Howie Choset’s Research Statement

Professor Choset's education and research interests straddle the border between computational theory and mechatronic engineering implementation: rigorous mathematical results enable engineering advancements while the practical aspects of implementation drive theoretical derivation. Choset’s research program centers on two foci: highly articulated systems and coverage tasks. These foci touch upon a number of fundamentals in robotics including: topological methods, design, mapping, and coverage. This work is directly tied into urban search and rescue, de-mining, auto-body painting, inspection of space structures, and medical surgery.

Choset’s research group has constructed a variety of highly articulated devices. One such highly articulated system is a snake robot which can exploit its many internal degrees of freedom to thread through tightly packed volumes accessing locations that people and conventional machinery otherwise cannot. Already, we have implemented some basic snake robot locomotion gaits – see http://snakerobot.com. Two of the challenges facing snake robot research are design and path planning. Since we are interested in applications such as urban search and rescue, our snake robots must maneuver in three-dimensions and still posses a small cross-sectional diameter. Our current designs maximize mechanical strength per cross-section diameter. Ultimately, Choset’s long-term goal is to develop snake robots for minimally invasive surgery; the idea here is that the snake robot can reach deeper into the body without a need for additional or large incisions. Currently, we are developing a device for cardiac surgery.

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 multi-dimensional, one for each degree-of-freedom, 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, Choset received an NSF Career award to develop a topological map based on a retract-like structure. However, the retract-like structure is not enough; each path generated by the retract must be optimized so that the snake robot can more easily follow it. Naturally, with all optimization problems, we must contend with local minima. Here, we take recourse to homotopy theory where the retract-like structure seeds a set of candidate searches of the robot’s free space, one of which leads to the global optimum. Essentially, we are exploiting the natural topology encoded in the free space to divide it into regions each having simple structure and optimizing within each simple space a cost function. This approach is general: the cost function can be anything: path length, safety, energy, etc. For snake robots, we have defined a “snake robot” cost function. In collaboration with the Johnson Space Center, we have also applied this approach to a free-flying robot called AERCam, which will fly around the future space station.

Our topological mapping routines have the added benefit that they induce well-defined sensor-based control laws that can direct a robot to explore an unknown space. Here, we are able to endow robots with the ability to reactively maneuver through a space with provable guarantees of achieving navigation and exploration. However, one of the critical challenges in exploring unknown spaces is localization. Nominally, a robot has encoders on its wheels that count the number of times the wheels rotate and after integrating this information, the robot determines its location. Due to slippage of the robot's wheels, the robot accrues localization error. Initially, we have developed a topological approach to simultaneous mapping and localization (SLAM). This approach works well into large spaces but does not provide a high resolution map. On the other hand, conventional feature-based SLAM approaches, mainly based on Kalman filtering and Bayesian techniques, provide a high resolution map, but do not scale well into large spaces. Recently, we developed a hierarchical SLAM technique where we use a topological map to divide the free space into regions where high resolution maps can be created. Specifically, each edge of the topological map has a corresponding high resolution local map. In a sense, the topological map threads together all of the local maps in a robust manner. This approach scales well because one giant high resolution map is never created and yet a large space in represented by a collection of maps tied together by a topological map. Experiments in large-scale environments have verified the utility of this method.

The symbiosis of applied math and engineering, which is at the core of this research program, has already had an impact on a vital area, the robotic search for mines. Choset's 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 Choset its Young Investigator Program award to further work in de-mining, both on land and in the surf zone. The coverage approach uses a cellular decomposition, a representation where the environment is divided into cells and a graph is formed encoding the adjacent relationships (topology) among the cells. Since we use critical points of Morse functions to define 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 a target environment completely, as may be the case in robotic de-mining. However, if the planner has access to a probabilistic map of mine locations, it can opportunistically guide the robot. For mine fields that have been laid out in a pattern, 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 Mark Schervish in Statistics at Carnegie Mellon.

In collaboration with Dr. Rizzi at Carnegie Mellon, Choset 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. The paint work is also coverage in three-dimensions, but it must respect the dynamics of the paint applicator. Already, we have demonstrated utility of this work on car body parts painted at Ford. The next step in this research thrust is to apply coverage to develop software tools for semi-automated milling for both rapid prototyping and surgical bone shaping with a minimally invasive device.

In the above research endeavors, Choset's group has brought the realities and uncertainties of mechanical systems into harmony with the precision of applied math and computer science. This philosophy of using construction and implementation to reinforce theory permeates Choset's courses. In Choset's undergraduate robotics course, students use LEGO robotics labs, developed by Choset and his students, to reinforce the theoretical materials presented in class. Via construction of a programmable three-dimensional artifact, the lab experiences seriously motivate students to synthesize lessons, critically explore beyond them, and then think creatively with meta-lessons. Choset termed this style of education as "directed constructionism" because it strikes a balance between conventional on-way lectures and modern constructionism.