

Chapter 10

Final Remarks

10.1 Concluding Discussion

There are three major achievements in this thesis. The first is the development of a useful hydrodynamic model, FINS, which combines a high-resolution unsteady vortex lattice code, used to compute the loads generated by a pair of fins attached to a ship, with a Green-function source distribution code, LAMP, used to predict the loads on a ship as it interacts with the sea. Having computed all loads acting on a ship, LAMP solves the six-degree-of-freedom equations of motion of the ship. The method proved successful for the different sea-states and sea-characteristics explored. This was discussed in Chapter 2. Since the training process of neural-network and fuzzy-logic controllers for active FINS, described in Chapters 5, 8 and 9, is computationally demanding, the LAMP-FINS code had virtually been running without interruption over the last two years to accomplish part of the research of this dissertation. During this time the method and corresponding code, have proven reliable and yielded excellent results.

The second major achievement is the development, training and evaluation of neural-network and fuzzy-logic controllers for the fin control systems. As we discussed in the first chapter, a common practice to train such controllers is to make a system identification of the system to be controlled. This requires the generation of a neural-network/fuzzy-logic simulation, which should behave as closely as possible to the original system. The original system could be a real-life implementation or a model of it.

For the naval applications of our work, this would be the LAMP-FINS model. Though it is a powerful tool, such an interactive model is very computationally demanding. Making a system identification of LAMP-FINS would have required a large and slow computational effort. Generating a successful neural-network/fuzzy-logic system capable of emulating the LAMP-FINS system would have demanded numerous training sessions, in order to take into account different sea states and characteristics. Even if the identified system would have effectively reproduced the target system (LAMP), still the final product would have been limited to a particular ship, with a particular set of fins; in any case, it would have been a *model of a model*. From the very beginning, it became almost a requisite to find an alternative way to train the controller other than a system identification of the LAMP-FINS model. We started exploring a gradient search approach, which later evolved in the adaptive gradient search, which is described for a seismic application in Chapter 7. While still refining and testing this approach, we conceived the moment-matching procedure as a very expedient alternative to provide training for the neural-network controller, as we described in Figure 5-8. Later we used the same procedure to train a fuzzy-logic controller, which is described in Chapter 9. Even if we were using a pair of fins, since they were set to move antisymmetrically, the system was a multiple-input-single-output controller (MISO). However, more involved problems would demand multiple-input-multiple-output (MIMO) implementations. We find a suitable way to attack such problems by introducing the concept of artificial modal neurons, which allowed us to handle MIMO control systems by means of modal neural networks. We discussed this in the context of roll-pitch-heave control in Chapter 8.

As our research on naval applications progressed, we came in contact with Doctor Matheu¹'s and Professor Singh²'s work in the seismic engineering field. Soon we realized that applying the same control techniques we were developing for naval applications to the control of seismically excited building structures was not only an interesting

¹ Research Assistant Professor at the Engineering Science and Mechanics Department (Virginia Tech).

challenge but also very feasible. This encouraged us to extend the principles behind the moment-matching training technique used for fins, to the equivalent force-matching technique used to control buildings by active tuned mass dampers (TMD's), which was described in section 6-6. Since the TMD-building model was computationally simpler and faster than the LAMP-FINS model, this also allowed us to refine the adaptive gradient search and implement it in seismic engineering applications, as we discussed in Chapter 7. In all cases, we obtained very good results. Our work with the seismic problem also produced a novel datum-training approach, in which a set of synthesized earthquakes is used to train the neural-network controller for possible future earthquakes of unknown characteristics. The synthesized earthquakes are generated using data collected from past earthquakes registered in the building area (Chapters 6 and 7).

10.2 Future Work

For naval applications:

- Develop a learning algorithm for the neural-network and fuzzy-logic controller capable of adapting to changes in the sea, structure, and load distribution on the ship.
- Explore multiple pairs of fin configurations.
- Explore more efficient control configurations by using neural-network or fuzzy-logic controllers capable of combining fins and rudder as active elements.

² Professor at the Engineering Science and Mechanics Department (Virginia Tech).

- Extend the hydrodynamic fin-model to a fin-rudder or multiple-fin-multiple-rudder model.
- Extend the hydrodynamic fin-model to a propeller or multiple-propeller model.
- Study the fin-propulsion interaction, and design a fully integrated propulsion-fin control system.
- Include the FINS code as part of the LAMP libraries.
- Parallelize the FINS code.

For seismic engineering applications:

- Develop a fuzzy-logic controller for the current active tuned-mass-damper system.
- Explore multiple tuned-mass-damper systems.
- Explore other active controllers, especially base isolation, external cable driven actuators and magneto-rheological dampers.
- Develop a fuzzy-logic/neural-network system capable of inferring damage in structures from linear structural behavior information.
- Develop a genetic algorithm to train fuzzy-logic/neural-network controllers.

- Extend this work to three-dimensional structures by using modal neural networks.
- Parallelize the codes.

In general:

- Implement modal neural networks for multiple-fin-multiple-rudder configurations for ship applications, and multiple control actuators for seismic engineering.
- Explore other training routines, especially genetic algorithms.