From Geometric Control to Collective Behavior

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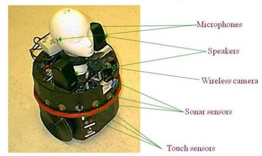
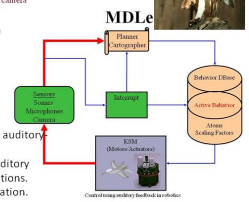
This is a guided tour of highlights of my work in ISR, as manifested in theorems, algorithms and artifacts.

Artifacts from ISL and signal processing inspired by nature



Control using auditory feedback in robotics



Control using auditory feedback in robotics

Biologically inspired sound localization and motion control software was used to guide an auditory-enabled mobile robot to track sound sources. Understanding key aspects of the barn-owl auditory system proved to be important for robust solutions. MDLe is now part of a commercial implementation.

Coping with non-ideal Nonlinearities

Actuators and mechanisms display non-ideal nonlinear behavior due to backlash in gear trains, friction in bearings, impact during contact, and hysteresis in constitutive relations. Mitigating the influence of such uncertain behavior on the performance of robotic devices and systems demands a multi-pronged effort through modeling, inversion, and control. The exploitation of coupled fields (piezo-electric effect, magnetostriction) in precise "smart" micro-positioning devices also demands similar approaches. In my work, the problem of hysteresis was investigated by resorting to microscopic modeling via the Landau-Lifshitz equations, and phenomenological input-output descriptions such as the one associated with Preisach and others in magnetism. Alternative low-dimensional models for ease of use in real-time control applications were also investigated.

My collaborators in this challenging area included **Lung-Wen Tsai, W. P. Dayawansa**, J. Loncaric, J. Baras, **R. Venkataraman**, and **X. Tan**.

Mathematical Bearings

Beginning from a strong affinity for geometrical modes of thinking, I have pursued a wide variety of problems in control, filtering theory, and signal processing.

The role of geometry in defining the fundamental structure of mathematical models in physics is now widely appreciated. It is important to recognize that there are significant payoffs to exploring such structures in engineering problems as well. For instance in the discussion of problems of nonlinear dynamics and control in space applications, and in related settings for robotics, the Euclidean group SE(3) enters as an ingredient of **configuration space, as a symmetry group, and as the space of goals and observations**.

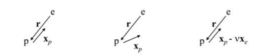
The structures of geometric mechanics, including **symplectic and poisson structures, symmetry and reduction, momentum maps and connections, and lagrangian systems with nonholonomic constraints**, have formed a basis for my work. Problems of stability and bifurcations guided my early work in ISR. The role of feedback in stabilization and preservation of geometric structures was examined in a variety of settings, including gyroscopic Lagrangians, inspired by applications in aerospace systems. The models analyzed range from examples in finite dimensional solid mechanics such as gyrostats, to elastodynamics, rigid bodies interacting with fluids, and wheeled vehicles in robotics. The notion of **geometric phase and associated optimal control** problems were investigated. Dissipation mechanisms and instabilities were studied from a geometric viewpoint.

Recursive Algorithms

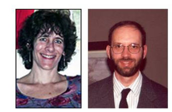
The subject of nonlinear filtering is a basis for a variety of estimation problems including system identification, in my work. Modern approaches to the nonlinear filtering problem exploit computational advances by stochastic simulation leading to a family of particle filters. In ISL, **we originated the projection particle filter with continuous time dynamics and exponential families**. In contrast to model-based methods for filtering, signal processing applications such as blind separation of mixtures of signals demand methods such as ICA derived from a statistical-geometric framework. Advances in wavelet theory and frames stimulated our contributions to approximation of static maps and transfer functions. The **orthogonal matching pursuit (OMP)** algorithm is an efficient and widely-used tool for constructing approximations. A variety of technologies, including **tactile sensing and acoustic guidance in robotics, and adaptive optics** for correcting wavefronts distorted by propagation media, influenced novel solutions to inverse problems arising from our work.

Collaborators include Y. C. Pati, R. Rezaiifar, W. Dayawansa, B. Azimi-Sadjadi, B. Afsari, S. Shamma, Y. Qi, E. Justh, M. Vorontsov

Bats, pursuit and collective behavior



Classical Pursuit | Constant Bearing | Motion Camouflage

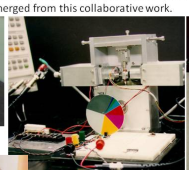


In the search for Interactions amongst agents leading to collective behavior, I have been inspired by models based on gyroscopic forces developed in my study of prey-capture behavior in bats (joint work with **Cynthia Moss** and students). A special class of strategies of interest is pursuit. Pursuit is a familiar mechanical activity that humans and animals engage in. With **Eric Justh** and students, I have been studying the role for such strategies as building blocks for coherent structures (flocks, swarms, schools, etc). A new collaboration with Italian physicist **Andrea Cavagna** is concerned with flocking and swarming in birds and insects. The ideas emerging from this work are relevant to collective robotics.

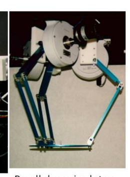
Technologies from ISL

I have directed the Intelligent Servosystems Laboratory from its founding in 1986. The work of the lab was informed by the interests of a number of collaborators, including **Roger Brockett**, Lung Wen Tsai, Wijesuriya Dayawansa, John Baras, **Josip Loncaric**, Gregory Walsh, Dimitris Hristu, and several generations of students in ECE, ME and CS. Many interesting ideas, technologies, and artifacts, emerged from this collaborative work.

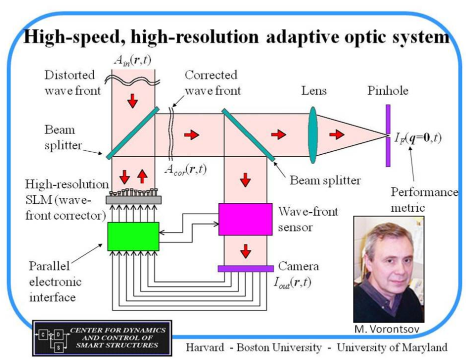
Modular Dexterous Hand



Hybrid Motor



Parallel manipulator



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