Biorobotics for Undersea Vehicles:
Trends in Hydrodynamics, Actuators and Control

Foreword

Building an undersea vehicle that is fully autonomous and leaves no noise or turbulence signature remains a dream. The Office of Naval Research Biorobotics Program seeks to distill the science of swimming and flying animals and implement that on existing platforms with minimal changes to seek performance improvement towards that goal. As a beginning toward that goal, during the early 1990s, a NUWC-URI team undertook the task of comparing the maneuvering performance of fast and yet agile varieties of fish quantitatively with that of small undersea vehicles[1]. At a constant value of the maneuvering parameter, bluefish and mackerel carried out lower radii turns relative to their body lengths compared to those by tactical scale vehicles of the 1950s or 1980s. The data also showed that the gap has narrowed greatly over three decades. However, this could be attributed only to the advent of digital control engineering and not hydrodynamics. Thus, it also became apparent that the steady state hydrodynamic technology based on which these vehicles and, for that matter all contemporary submarines or aircraft are built, has largely matured. The clue to closing the gap then must be sought in the unsteady hydrodynamic principles that swimming and flying animals employ.

Independent of studies on biolocomotion, engineers have been aware of that heaving and pitching foils with appropriate phase difference, produce lift forces exceeding those by steady state flows by a factor of as large as four to five. Barring some passive ingenuous inventions, such unsteady hydrodynamics would however, require the availability of appropriate actuators and non-linear control technology because the large alternating components of forces tend to couple with those of the steady levels. Experience restrains us from embarking on programs for the implementation of unsteady hydrodynamics because of cost and reliability issues of moving underwater hydrodynamic load bearing components. Because penalties associated with drag and efficiency of unsteady hydrodynamics are not well understood, it is not clear if a complete engineering system can indeed be built that employs unsteady hydrodynamics. However, the works of Ellington[2] and Dickinson[3] clarifying the high-lift mechanism of the flight of insects, indicate that a complete albeit biological system, is indeed feasible that can survive in the competitive environment of their habitat. This thread of thinking has led to the ONR initiative on an integrated effort to develop biology inspired high-lift control surfaces, electro-active polymer (EAP) artificial muscle materials and neurology-based control technology to fully utilize the opportunities offered by EAP. A pre-workshop was held in January 2002 in Arlington, Virginia to discuss the maturity of biology-based high-lift hydrodynamics and if this was suitable for enhancement of propeller performance[4]. Several leading scientists in the abovementioned three disciplines, and Navy propeller designers and program officers participated. The established community was receptive of the emerging maturity of the disciplines although there are miles to go. The present workshop is a continuation of this process of integration of the three disciplines and evaluation of their maturity toward technology development. The highlight here is the presentation of the ONR tasked reviews of the state of the art of the science and technology of the three component disciplines, namely the maneuvering hydrodynamics inspired by the swimming of aquatic animals, actuators and their fish neurology-inspired control.

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