California Maritime Academy
Application for Sabbatical Leave

1. Name: Michael Holden Date: 6 October 2023

2. Department: Mechanical Engineering

3. Current academic rank or job classification: Professor

4. a. Date initially hired into a tenured or tenure-track position: 2007

5. Are you presently on the Cruise Calendar or Academic Year? Academic Year

6. If you are on the Cruise Calendar, are you planning to submit a written request to be temporarily placed on the Academic Year pay scale during the academic year of your sabbatical? n/a

7. Type of sabbatical leave presently requesting:

   __X__ One semester at full-pay _____ Two semesters at half-pay

8. Effective dates for proposed sabbatical leave (not to exceed one academic year):

   First choice: Fall and/or spring semester and year Fall 2023

   Second choice: Fall and/or spring semester and year Spring 2024

9. Write a statement of purpose for your sabbatical leave. Your statement of purpose must describe how your sabbatical leave will provide a benefit to the Academy and/or the CSU.

10. Write a description of your proposed project. Your description should include:
    a) a detailed outline of your proposed project;
    b) an itemized list of Academy/CSU resources needed;
    c) any financial support from grants, fellowships, or other non-Academy compensation you expect during your sabbatical leave (requires prior approval from the Academy President);
    d) the tangible results, outcomes, or end-products from your sabbatical leave.

Statement of Purpose

Introduction

I have been working with autonomous vehicles since 1998, initially as part of a small company that manufactured drone aircraft-- writing flight control software, building electronics subsystems, and developing telemetry communication protocols and software. For many years, my students and I have been designing and building autonomous vessels designed to gather oceanographic information with onboard sensors. *Dumbo* [1] was built by a Cal Maritime student who went on to graduate school and just recently finished his Ph.D. in robotics. It was followed by *n3m0* [2], a small 3D printed vessel. *N3m0* was recently refitted into a catamaran (*n3m02*) for harbor depth surveys [3]. My students have also built a series of autonomous sailboats for the capstone ME project class. I would like to extend this work during my sabbatical leave and dig into some new uses for small autonomous boats operating on the Cal Maritime waterfront.

Purpose of the Sabbatical

If granted a sabbatical leave, I propose to develop a small autonomous boat to measure surface sea current flow in-situ, then use the results to optimize the routing of the boat to minimize energy or time by taking advantage of the "tailwind" that a favorable current offers. The project is described in two phases: the first phase will test current measurement using an existing autonomous vessel, and at the same time use numerical simulation to test navigation algorithms. This phase 1 work breakdown is low risk and the tasks can be worked in parallel. The phase 1 results will be used in the second phase, which will refine the vessel design for the measurement task, and incorporate the best navigation scheme into the autopilot system for testing on the water. The vessel will have capability to measure power usage so that energy savings can be quantified.

A sabbatical leave also gives opportunities to find new avenues of research-- during my 2017 sabbatical, a small part of the proposed work turned into the design of *n3m0*, which was a semifinalist in the 2017 Hackaday Maker Project Design Contest [2] and is now part of the proposed project. I am hopeful I may follow unknown avenues that arise during the creative work of a sabbatical, with this project as a springboard. Regardless of whether new ideas are found, I believe the baseline proposal is a solid research project worthy of a sabbatical leave.

Benefit to the Academy and the CSU

The project will have a direct benefit to the academy and its students. The primary beneficiary of the proposed work will be my own professional development and engagement with engineering research. Additionally, the most recent ABET accreditation visit for my department warned that faculty professional development was underperforming, so this project will directly benefit the ME program and the University by addressing this issue. Finally, I have had many students work with me on previous autonomous boat projects (such as [1]), but this collaborative work stopped during the pandemic shutdown. I hope that by starting an interesting new project, with the bulk of the work visible from the waterfront, I will be able to find students willing to collaborate on future work when I return from my sabbatical.

Project Description

Project Outline

The first phase of the project has two parts that can be worked in parallel.

Phase 1A: Modify Existing Vessel to Measure Currents

Figure 1: the vessel n3m02

N3m02, pictured in Figure 1, is a catamaran vessel approximately 1 meter in length, with fully autonomous control hardware, and a separate data-logging computer on board to manage sensors and log the findings along with the vessel state received from the autopilot. It has been configured with a depth sensor for sea-floor surveys and was used to generate charts of harbor depth [3]. In the first phase of the proposed project, *n3m02* will be used to measure the surface current by navigating to a specified point and drifting with the current, then repeating as needed to create a surface current vector field. The process will be evaluated to see what modifications to the vessel or operations make this basic form of current measurement most effective. The main test area will be around Morrow cove, which has a very strong eddy current that opposes the flow in the main channel in both ebb and flood tides, giving large changes in current flow magnitude and direction that can be measured conveniently close to campus.

Phase 1B: Simulate for Navigation

Once a vector field of the current is measured, the optimal route for either minimum time or minimum energy must be calculated. An algorithm to minimize time is given by Fenelon [4], which used the vector field image shown in Figure 2. Using a simple mission such as a harbor safety patrol, the simulation will find the best route that takes advantage of favorable currents. The task is made more difficult when the current measurement and navigation are simultaneous, because careful placement of points is required for a good field of measurements without traveling too far. Many potential algorithms have been proposed in related work by other researchers [5][6][7][8][9]. Being able to simulate the system and test various algorithms for optimal field measurements should yield interesting results that can be applied in the second phase of the project.

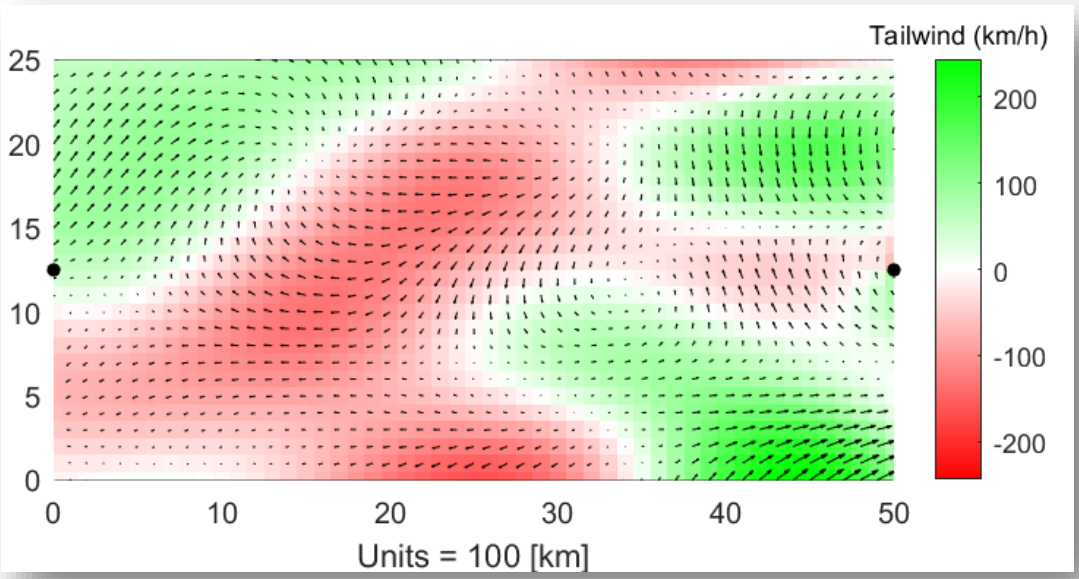

Figure 2: Vector Field from [4]

Phase 2: Update Based on Results of Phase 1

The second phase combines the two parts of the first phase into a more refined system. Based on the *n3m02* test results, I will decide whether a different vessel design would be better for this task, document the design goals for a new design, and if feasible modify the existing boat or build a new one. The new, modified, or original boat will then be used to test the navigation algorithms developed in the simulations.

Based on the simulation-based route optimization, I will implement the best navigation method into the vessel's programmed mission for testing. The target route will traverse up and down Morrow cove, to take advantage of the the main tidal flow and opposing eddy currents. During the mission the vessel will measure real-time surface currents in the local area, then use this information to optimize the route. Measurements of the time and power used over a route between waypoints can be taken to compare the rhumb line course and the optimized route.

List of Academy/CSU Resources Needed

This project will require the use of the autonomous vessel *n3m02*, as well as my office and computer, but these are readily available.

Financial Support Expected

No special support is required. Upgrades to the vessel should be relatively low cost, and I am prepared to supply whatever is necessary. If a high-cost need should arise, an application to the CSU COAST program will be prepared, but nothing of this magnitude is foreseen at this time.

Project Outcomes and End-Products

I expect at the end of the sabbatical to have the following end-products:

- A report presenting the results of the sensing and navigation project, ready to be published if the results are suitable, or suggesting future work if not.
- An autonomous vessel that can measure current and be used for future projects.

I expect the research to continue after my sabbatical is over, and I believe the sabbatical is an essential part of a healthy research program that Cal Maritime will be proud of.

References

1. Jacob Steiner, Rose Hendrix, Alec Safreno, Michael E. Holden, "A Student-Run Autonomous Oceanographic Research Vessel", Poster at the 23rd Biennial Conference of the Coastal and Estuarine Research Foundation, November 2015

2. Holden, Michael, n3m0 the Autonomous Boat (https://hackaday.io/project/25508-n3m0-the-autonomous-boat) Hackaday. Retrieved October 6, 2023.

3. No publication, but see, for example, data at https://github.com/meholden/data_archive/blob/master/n3m0/20221027_164152.geojson

4. Mary Fenelon (2023). *Finding an Optimal Path* (https://www.mathworks.com/matlabcentral/fileexchange/36321-finding-an-optimal-path), MATLAB Central File Exchange. Retrieved October 6, 2023.

5. Johanna Hansen, Sandeep Manjanna, Alberto {Quattrini Li}, **Ioannis Rekleitis**, Gregory Dudek. Autonomous Marine Sampling Enhanced by Strategically Deployed Drifters in Marine Flow Fields. In *MTS/IEEE OCEANS - Charleston*, 2018.

6. Data-driven Selective Sampling for Marine Vehicles Using Multi-scale Paths
Sandeep Manjanna and Gregory Dudek. IEEE/RSJ International Conference on Intelligent Robots and Systems, 2017, Vancouver, Canada

7. Fully Autonomous Focused Exploration for Robotic Environmental Monitoring
G. Hitz, A. Gotovos, F. Pomerleau, M. E. Garneau, C. Pradalier, A. Krause, R. Siegwart
In In Proc. International Conference on Robotics and Automation (ICRA), 2014

8. Near-Optimal Sensor Placements in Gaussian Processes: Theory, Efficient Algorithms and Empirical Studies, A. Krause, A. Singh, C. Guestrin
In Journal of Machine Learning Research (JMLR), volume 9, 2008

9. T. Li, C. Wang, M. Max Q.-H. and C. W. d. Silva, "Coverage Sampling Planner for UAV-enabled Environmental Exploration and Field Mapping," 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Macau, China, 2019, pp. 2509-2516, doi: 10.1109/IROS40897.2019.8967735.