Redefining Fish Locomotion through Center of Mass Oscillation

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Abstract: This proposal seeks to redefine current fish locomotion categories, which are based on 2D body oscillation a fish body experiences when moving, with 3D center of mass (COM) oscillation data. We seek to generate COM oscillation data for a large parameter space for each traditional locomotion category. Through statistical analysis, we expect to be able to either correlate specific patterns with the current categories, or to redefine the categories based on novel COM oscillation patterns.

Keywords: fish locomotion, hydrodynamics, center of mass, CFD, AUV

I. Introduction

The study of fish locomotion is an incredibly useful and important field of interdisciplinary study located at the intersection of biology, physics, robotics, and computer science. For example, insight into structural and functional development promotes biological understanding.[1] Regarding physics, the movement of objects through a viscous, dense, and incompressible fluid (e.g. water) yields valuable information about kinematics in regards to surrounding media.[2-4] Scientists are constantly improving computational models and robotic methods to test hypotheses.[5-8] Lastly, studying fish locomotion has practical applications, which are often applied to increasing the efficiency and maneuverability of autonomous underwater vehicles (AUVs).[5,6,8]

Center of mass (COM) analysis is traditionally used to understand terrestrial locomotion. The COM of a mass or collection of masses is that unique point at which all of the weighted position vectors relative to that point sum to zero. COM motion provides information about locomotor dynamics and energy efficiency.[9,10] Until recently, COM analysis has not been used to evaluate fish locomotion because identifying and analyzing COM oscillations is quite difficult.[8-10] Historically, factors such as flexural stiffness have been used to characterize and define the 2D kinematics of traditional fish kinematic categories (e.g., anguilliform, sub-carangiform, carangiform).[2,11,12] With COM analysis, we have the potential to redefine our current understanding of the 3D biomechanics and the associated energy costs.

Lauder and Xiong have presented a novel paper in which COM oscillations are examined in three species, representing three different locomotion categories, each at three different speeds.[10] The results shows that COM motion with regards to sway (side-to-side), surge (forward-backward), and heave (up-down) oscillations do in fact show different patterns in the different kinematic categories. However, correlations are not constant.[9,10]

The goal of this project is twofold: (i) to determine if traditional fish kinematic categories can be individually defined by the patterns of COM oscillations with regards to the traditional kinematic characteristics (e.g., flexural stiffness, body length) in addition to sway/surge/heave oscillations, and (ii) to compare the results of (i) to current AUVs and determine points of improvement with regards to energy costs and performance.

II. General Methodology and Timeline

We expect this project to take no more than three years. Two years should be allotted to complete the necessary experimentation and modeling, with a final year allocated to data analysis and publication(s).

Goal 1: *Hydrodynamics:* The main focus is to collect data from which computational models and robotic performance can be evaluated. The methodology and analysis for examining the hydrodynamics and COM oscillations of specimens will follow the methodology outlined in.[10] To expand upon this study, a larger set of test specimens will be examined. By adopting the methodology of Lauder and Xiong, we implicitly adopt the assumptions made by the authors for their experimentation. Because this area of study is relatively new, combining the findings of this study with the results in[10] could lend credibility to both studies and provide a solid foundation from upon which future experiments can be based.

Computational Modeling: Because it is impossible to modify a single parameter while keeping others constant in live fish, it is necessary to use computational models and simulation software (e.g., computational fluid dynamics [CFD]) to create data over the desired parameter space. The data procured via hydrodynamics will be used to evaluate the performance and realisticity of computer simulations. Once we are satisfied the models are realistic, virtual experimentation can begin.

Goal 2: Lastly, the COM oscillation data from live fish could be compared to current AUV COM oscillation patterns. High COM oscillations are associated with higher energy costs. By using the data produced in the previous steps as a performance metric from current AUVs, we can determine the differences in efficiency and energy costs and pinpoint points for improved performance and design.

Institutional Resources: The basis for this proposal comes from the recent work of George Lauder at Harvard Univ.[9-11] His lab, as well as other labs at Tufts University and Georgia Tech, possess the aquatic equipment and particle image velocimetry (PIV) access necessary to perform the study as proposed. If such equipment is not available, the research plan will be modified accordingly.

III. Intellectual Merit

The traditional fish locomotion categories are easily applied to 2D kinematics, but in the face of 3D kinematics, are old and oversimplified. By attempting to redefine the categories based on 3D COM oscillations, we can either lend credibility to a traditional system or completely redefine how fish locomotion is categorized.

IV. Broader Impact

This project seeks to impact the community at large and spread the results of this study in two ways: (i) Educational Benefit and (ii) Direct Applications. (i) First, undergraduate research and perhaps high school research will be promoted in this project. Second, the resultant information will be disseminated via four main avenues: papers, conferences, a Wordpress website meant to provide supplemental information, and high school seminars. (ii) By evaluating AUV performance, future AUVs might be able to explore the oceans for greater lengths of time for decreased costs. This will promote exploration of a still greatly unexplored component of our planet. The success of the broader impact goals will be assessed over time and altered as needed.

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