

HOWIE CHOSSET'S STATEMENT

My education and research interests straddle the border between computational theory and mechatronic engineering, makes mathematical principles accessible to engineering, and reaches out to practitioners in the chosen application fields. In my group's research, rigorous mathematical results enable engineering advancements while the practical aspects of implementation drive theoretical pursuit. My program centers on two foci: highly articulated systems and coverage tasks. These foci touch upon fundamentals in robotics including: topological methods, control of mechanical systems, design, mapping, and differential geometry. This work is directly tied into search and rescue, de-mining, auto-body painting, and medical surgery. These endeavors require the interaction between people and technology and thus, I seek to exploit its benefits and understand the barriers of this interaction.

My research group has constructed a variety of snake robots which can exploit their many internal degrees of freedom to thread through tightly packed volumes accessing locations that people and conventional machinery otherwise cannot. Three challenges facing snake robot research are design, path planning and locomotion. Since we are interested in search and rescue (I am an Associate Director for the Center for Robotic Assisted Search and Rescue), we designed our robots to maneuver in three-dimensions and possess a small cross-sectional diameter.

Once the snake robot is built, it still requires control. Simple engineering hacks alone are not sufficient to coordinate the internal degrees of freedom to allow for purposeful motion. Essentially, the robot must plan in a non-Euclidean multi-dimensional space. Our approach uses a topological map of the space, which reduces planning from a multi-dimensional search problem to a one-dimensional search. In 1997, I received the NSF Career award to develop a topological map based on a retract-like structure for rod-shaped and convex-body robots operating in a non-Euclidean configuration space. In collaboration with the Johnson Space Center, we have applied this approach to AERCam, a free-flying robot.

Our topological mapping techniques have the added benefit that they induce well-defined sensor-based control laws that can direct a robot to explore an unknown space with provable guarantees. However, one of the critical challenges in exploring unknown spaces is localization while mapping, or the so-called simultaneous localization and mapping (SLAM) problem. We developed a hierarchical SLAM technique that works well in large spaces. Specifically, we use a topological map to divide the free space into regions where high-resolution maps, corresponding to each edge of the topological map, can be created. This approach scales well because we never create a large high-resolution map, but rather represent a large space with a collection of small high-resolution maps tied together by a topological map. Scott Thayer's group in the FRC used this approach to map underground mines.

The topological approaches do not apply to "snake robots," per say, but to elephant trunk robots which generally have a fixed base and move around in three dimensions. Snake robots, on the other hand, must coordinate their internal degrees of freedom and interact with their environment to propel themselves in a desired direction. Here, we analyze a broad spectrum of mechanical systems, those governed by both conservation of momentum and non-holonomic constraints. Specifically, we take recourse to the fundamental mechanics to develop gait evaluation techniques that are based on a geometric/kinematic contribution and a dynamic contribution. These evaluation techniques are then used to synthesize kinematic, dynamic, and kinodynamic gaits for systems whose Lagrangian is invariant under group actions. The principle contribution here is that we determined the "right" space inside of which one can intuitively design and optimize gaits for mechanical systems such as snake robots.

The symbiosis of applied math and engineering has already had an impact on the robotic search for mines. My group has developed provably complete techniques for coverage path planning, a method that determines a path for a robot to follow so that the robot passes over every point in a target region. The mathematical guarantee is critical in mine-sweeping where missing one mine makes the mission a failure. In 1999, the Office of Naval Research awarded me its Young Investigator Program award to further this work. Our approach uses a cell decomposition, a representation where the environment is divided into cells and a graph is formed encoding the adjacent relationships (topology) among the cells. Coverage in each cell is “simple,” and thus complete coverage is achieved by visiting each cell in the decomposition. In many situations time may not permit covering an environment completely. However, if the planner has a probabilistic *a priori* understanding of how mines are laid, it can opportunistically guide the robot. For patterned mine fields, we developed a Bayesian method of efficiently decoding the parameters that describe the minefield. Once these are known, the robot can cover a fraction of the target region and locate most of the mines. This work is done with Prof. Mark Schervish in Statistics.

In collaboration with Prof. Rizzi at Carnegie Mellon, we applied similar coverage technology to the application of auto-body painting with the Ford Motor Company to expedite the paint operation while minimizing hazardous waste. This is a coverage problem in three-dimensions, but must also respect the dynamics of the paint applicator and effects due to curvature of the surface. Already, we have demonstrated utility of this work on car body parts painted at Ford.

Also, in collaboration with Prof. Rizzi, we combined the above described cell decomposition concept with sequential composition to develop a new type of hybrid control. Recall that hybrid controls is a combination of discrete and continuous planning where an arbitrator selects which continuous feedback control law to invoke. Here, we define policies in cells and as the robot travels through its free space, our method uses the adjacency relationships among the cells to select which policy to invoke. In a sense, instead of using path planning to determine a “thin” path, we now have a procedure which determines a “fat” path or vector field along which the robot “flows” from a start location to a goal.

In the above research endeavors, my group has brought the realities and uncertainties of mechanical systems to the precision of applied math and computer science. This philosophy of using construction and implementation to reinforce theory permeates my courses and advising. My graduate students participate in rigorous reading groups on basic mathematic theory (e.g., see <http://differentialgeometry.org>) and they construct mechanical artifacts. Moreover, my students have first-hand experience with the applications: we have participated in mock search and rescue scenarios, we have fielded our de-mining robot, we have performed experiments at Ford, etc. My four Ph.D. graduates all have a strong theoretical contribution as well as a thorough experiment.

In my undergraduate robotics course, students use LEGO robotics lab modules, developed by my students and myself, to reinforce the theoretical materials presented in class. Via construction of an artifact, the lab experiences seriously motivate students to synthesize lessons, critically explore beyond them, and then think creatively with meta-lessons. The course strikes a balance between conventional one-way lectures and modern constructionism. This course sits as the centerpiece for the robotics minor, which I developed and currently direct at Carnegie Mellon

I am the lead author of a motion planning textbook which makes the deep fundamental underpinnings of robotics accessible to the novice. At the same time, the book focuses on implementation issues and ties

together low-level concepts with theoretical concerns. I use this book in a newly designed course on motion planning (<http://voronoi.sbp.ri.cmu.edu/~motion>).

My near-term research goals include multi-robot systems, hybrid controls, and medical devices. In terms of hybrid controls, we are using conventional motion planning algorithms to develop synthesis tools for hybrid controls of systems possessing non-trivial dynamics and non-holonomic constraints. With medical devices, we already have developed a snake robot for minimally invasive surgery, where the device can reach deeper into the body without a need for large incisions. We have tested our prototype several times in a live pig with Dr. Zenati at UPMC. With Dr. Wolf, we have developed a mechanism for bone shaving; this draws from our paint work where instead of depositing we are removing material.

Understanding motion is important. We will apply the rigorous fundamentals of robotics to modeling biological motion. Already, we have begun using our kinematic analysis to model the knee as a parallel mechanism. I also find the social aspects of human-technology interaction to be interesting and important. My future work will consider: how technology can be used to teach basic principles and what are the barriers for technology acceptance. Already, the LEGO-based robotics course has given us insight on how technology can teach some basic math. For the auto body painting work, the medical robotics, and the urban search and rescue experiences, I have seen how “social” issues impact the decision to use technology. For example, we never would have performed so many experiments and developed a keen medical robotics perspective without Dr. Zenati and his willingness to “push” this technology, and introduce it to his colleagues. My future work seeks to model the non-economic aspects of technology acceptance and its barriers.