Sensor Based Coverage of Unknown Environments for Land Mine Detection

Ercan Acar, Morgan Simmons, Michael Rosenblatt, Maayan Roth, Mary Berna, Yonatan Mittlefehldt, Howie Choset
Carnegie Mellon University
Pittsburgh, PA15213
eua@andrew.cmu.edu

Abstract

This paper introduces a sensor based coverage algorithm and an overview of a mobile robot system for demining. The algorithm is formulated in terms of *critical points* which are the points where the topology of an environment changes. We developed a provably complete coverage algorithm which makes a robot pass over all possible points of an unknown environment.

Overview of The Coverage Algorithm

Conventional path planning determines a path between two points. This type of planning is suitable for guidance, pick and place operations etc.. Applications such as vacuum cleaning, floor scrubbing, area surveying, demining (Land & Choset 1998) and harvesting (Ollis & Stentz 1996) require more than point to point planning. They require a coverage algorithm which determines a path that passes the robot over all possible points in an environment.

In many scenarios, the robot may not know its environment a priori, and thus a sensor based coverage algorithm is necessary. Sensor based coverage determines a path for a robot such that it passes over all possible points in an unknown environment. Completeness of such a coverage algorithm is of utmost importance. As an example, all possible points of a minefield should be covered to guarantee not to miss a single mine.

Different types of coverage algorithms were developed by several researchers. Some of the algorithms are grid based (Zelinsky *et al.* 1993), (Pirzadeh & Snyder 1990) and some of them are cellular decomposition based (Cao, Huang, & Hall 1988), (Vladimir J. Lumelsky & Sun 1990), (Hert, Tiwari, & Lumelsky 1996). Behavior based algorithms for coverage are also considered (MacKenzie & Balch 1996). However all these algorithms either work only in certain types of environments, make unrealistic assumptions about the sensors, or completeness of the algorithm is not shown. We developed a provably complete coverage algorithm and implemented it on a mobile platform.

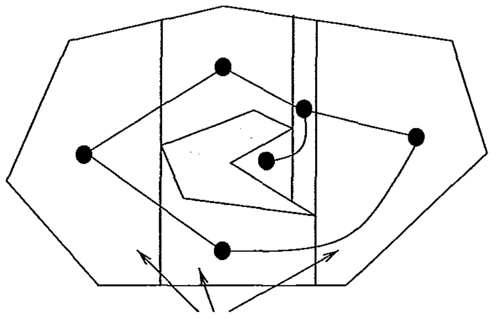

Figure 1: Cellular Decomposition

Our method is based on a geometric structure called cellular decomposition (Latombe 1991), which is the union of non-overlapping subregions of the free space, called *cells*. An adjacency graph encodes the topology of the cells in the environment where nodes are cells and edges connect nodes of adjacent cells (Fig. 1). Since simple back and forth motions cover each cell, *complete* coverage is reduced to finding an exhaustive walk through the adjacency graph (Choset & Pignon 1997).

The cellular decomposition defines its cells in terms of critical points. If the robot knows the critical points, then it effectively knows the decomposition. When the environment is not known, neither are the critical points. Therefore sensor based coverage is covering the environment while determining the locations of critical points.

We developed methods to sense critical points in unknown environments. The notion of critical point sensing was first introduced in (Rimon & Canny 1994) and it was called the critical point sensor.

Generically each cell is characterized by two critical points. Instead of forming an adjacency graph with nodes as cells, we form a dual graph where nodes are critical points and edges are the cells. Each time the robot encounters a new critical point, a new node is

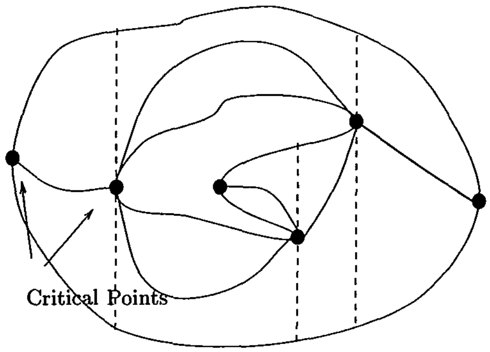

Figure 2: Dual adjacency graph representation of the environment. Nodes represent critical points, branches represent cells.

created, the edge corresponding to the current cell is terminated at the new node and depending on the type of the critical point two more edges are instantiated or no edge is created. If the robot encounters an already discovered critical point, then the edge corresponding to the current cell is terminated at the critical point and the "dangling" edge (*i.e.* it only has one node) of the already discovered critical point is deleted. When all the nodes have edges ending with another node, coverage is completed.

An essential part of the complete coverage is developing an algorithm which guarantees to see all the critical points. Such an algorithm was developed and its completeness was proved.

Overview of the Demining Robot

It is estimated that there are over 120 million active land mines in the world which cause the deaths of over 25,000 people each year. Many of these casualties are civilians, many of which are children. Current removal methods involve trained technicians searching with hand held electronic instruments (often metal detectors), while working on their hands and knees. Not only is this dangerous, but it is also very difficult for a person to reliably cover an entire area. Autonomous robotic coverage provides a solution which helps to remove people from this dangerous occupation, as well as to enable more reliable and efficient coverage strategies.

The testing vehicle that we are using in the implementation of our project is an original design which provides ruggedness and flexibility for an outdoor environment. The welded aluminum structure has a payload space of $13 \times 8 \times 20$ inches, and is impact resistant in all directions. Four ten-inch pneumatic wheels are driven in a differential drive configuration by twin variable-speed electric motors (one for each side, front, and rear wheels will be chained together). A removable fiberglass cradle is attached to the front of the vehicle and houses an array of four metal detecting sensors.

The vehicle's on board computer is currently a HandyBoard robot controller which is powered by Motorola 68HC11 micro-processor. The Motorola 68HC11 can control external devices, read input information, and communicate with a personal computer. A Pentium based computer can be easily added to the system whenever the processing power of the 68HC11 becomes insufficient. The vehicle is equipped with numerous sensing systems. Attached to the drive train are shaft encoders that monitor the displacement and velocity of the wheel. Also on board is a digital compass which uses coils (no moving parts) to detect the earth's magnetic field and returns a compass heading in degrees. The shaft encoders and digital compass are used to enable the vehicle to position and direct itself through the environment. The metal detection sensors cover the entire front of the vehicle and are used to detect simulated land mines.

References

Cao, Z. L.; Huang, Y.; and Hall, E. 1988. Region filling operations with random obstacle avoidance for mobile robots. *Journal of Robotic systems* 87–102.

Choset, H., and Pignon, P. 1997. Coverage path planning: The boustrophedon decomposition. In *Proceedings of the International Conference on Field and Service Robotics.*

Hert, S.; Tiwari, S.; and Lumelsky, V. 1996. A Terrain-Covering Algorithm for an AUV. *Autonomous Robots* 3:91–119.

Land, S., and Choset, H. 1998. Coverage path planning for landmine location. In *Third International Symposium on Technology and the Mine Problem.*

Latombe, J. 1991. *Robot Motion Planning.* Boston, MA: Kluwer Academic Publishers.

MacKenzie, D., and Balch, T. 1996. Making a Clean Sweep: Bahavior Based Vacuuming. In *AAAI Fall Symposium, Instationating Real-World Agents.*

Ollis, M., and Stentz, A. 1996. First Results in Vision-Based Crop Line Tracking. In *IEEE International Conference on Robotics and Automation.*

Pirzadeh, A., and Snyder, W. 1990. A unified solution to coverage and search in explored and unexplored terrains using indirect control. In *Proc. of IEEE Int'l. Conference on Robotics and Automation,* 2113–2119.

Rimon, E., and Canny, J. 1994. Construction of C-space Roadmaps Using Local Sensory Data — What Should the Sensors Look For? In *Proc. IEEE Int. Conf. on Robotics and Automation,* 117–124.

Vladimir J. Lumelsky, S. M., and Sun, K. 1990. Dynamic path planning in sensor-based terrain acquisition. *IEEE Transactions on Robotics and Automation* 6(4):462–472.

Zelinsky, A.; Jarvis, R.; Byrne, J.; and Yuta, S. 1993. Planning Paths of Complete Coverage of an Unstructured Environment by a Mobile Robot. In *Proceedings of International Conference on Advanced Robotics,* pp533–538.