John and Cathi Drake Chair in Mechanical Engineering

2019 Update, February 2020

1. Summary

The update below is a condensed version of the projects my students and I have been exploring since August. The John and Cathi Drake Chair funds have helped both undergraduate and graduate students develop as engineers while expanding new opportunities for Michigan Tech. The two senior design projects were a great success with a new, one-year project launched in January 2020. This award continues to touch every aspect of my work at Michigan Tech, as well as the lives of many students.

2. Research and Education Initiatives

The summaries below combine both research and education. In the past these were broken out separately. As you will see, they've become tightly coupled and so segregating them detracts from their combined impact.

Naval

There have been some new developments in this area that have (1) resulted in external funding for the wave tank and (2) a proposal with a somewhat new research direction.

Wave Tank Tests

Last year we had a Navy project that looked promising for funding a wave tank test project. That was successful and the first tests are being conducted this week. We were able to secure a second test project with a different theme that will follow almost immediately after. We've discovered that our facility has two selling points over similar wave tanks (1) our instrumentation is state-of-the-art and (2) we are nimble. The combination of these two factors is unique in wave tank testing. For example, most facilities are much more expensive and sometimes have tank-specific administrative overhead that we avoid. We are retooling our marketing information to highlight these points and some of the recent test successes.

Michigan Tech / U.S. Navy Educational Partnership Agreement (EPA)

The EPA is designed to facilitate collaboration between Michigan Tech and the Naval Surface Warfare Center, Carderock. This past Spring semester we put it to use with the senior design projects. Most of our senior design projects are funded externally where students have weekly phone conferences with their customer. Since our two-wave energy converter (WEC) projects were internal, I was the customer. This was fine, but didn't give the students quite the same experience. This is where the EPA came in. Frank Leban (NSWC) agreed to review the student projects and meet with them to provide feedback. As an extra bonus, Frank connected us with Nathan at the U.S. National Renewable Energy Laboratory in CO to have a similar role. Nathan is well-known in the WEC community and is part of the recently created DOE Marine Energy Collegiate Competition. It's currently in the inaugural year where the competition focuses on analysis, a paper design study and a static model.

Our seniors did a fantastic job with the two projects, and both Nathan and Frank were impressed. This has led to discussions with Nathan of ways to connect NREL with Michigan Tech and our students. Nathan will be visiting campus in March to give a seminar and to meet with a newly minted senior design team supported with Drake Chair funds.

This new senior design team is building a WEC that will be installed in the wave tank on a somewhat permanent basis. This will be a unique system where researchers and students around the world can connect to it, download a control strategy and acquire data remotely. This opens up the ability for people in the WEC control community to run experiments without a wave tank. Additionally, it would be a perfect

platform to incorporate into the DOE Marine Energy Collegiate Competition that Nathan is part of. If all of these pieces come together, we will have a tremendous visibility opportunity for Michigan Tech.

Exergy

This year we have one exergy project funded by the U.S. Army Research Lab. Its two parts are: (1) documenting the research to date on blending information exergy with what I call physical exergy and (2) using local weather information to improve energy management of a microgrid. In the remainder of this section, I'll summarize each topic.

Physical exergy is the form we are most familiar with - the subset of energy that is available for doing useful work - and is much related to Adrian's research. Information exergy stems from the notion of information entropy; a topic that is well established in the signal processing community. It captures, for example, the quality of information in a measurement. One of the promising aspects of using exergy for control design is that it is the common commodity between disparate physics - mechanical, electrical, thermal, etc. The question we are exploring is: What are the advantages (or disadvantages) of controlling a dynamic system based on reducing the combined physical and information exergy destruction?

Our approach to information exergy will likely be based on how its quality decreases with time. This approach provides comparison to some well understood issues in feedback control of systems with time delays. For example, a position controller can become unstable if the time lag between the measurement and the computed command becomes too large. Cast in terms of information exergy, the measurement quality for its control objective degrades with time. The idea of looking at information exergy in this way came from a conversation with Mike, a former Ph.D. student who was for a time supported by the Drake Chair. Mike is now a professor at Milwaukee School of Engineering and we are always working on ways to continue our collaboration.

Marine Renewable Energy

In the Fall semester we secured funding for six weeks of testing in Michigan Tech's wave tank on two U.S. Navy projects. This provides some valuable resources for tank maintenance along with visibility. The summaries below give updates on the projects we discussed in August with a view to future proposal development. These activities are all supported, either in part or in whole, by the Drake Chair funds.

Oscillating Water Columns (OWC) Wave Energy Converter (WEC)

Kevin should complete his M.S. this semester in optimal control with application to OWCs. His focus shifted this past year where he's developing fundamental results that *could be applied* to OWCs instead of a direct application. The reason for this change is due to the realization that the OWC problem he was trying to solve was a subset of a general problem in optimal control.

Optimal control is the act of creating a dynamic system's input so that it has some desired behavior. Although the word 'control' is used, it doesn't necessarily imply the existence of feedback. Finding these optimal input solutions is devilish for all but the most basic dynamic systems. Kevin is developing a scheme to modify the optimal control solution based on the external disturbance caused by waves.

Nonlinear WEC Optimal Control

Yaqzan developed a control strategy that exploits a more accurate, nonlinear model of a WEC. Most control designs are based on a WEC's linear response and neglect the terms in the model that make it quite nonlinear. Yaqzan has graduated and is finishing some edits on his paper that will be submitted this semester. We need to hurry on this as we've recently learned that there is another research group starting to look at this very same topic.

Closely Spaced WEC Array Modeling and Control

Sal is moving along very nicely on modeling multiple WECs that are in close proximity to each other. This is a difficult problem since each of the buoys radiate waves that interact with their neighbors. WEC arrays are of interest since it's possible to extract more energy from several smaller WECs than form one large one. Sal has shown this in a recent article he wrote, but the theory needs to be tested. The first step is to develop fast running models that can help guide the WEC control system design.

Sal has improved his strategy for developing compact WEC array models such that his work is at the front edge of this field according to external colleagues. He's also developed a novel strategy of WEC optimal placement that make their transmission of energy to a terrestrial power grid more efficient. After he finishes two technical articles he's writing, he will move on to testing his ideas in the wave tank.

WEC Machine Learning Control

Tania successfully passed the Ph.D. qualifying exam last semester and is now focusing on her research. Her idea is to control a single WEC using a machine learning technique based on wave height measurements taken upstream of the WEC. The first step is to modify one of the senior design WECs for her purpose. This means adding a linear encoder to measure the relative motion of the buoy and drag plate and install a regeneration circuit so that WEC can charge a battery placed inside the buoy.

Tania will have some help with a graduate student, Isha, who is helping in our lab this semester. I've also been working with two second-year undergraduate students to apply for a summer research grant. If either (or both) are successful, then they will be working with Tania as well.

3. Budget

Like recent years, most of the Drake Chair funds spent since August, were used for student support, the wave tank and program development.