ship. Figure 9 shows, as an example, the experimental results with irregular waves SSN 5 and a speed of 40 knots. Near the bow, passengers experiment the worse vertical acceleration ("WVA"). The figure shows measures of this acceleration without appendages, and with controlled moving appendages. There is a reduction of about 75%.

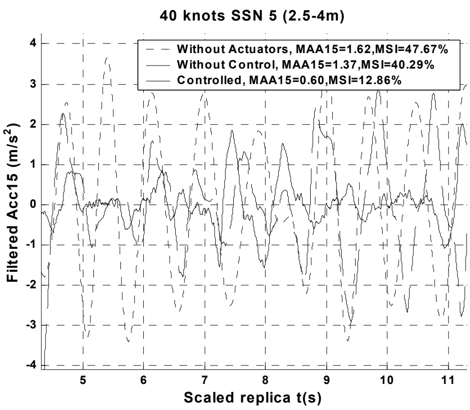

Figure 9: Experimental Results: WVA at 40 knots and SSN 5.

Another important result is the creation of a simulation environment that provides an efficient tool for the design, test and evaluation of control alternatives. Figure 10 shows a screen of the simulation environment.

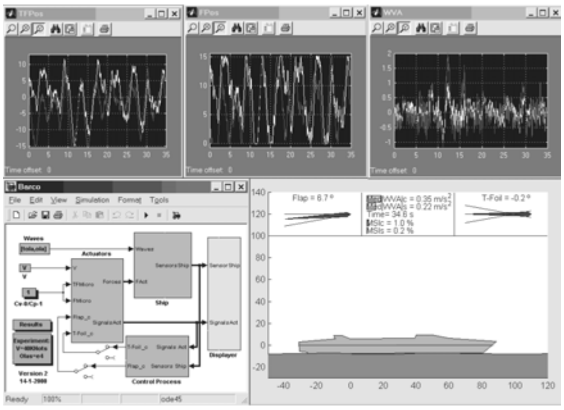

Figure 10: A Screen of the Simulation Environment.

The simulation environment enables us to do on computer the same experiments as in CEHIPAR with the replica. During an experiment, the simulation shows animated pictures and data displays about the motions of the ship and actuators, and about the pertinent variables. When an experiment is finished, the simulation tool perform a data processing to obtain qualification indexes for the evaluation of the control (for instance, the MSI).

Other important result is a set of models of the ship and the actuators. They are control-oriented models in MATLAB-SIMULINK. Among other uses, they allow for the estimation of the ideal contribution of the actuators to decreasing the vertical acceleration. Figure 11 shows the expected ideal reduction of pitching acceleration for irregular waves. Since there are three ship's speeds (20, 30 and 40 knots) and three sea states (SSN 4, 5 and 6), nine cases are studied.

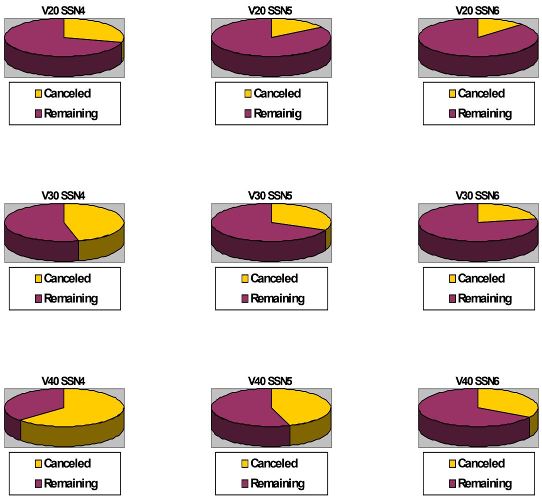

Figure 11: Ideal Effect of Actuators on Pitching Acceleration Reduction

With regard to methodologies, the main contributions belong to two important aspects. First, a modelling methodology has been achieved, based on the hybridising of genetic algorithms and non linear least squares. Second, a fast method for real-time testing of control algorithms on the experimental system has been implemented. This has been accomplished using EdROOM: a software engineering tool developed by one of the research groups.

From another perspective, the research has obtained as important result the creation of an infrastructure of people, means, methods and experiences, that can embark on new topics of marine systems control.

5. CONCLUSIONS

The paper describes the definition and realization of a research project. The target is to attenuate as much as possible the vertical accelerations of fast ships, by using controlled actuators.

To accomplish the project, a research team has been organized with participation of Bazan, CEHIPAR and three university research groups. Funding has been obtained from CICYT. A first stage of the research, along three years, has been concluded.

The research focus on a specific fast ferry. CEHIPAR built a replica, and numerous experiments have been performed for the several needs of the research.

It has been confirmed that the controlled actuators are effective to attenuate the vertical accelerations. In addition, a simulation environment has been developed for the control design and evaluation. New models of the ship and the actuators have been established, and used as the basis of the simulation. It is a set of results really satisfactory.

In achieving the research, an infrastructure and a methodology has been established, enabling for new research topics on marine systems control. The collaboration of different entities, from industry and academia, has been a fruitful and pleasant experience.

In the next future, the context of the study will be enlarged, considering other ship's motions.

This paper has the objective of giving a general view of our research. Other papers of our team, in this conference, will present more details on each of the main aspects of the research.

Acknowledgements

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