An Atlas Framework for Scalable Mapping

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The Problem: The goal of our work is to develop a scalable method for egomotion and environment capture. Existing methods for simultaneous localization and mapping (SLAM) and Structure from Motion (SFM) can perform well in local, small-scale regions, but struggle when applied to larger environments. The concurrent recovery of scene structure and the sensor trajectory is a high-dimensional, coupled state estimation problem. The key challenges include coping with uncertainty and scale and the coupling (non-independence) of errors in feature and sensor pose estimates.

Motivation: The large-scale SLAM and SFM problems have been key unsolved problems in robotics and computer vision research. Many application domains require autonomous navigation and mapping in extended environments (thousands of square meters to tens of square kilometers in area) with long sensor excursions and closing of large loops [3].

Previous Work: While there has been substantial recent progress in SLAM and SFM in local, small-scale regions, the development of methods for very large large environments remains a difficult open research problem.

Approach: We have developed a method in which existing small-scale mapping algorithms can be applied to large-scale problems via a new framework called *Atlas*. Our approach combines the advantages of topological [1] and metrical representations [3, 2]. The representation is a graph of coordinate frames. Each vertex in the graph represents a local coordinate frame, and each edge represents the transformation between adjacent local coordinate frames. In each local coordinate frame, we build a map that captures the local environment and the current robot pose along with the uncertainties of each. Each map's uncertainties are modeled with respect to its own local frame. Probabilities of entities with respect to arbitrary map-frames are generated by following a path formed by the edges between adjacent map-frames. We compute such paths via Dijkstra's shortest path algorithm using the uncertainties of the transformations as a statistical distance metric. Loop-closing is achieved via an efficient map matching algorithm.

Impact: We have pursued the challenge of mapping MIT's "Infinite Corridor" and nearby buildings. The experiments utilized a standard B21 mobile robot equipped with SICK scanning laser and a ring of 24 Polaroid ultrasonic sensors. Figure 1 shows the topological path of the vehicle superimposed on an architectural drawing of the MIT main campus, along with the trajectory derived from odometry only. The total path length was 2.2 km and the experiment lasted 2.5 hours. The route contains nested loops of various sizes and topologies. Figure 2 shows the maps produced with our approach using laser (left) and sonar (measurements). Figure 3 overlays the laser map onto a schematic of the MIT campus. These maps are an order-of-magnitude larger than any maps ever produced of an indoor environment with a feature-based SLAM algorithm.

Future Work: Work in progress includes the extension of *Atlas* to accomodate omnidirectional video sequences, the incorporation of super-resolution texture estimation from multiple views, and the implementation of *Atlas* with undersea sonar data acquired by an Odyssey III autonomous underwater vehicle.

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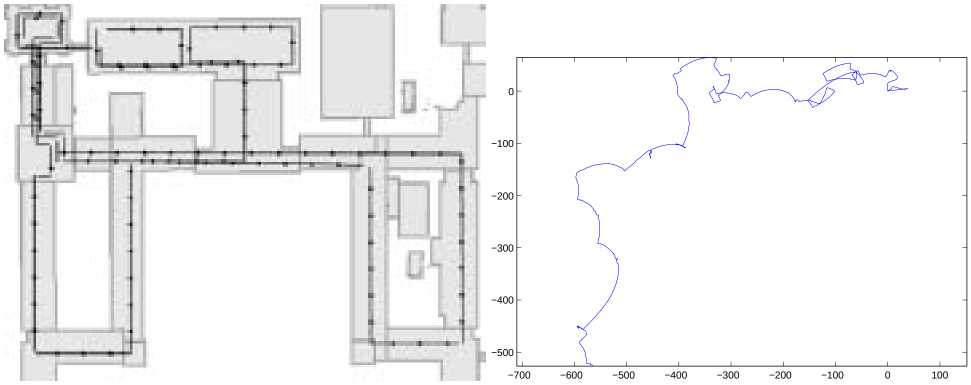

Figure 1: Left: The manually drawn topology of the driven route overlaid on an architectural drawing of part of the MIT campus. The large east-west passage (a.k.a. the "Infinite Corridor") is about 250m long. Right: The trajectory derived from odometry alone.

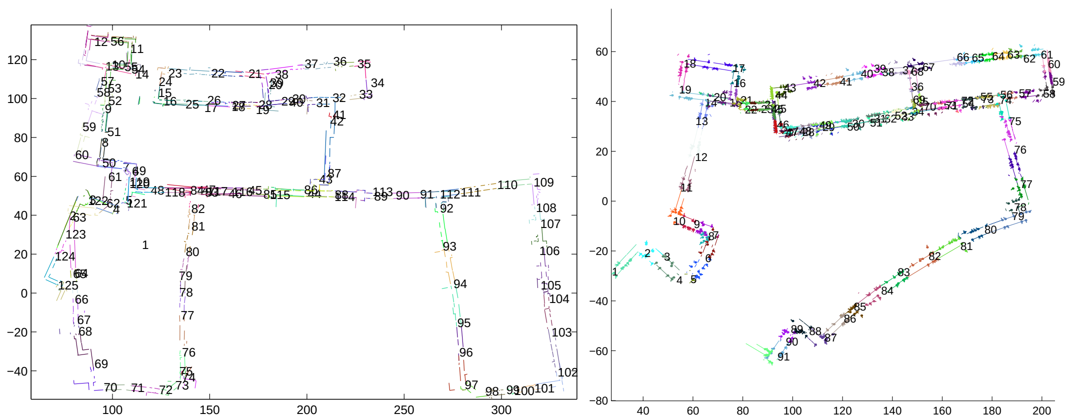

Figure 2: A visualization of the complete set of numbered map-frames. For the purposes of visualization, a posterior loop constraint has been applied. Left: map built from laser data. Right: map built from sonar data.

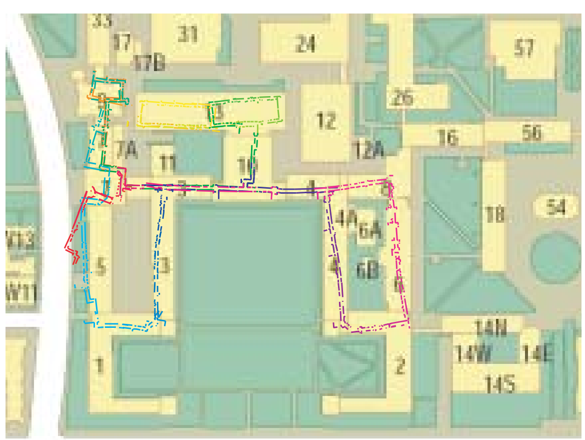

Figure 3: Laser map overlaid on a map of the MIT campus.