Maximizing the Area Coverage in Constrained Environment for Mobile Sensor Network

G.A .Nighojkar[1], J.M.Watkins, PhD[1], J.M.Esposito, PhD[2]

[1] *Department of Electrical Engineering, Wichita State University, Wichita, Kansas 67260, U.S.A.*

[2] *Department of System Engineering, United States Naval Academy, Annapolis, Maryland 21402, U.S.A.*

1. Introduction

With rapid developments in sensing and communication, mobile sensor networks are expected to cooperatively perform tasks in dangerous and remote environments. A mobile sensor network or robotic swarm is a distributed collection of mobile robots. Swarm robots are equipped with sensors and they work together to execute tasks, which are beyond the scope of single robot. There are many potential applications for mobile sensor networks including border patrol, intrusion detection, search and rescue operation and surveillance of large geographical territories, in which primary importance is given to covering as much area as possible of the free space. Covering an entire area for surveillance in minimum time is one of the most important tasks in a mobile sensor network. It is also important that the mobile robots communicate with other members, collect data, and sometimes send it to central server. Robots need to cover an unknown environment, which may contain obstacles, while maintaining proper communication between their neighbors.

2. Potential field Theory

A lot of attention has been given to this problem over the last decade. Spanning tree and polynomial time coverage algorithms, which primarily involve single robot and cell decomposition, are time consuming. Failure of this single robot due to energy depletion problem will never accomplish the primary aim of covering an entire area [1]. The local dispersion approach was developed by Batalin and Sukhatme to achieve better coverage of the whole area [2].The Potential field theory approach was first addressed by Khatib [3] and thereafter was employed for development of elegant path planning algorithms for mobile robots [4], multi robot manipulation by Song and Kumar.[5]. Poduri and Sukhatme have introduced the algorithm for area coverage [6] based on potential fields.

The aim of this project is to develop a completely decentralized and scalable algorithm based on potential field theory such that there is no "master" robot that controls the rest of the swarm and the algorithm works well as size of the swarm increases. Potential field theory can be used when robots do not have prior knowledge of an environment and obstacles. The potential function is generally defined over free space. According to this theory, each mobile robot, commonly called a node, is considered as an artificially charged particle. This theory is similar to electrostatic field theory in which charged particle moves from the point of higher potential to lower potential. This potential function is the summation of attractive potential and repulsive potential. Though potential field approach is fastest and descent technique of optimization in wide range of situations, it is partial and it can fail at a local minimum. [7] This problem can be solved by assuming virtual obstacles and virtual target position or by selecting the potential function with few or no local minima like Navigation function which has unique minimum and uniformly maximal over the boundary.

3. Problem Statement

We are developing the algorithm for motion control of mobile sensor networks such that, robots should attain the position by themselves to cover the maximum area of the free space in minimum time. The constraint on the algorithm is that every robot should communicate with at least a fixed number of robots, *K*. The robot is said to have *K* degree *of connectivity.* We are trying to optimize this number so that the percentage area covered by the algorithm maximizes.

4. Algorithm

For the algorithm development we assumed following.

(a) The robots operate in two dimensional environments
(b) Every robot is disc robot. The robot's coordinate indicates the center of the disc. Every robot will know its current position.
(c) Every obstacle is circular in shape
(d) Enough robots are available to cover the free space. No robot will fail during the deployment process.
(e) Sensing range SR and communication range CR of each robot is uniform in all direction and quality of sensing and communication is constant within sensing and communication range.
(f) Each robot will know about the behavior of the *K* nodes only. At any instant these *K* nodes are called as the stable nodes connection between node and its stable nodes is called as the stable connection as the number of stable neighbors decrease network will become unstable.

In this experiment every robot will start its motion with more than *K* neighbors. Consider the network of *n* mobile nodes 1, 2, 3… *n*. with positions p_1, p_2, p_3 ……, p_n respectively. The virtual forces F_{an} and F_{rep} will act on each robot. This attractive force maintains the required degree for each node and repelling force will maximize the area coverage along with obstacle avoidance. The net force on each node at any instance is given by

$$F_{tot}(x, y) = F_{att}(x, y) + F_{rep}(x, y)$$

The field of virtual forces is produced by the artificial potential function ϕ_i whose local variations reflect the structure of the free space F (x, y) = $-\nabla\phi(x, y)$,

where $-\nabla\phi(x, y)$ denotes the negative gradient vector of ϕ at point (x, y) for any node i. For two dimensional environments the negative gradient can be defined as

$$-\nabla\phi = \begin{bmatrix} -\partial\phi / \partial x \\ -\partial\phi / \partial y \end{bmatrix}$$

This potential function is the sum of attractive potential which governs the constraints of *K* degree connectivity and repulsive potential which maximizes area coverage while avoiding an obstacles present.

$$\phi_{tot} = \phi_{att}(x, y) + \phi_{rep}(x, y)$$

Total force can be written as the sum of two vectors, one due to attractive force and other due to repulsive force.

$$F_{att}(x, y) = -\nabla\phi_{att}(x, y) \text{ and}$$

$$F_{rep}(x, y) = -\nabla\phi_{rep}(x, y)$$

Let Δp_{ij} be the Euclidean distance between nodes i and j. It can be represented as $\Delta p_{ij} = \left\| p_i - p_j \right\|_2$.

Repulsive forces can be defined as

$$F_{rep}(x, y) = \frac{-k}{\Delta p_{ij}^{2}} \left[\frac{p_i - p_j}{\Delta p_{ij}} \right]$$

and attractive force for stable system is given by

$$F_{att}(x, y) = \frac{k}{\left(\Delta p_{ij} - c_R\right)^2} \left[\frac{p_i - p_j}{\Delta p_{ij}} \right]$$

This force is 0 for any other system conditions.

With these forces, new velocity can be found out for respective node. Node moves to its new position with this velocity. MATLAB code can be developed to simulate motion of the node with new velocity. Area covered by each node can be calculated by sensing range of that node. Summation of these areas is the total coverage area. We will select the optimum value for *K*, such that the percentage area covered will get increase in minimum time.

5. Conclusion:

We are addressing the issues regarding maximum area coverage by the network in minimum amount of time and obtaining the optimal value for *K*. With this optimal *K*, percentage area covered will get increased. We can apply this algorithm in designing faster coverage sensor networks which maximizes the coverage area in minimum time while maintaining the degree of each node.

6. References:

[1] Y.Gabriely and E.Rimon: Spanning-tree based coverage of continuous areas by a mobile robot. *Annals of Mathematics and Artificial Intelligence,* 31: 77-98, 2001

[2] M.A Batalin and G.S. Sukhatme, Spreading out: A local approach to multi-robot coverage. *6th International Symposium on Distributed Autonomous Robotic Systems,* Fukuoka, Japan 2002 pp. 373—382

[3] O. Khatib,Real time obstacle avoidance for manipulators and mobile robots, *International Journal of Robotic Research*, vol. 5, no. 1, pp. 90–98, 1986.

[4] R. Shahidi, M. Shayman, and P. S. Krishnaprasad, "Mobile robot navigation using potential functions," in *Proceedings of the IEEE International Conference on Robotics and Automation*, Sacramento, CA, 1991, pp. 2047–2053.

[5] P. Song and V. Kumar, "A potential field based approach to multi robot manipulation.," in *Proceedings of the IEEE International Conference on Robotics and Automation*, Washington, DC, 2002, pp. 1217-1222.

[6] S.Poduri and G.S. Sukhatme, Constrained coverage for mobile sensor networks in *IEEE International conference on robotics and automation, NewOrlens, LA, 2004, pp.165*-172

[7] J.Latombe. *Robot Motion Planning*. Kluwer Academics Publishers, 199