

Omnidirectional sensing in a highly maneuverable animal: the coupling of sensing to locomotion in the weakly electric fish

Malcolm A. MacIver^{1*}, Joel W. Burdick², Mark E. Nelson³

^{1,2}Division of Engineering and Applied Science and
the Program in Computation and Neural Systems,
California Institute of Technology, Pasadena, CA 91125

³Department of Molecular and Integrative Physiology,
University of Illinois, Urbana, IL USA 61801

*To whom correspondence should be addressed:

Dr. Malcolm A. MacIver

Division of Engineering and Applied Science
California Institute of Technology, MC 104-44

Pasadena, CA 91125

626-395-3683 (phone)

626-583-4963 (fax)

maciver@robotics.caltech.edu

One key measure of an animal's sensory ability is the shape and extent of the volume of space within which the typical objects of interest, such as prey, can be detected. We examined this volume for the weakly electric fish. These animals are nocturnal and, like bats, sense their surrounding using a self-generated signal under motor system control. The self-generated signal is a weak, quasi-sinusoidal electric field. Objects that enter this field modulate the activity of thousands of sensors scattered over the body surface. Despite orders of magnitude variation with fish length in both the emitted electric field strength and the density of sensory receptors on the body surface, and the large variation in surface area with length of the knife-like body plan, our findings indicate that this animal has evolved a remarkably uniform, space-filling cylindrical sensing volume. The omnidirectionality of this volume complements the animal's high maneuverability and bi-directional locomotory behavior. We show the regularity is largely due to the spatial variation in the electric field. These results show a high degree of complementarity between signal emission patterns, body plan, locomotory behavior, and to a lesser extent sensor density in generating the shape of this animal's perceptual space. Similar findings in the bat suggest that the close coupling of these attributes may be a general feature of vertebrate sensing systems that rely on modulations of a self-generated signal.