Data Science for Dolphin Biomechanics

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Cetaceans, a marine order of mammals that encompasses dolphins, whales, and porpoises, are very efficient swimmers, more so than mechanical propellers according to literature [1]. Conducting experiments to verify these efficiencies are difficult because swimming kinematics and kinetics are difficult to measure due to the inherent challenges of the marine environment. Biologging tags are used to measure kinematic data from a single location on the animal, but information about whole body kinematics and kinetics are limited [2]. As such, how these animals manage such efficiencies is not fully understood, particularly in the wild. The goals of this work are to investigate the cost of swimming locomotion using biologging tags and to develop new knowledge about dolphin swimming biomechanics.

Dolphins use caudal oscillations to move their 'wing-like' fluke through the water and generate propulsive force for locomotion. In this work, we present a low-order, sagittal-plane, hydrodynamic model of a swimming dolphin that captures the relationships between heaving amplitude, frequency, angle of attack of the fluke and the thrust and drag forces generated. The model characterizes the animal as a series of links, each having their own hydrodynamic properties, propelled by a semi-passive, flexible fluke described as a partially clamped plate. We use this model to estimate both the propulsive force generated for locomotion, and the internal moments at the 'joints' required for fluke movement (Fig. 1A).

Unlike in the wild, where cameras would be infeasible, these sensors can be used in a controlled environment to capture sagittal plane kinematics of swimming animals. Through this method, we calculated the relative angle between segments of the dolphin body: the head-torso segment (θ_1), the torso and the proximal peduncle segment (θ_2), and the two peduncle segments (θ_3). These data were then used to create functional relationships for the rigid body joints and prescribe the motion of the model. The swimming speed of the model was controlled by modulating the frequency and amplitude of the phasing relationships, and simulation results capture key characteristics of dolphin swimming reported in literature, such as the body speed versus tail-beat frequency, drag coefficient versus Reynolds number, and the thrust power versus speed [3].

With the model in hand, we have a means of using joint kinematics to estimate the kinetics of the swimming dolphin. However, data from tags alone can not be used to drive the hydrodynamic model because they only provide kinematic data from a single body segment, along with estimates of center of mass velocity. To address this issue, we present an approach to estimate whole body sagittal plane kinematics from from tag data using machine learning techniques, creating a map between the orientation of the torso segment and the resulting configuration of the modeled joint angles (Fig. 1B). This approach will be used to estimate body posture and swimming kinetics of dolphins in both managed and wild settings, greatly expanding our ability to investigate dolphin swimming behavior using biologging tags.

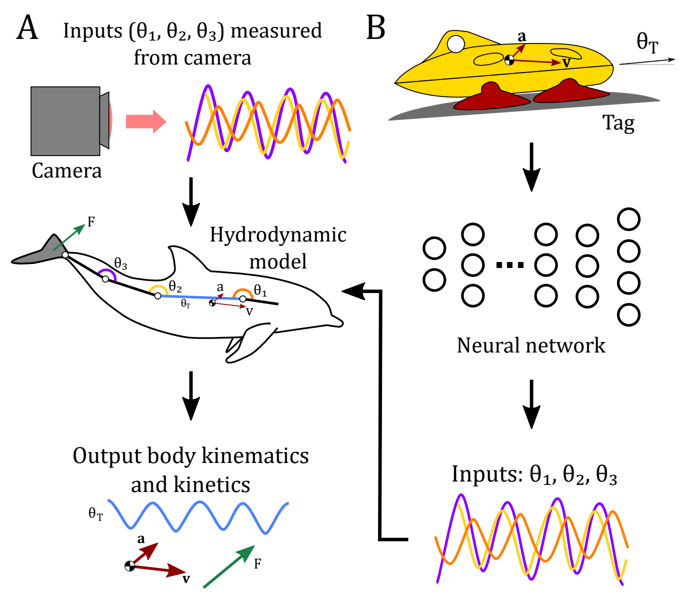

Fig. 1. Framework for modeling dolphin swimming. **A** In managed settings using camera **B** Using tag data to predict body posture and then the kinetics using the hydrodynamic model

References

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[3] F. E. Fish and J.J. Rohr, "Review of Dolphin Hydrodynamics and Swimming Performance" San Diego, CA: SPAWAR Systems Center. 1999