Complutense University of Madrid

Computer Architecture and Automatic Systems Department

Madrid, Spain

English summary of the doctoral thesis

MODELLING AND CONTROL OF LONGITUDINAL MOTION OF A FAST FERRY

Presented by

Mr. Segundo Esteban San Román

Directed by

Dr. Jesús Manuel de la Cruz García

Dr. José María Girón Sierra

This document is a brief explanation of my doctoral thesis. The original thesis has been written in Spanish, its title is *"Modelado y control del movimiento longitudinal de un ferry de alta velocidad"*. Here, I try to collect the main ideas of this thesis and present them to the English readers.

The original thesis is a 316 colour pages book; it covers all the problematic of modelling and controlling vertical motions, heave and pitch, of a fast ferry. Although methods are applied to a particular ship, a fast ferry called Silvi-Ana, they are enough generals to be applied to other ships. The results obtained for this ferry can be extrapolated to ships with similar characteristics too.

A brief explanation of each step of the thesis is presented. A collection of some of my English publications is attached to this document. I will reference to these publications in the text, and then the reader can go into topics in depth reading the publication.

1. Problem Motivation

An important part of new developments of naval architecture is fast ships for passenger's transportation. There is a growing market, with more than 200 companies handling 1250 fast ferries in this moment. Only in Europe, during year 2000, 82,6 million passengers and 12,8 million cars were transported on fast ships. New technologies are called to get the performances required. For instance, there are aluminium made hulls, new types of propulsion systems, new ship design concepts, etc. New technologies are applied for more speed and better performances. Also, new control systems and appendages are added for several uses: to improve the comfort of passengers, to avoid negative effects on the ship, to increase the operational capabilities of the ship. In many cases, ferries are in competition with other transportation alternatives. Speed is a crucial factor to be competitive. But also comfort is important: there are many passengers who need to go frequently to a destination, and to get sick sometimes, along travels, is a serious inconvenience.

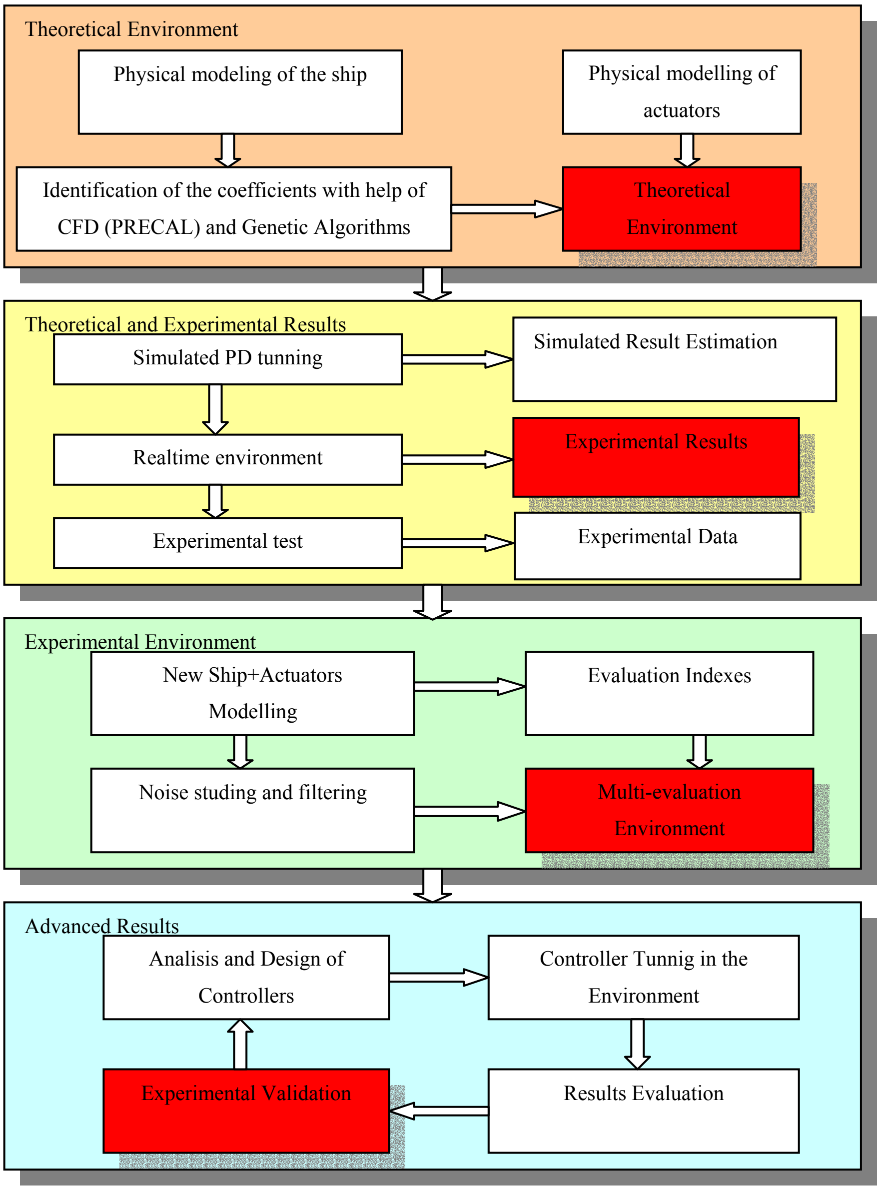
Fast ships can experiment large vertical accelerations. In certain conditions, these accelerations can originate sea-sickness. In addition, excessive vertical motions of the ship can even be dangerous, for instance causing slamming, deck wetness or propeller emergence. There are several ways to smooth vertical motions. One of the alternatives is to use appendages to counteract each incident wave. There is a problem of automatic control: how to move them in the most efficient way.

This thesis is about a research on the use of active appendages to smooth the longitudinal motions of fast ferries. According to BAZAN specifications, the research focused on a fast ferry with a T-foil and transom flaps. To have a solid experimental basis, the services of CEHIPAR (Canal de experiencias hidrodinámicas de El Pardo, Madrid), a prestigious towing tank institution, have been of particular importance. The research project was defined and submitted to CICYT (Comité interministerial de ciencia y tecnología), the most important government entity for research promotion and support in Spain. The project obtained the approval and financial support from CICYT, and started in 1997. A summary of this project, that is very similar to this thesis, can be found in [1]

2. Thesis Development

The research was scheduled with two main objectives. A first objective is to show that comfort can be drastically reduced; in this particular ship this is not obvious. First experimental results confirm good expectations with the use of the active controlled appendages. The second objective is refining models and controllers, seeking for the best solution.

The next figure represents the steps of the Thesis:



The different steps are explained and referenced to the publications.

3. Theoretical environment

To design control strategy, a good control-oriented model of the vertical dynamics of the ship is welcome. Our research deals with the frequency-domain modelling of a high-speed aluminium-made ferry. The model development is based on experimental data from a towing tank institution, and simulations with PRECAL, a CFD Program.

Based on literature, the model can be considered as composed of two main blocks connected in series. One of the blocks represents the transformation "Waves to Forces". The other block represents the transformation "Forces to Ship Motion". The models generated by PRECAL must be transformed to a control oriented model, transfer functions, and this is not trivial. The block “Waves to Forces” is modeled like a shift register, and the block "Forces to Ship Motion" has problem of instability. A detailed explanation can be found in [2].

Other alternatives of modeling and identification based on frequency-domain and using Genetic algorithms can be found in [3]. To speed up the identification process, it has been implemented using Parallel Genetic Algorithms, see [4]. The results obtained, the model, shows good agreement with the experimental and simulated data for regular and irregular waves.

In order to do a control development, it is important to have a control oriented model of the actuators. In [5] it is shown part of the actuators modelling that has been done in this thesis.

Coupling the different models a Simulation Environment is obtained [6].

Once having a good model, we can use it to get initial information about what can be expected from control.

4. Theoretical and Experimental Results

Now, the simulation environment developed in the above section is used to tune a PID. This is done by a systematic searching using the computer. Integral control is not used since it has a degrading effect; it was observed that the more useful control action is proportional. The control can focus on reducing heaving motion, or pitching motion. Tuning parameters will be different for these extreme cases. The following criterion was decided: to alleviate the motions of the passenger in the worse place of the ship. These results are shown in [5].

Other control strategies have been tested, for example predictive control [7]. In this publication we try to decrease the vertical acceleration avoiding high vibration of the actuators. With a Predictive control it is possible to decrease vibrations, but it is not possible to reduce acceleration more than using the PD.

For different sea states and ship speeds may be necessary to schedule the control gains. In [8] a non linear gain scheduling has been designed. In the experimental implementation there were problems with noise and it was not possible to corroborate the simulated results. In the end, theses studies have not been published.

After a control design to get a good candidate for testing, it is necessary to validate experimentally this candidate. A T-foil and transom flaps are added to the scaled-down replica of the fast ferry. These appendages can move under control. So there is a control system installed on the replica, which moves the appendages using motors, and measures the main variables of the ship and actuators motions. This control system is based on an industrial PC with electronic interfaces for motors and sensors. The control algorithm obtained by the design, must be implemented as real-time control software, to be executed on the industrial PC. For a fast and easy translation from design to real-time application, a new software tool developed in the same group has been used. This tool generates directly C++ code, easy to compile, from a graphical description of the control. With this tool, the experiments have been achieved in short time. During experiments, several non expected circumstances appear, but this was not a problem: the tool allows for an easy improvement of the original design. The paper [9] describes this work.

First experimental confirmations of the efficacy of controlled appendages have been achieved. A well tuned P.D. has been tested, with very promising results. The paper [10] focuses on the experimental results. The good results forced us to go forward and to refine models and tunings.

5. Experimental Environment

A new model is developed; see [6] and [11]. New experiments have been done to identify the new model in the time domain.

In the thesis two different approaches, models with relative or absolute waves are compared. With relative waves it is possible to obtain better and simpler identifications, but it is necessary to solve other difficulties. Sensor noises and sensor bias are included in the new environment. A complete chapter of the thesis is dedicated to study and to filter the noises, some of the main results of this chapter have not been published yet.

The publication [11] explains the experimental problems that have been included in the new simulation environment. One important problem is the feedback of the actuators noise, which induces limit cycles. A Time Variant Relaxer (TVR) has been designed to avoid this limit cycles. The TVR is used to decrease the control effort too, it is not necessary to move the actuators when there is only a small acceleration.

New evaluation indexes has been modeled and added to the environment, [12]. It is obvious that the Motion Sickness Index is the main index, but cavitations and changes of sense of the actuators must be minimized too. We must to face to a multi-objective problem.

6. Advanced Results

The complete scenario calls for a multi-objective control design, considering comfort, control efforts and cavitations. The publication [12] affronts this problem.

Due to the complexity and the nonlinearities of the system (the ship with actuators), it is very difficult to accomplish analytical control studies. But the simulation environment can be used to "tune" any control strategy, by searching methods like Genetic Algorithms. As a natural choice to start with, the PID has been subject to study in this case. Other control alternatives have been also tested, with slight better results. Since the actuators have a limited influence on the ship vertical motions (the forces and moments exerted by the waves can be enormous), there is little hope for significant improvements due to a particular control strategy. But, in any case, the important point is to have the control obeying, as far as possible, several optimal criteria.

Since this research is centered in two sea states (SSN4 and SSN5) and two ship's speeds (30 and 40 knots), four different cases were studied, and the best controller obtained for each of them. Additionally, the same Genetic algorithm, slightly modified was used for searching a common controller (unique tuning) for the four possible cases. Finally it is shown that a multi-situation tuning is good for all the situations and it is not necessary a scheduling.

7. Conclusions

This thesis has described a research on ship's vertical motion smoothing, using controlled flaps and T-foil. SIMULINK Models and a simulation environment have been developed. Control studies have been accomplished. Every step has been done with an experimental basis. The results obtained are promising.

We have obtained first results with an optimal PD. Other control alternatives, do not improve significantly the results already confirmed with the optimal PD, at least with respect to MSI. A possible explanation is that the actuators have a limited action (small forces and moments, compared to the effects of waves), so, in practice, the motion of the actuators is usually of bang-bang nature (from limit angle to limit angle).

It was noticed during simulation and experiments that the control incurred into cavitation problems, and too many motion reversing of the actuators (due to excessive control gains). In this moment, the point of view regarding optimisation has changed. It is interesting to trade a little MSI for better action of the actuators. In consequence is natural to enter in a multi-objective treatment of the control problem. This has been done using genetic algorithms obtaining very good results in several fronts: MSI, less cavitation, less motion reversing (also energetic aspects may be considered).

Finally, a stability study of the problem has been done. A Time Variant Relaxer has been designed to relax limit cycles owing to actuators noise feedback. It is not just to avoid limit cycles; it saves control effort as well.

7. Future Works

When there is not control surface it is possible to uncouple the longitudinal and lateral motions, but with actuators and control action it is not possible as some experiments have shown. Now, we are making a self propel scale replica to experiment in open waters with all the degrees of freedom.

A good alternative to uncoupling motions may be eigenstructure control. Other problem is the low speed of maritime actuators and lateral dynamic of ships, a good alternative to solve this may be predictive control. In the publication [13] we have affronted a similar problem for a flight control. An eigenstructure inner loop is used to uncouple motions; an adaptive predictive outer loop is used to tracking. This strategy may be a good alternative to our problem too.

8. References

[1] De la Cruz, J.M., Perez de Lucas, P., Aranda, J., Giron-Sierra, J.M., Velasco, F. (2001). “A research on motion smoothing of fast ferries”. Control Applications in Marine Systems. Glasgow.

[2] Esteban, S., De la Cruz, J.M., Giron-Sierra J.M., De Andres, B. and Grau, L. (2000), "Frequency-Domain Model of Fast Ferry Vertical Motions", Proc. RINA Int. Conf. Hydrodynamics of High Speed Craft, London, paper 18, pp. 1-8.

[3] De Andres Toro, B., Esteban, S., Giron-Sierra, J.M., and J.M. De la Cruz (2000), "Modelling the Motions of a Fast Ferry with the Help of Genetic Algorithms", Proc. 3rd IMACS MATMOD, Viena, pp. 783-786.

[4] Hidalgo, J.I., Prieto, M., Lanchares, J., Tirado, F., de Andres, B., Esteban, S., Rivera, D. (1999). ”A Method for Model Parameter Identification Using Parallel Genetic Algorithms”. Proc. In 6th European Parallel Virtual Machine and Message Passing Interface. Barcelona.

[5] Esteban, S., De la Cruz, J.M., Giron-Sierra, J.M., De Andres Toro, B., Diaz, J.M., and J. Aranda (2000), "Fast Ferry Vertical Acceleration Reduction with Active Flaps and T-foil", Proc. IFAC Int. Symp. MCMC, Aalborg, pp. 233-238.

[6] Esteban, S., de Andres, B., Giron-Sierra, J.M., Polo, O.R., Moyano, E. (2001). “A Simulation Tool for a Fast Ferry Control Design”. Control Applications in Marine Systems. Glasgow.

[7] Esteban, S., Giron-Sierra, J.M., de la Cruz, J.M., de Andres, B. (2001). “Predictive Perturbation Cancelling for Seakeeping Improvement of a Fast Ferry”. Proc. European Control Conference. Porto.

[8] Esteban, S. Fossen, T.I. and dela Cruz, J.M (2000). “Non Linear Gain Scheduled Control for Vertical Accelerations Damping”. Not published.

[9] Polo, O.R., Esteban, S., Maron, A., Grau, L., De la Cruz, J.M. (2001). ”Control Code Generator Used For Control Experiments in Ship Scale Model”. Control Applications in Marine Systems, Glasgow.

[10] Giron-Sierra, J.M., Esteban, S., de Andres, B., Diaz, J.M., Riola, J.M. (2001). “Experimental Study of Controlled Flaps and T-Foil for Comfort Improvement of a Fast Ferry”. Control Applications in Marine Systems. Glasgow.

[11] Giron-Sierra, J.M., Katebi, R., De la Cruz, J.M. and Esteban, S. (2002). “The Control of Specific Actuators for Fast Ferry Vertical Motion Damping”. Send to the Conference on Control Applications, Glasgow.

[12] Esteban, S., Andres-Toro, B. Besada-Portas, J.M., Giron-Sierra, J.M. and De la Cruz, J.M. (2002). “Multiobjective Control of Flaps and T-Foil in High-Speed Ships”. Accepted in the IFAC World Congress, Barcelona.

[13] Esteban, S., De la Cruz, J.M., Giron-Sierra, J.M., (2000), "Adaptive Predictive Flight Control", Proc. IFAC Conf. on Control System Design. Bratislava.