SENSOR DEPLOYMENT AND TARGET LOCALIZATION FOR TACTICAL SURVEILLANCE

Yi Zou* and Krishnendu Chakrabarty
Department of Electrical and Computer Engineering
Duke University
Durham, NC 27708, USA
E-mail: {yz1, krish}@ee.duke.edu

1. INTRODUCTION

Distributed sensor networks (DSNs) provide the US Army with a key enabling technology that is responsive to the needs outlined in the *Concepts for the Objective Force*. DSNs are readily *deployable*, they are *responsive* to battlefield situations, and they provide force protection (*Survivable*). The effectiveness of DSNs is determined to a large extent by the coverage provided by the sensor deployment. As an initial deployment step, a random sensor placement in the target area is often desirable, especially without any *a priori* terrain knowledge, and also because of the fact that DSNs in military applications are initially established by dropping or throwing sensors into the sensor field. However, random sensor deployment leads to random sensor concentrations which does not provide effective coverage. We introduce the virtual force algorithm (VFA) as a sensor deployment strategy to enhance the coverage after an initial random placement of sensors. The VFA algorithm is based on the disk packing theory (Locateli and Raber, 2002) and the virtual force field concept from robotics (Howard et al., 2002). For a given number of sensors, VFA attempts to maximize the sensor field coverage using a combination of attractive and repulsive forces.

2. VIRTUAL FORCE ALGORITHM

Assume a total of k sensors have been deployed in the random placement stage, the total force $\vec{F}_i$ on S_i can be expressed as,

$$\vec{F}_i = \sum_{j=1,\ j\neq i}^{k} \vec{F}_{ij} + \vec{F}_{iR} + \vec{F}_{iA} \qquad (1)$$

where $\vec{F}_{iA}$ is the total attractive force due to preferential coverage areas, $\vec{F}_{iR}$ is the total repulsive force due to obstacles, and $\vec{F}_{ij}$ is the force exerted on S_i by another sensor S_j as,

$$\vec{F}_{ij} = \begin{cases} (w_A(d_{ij} - d_{th}), \alpha_{ij}) & \text{if } d_{ij} > d_{th} \\ 0, & \text{if } d_{ij} = d_{th} \\ (w_R \frac{1}{d_{ij}}, \alpha_{ij} + \pi), & \text{if otherwise} \end{cases} \qquad (2)$$

where d_{ij} is the Euclidean distance between sensor S_i and S_j, d_{th} is the distance threshold, α_{ij} is the orientation (angle) of a line segment from S_i to S_j, and $w_A(w_R)$ is a measure of the attractive (repulsive) force. During the execution of the VFA algorithm , a sequence of virtual motion paths is determined for the randomly-placed sensors, and an energy-restricted one-time movement is carried out to redeploy the sensors at these effective sensor positions.

3. TARGET LOCALIZATION

We also present a novel target localization approach based on a two-step communication protocol between the cluster head and the sensors within the cluster. In the first step, sensors detecting a target report the event to the cluster head. The amount of information transmitted to the cluster head is limited; in order to save power and bandwidth, the sensor only reports the presence of a target, and it does not transmit detailed information such as signal strength, confidence level in the detection, imagery or time series data. Based on the information received from the sensor and the knowledge of the sensor deployment within the cluster, the cluster head executes a probabilistic scoring-based localization algorithm to determine likely position of the target. The cluster head subsequently queries a subset of sensors that are in the vicinity of these likely target positions.

4. EXPERIMENTAL RESULTS

Figure 1-3 present simulation results for a 50 by 50 sensor field with an obstacle and a preferential area. The initial sensor placements are shown in Figure 1. Figure 2 shows the final sensor positions determined by the VFA algorithm. Figure 3 shows the improvement of coverage during the execution of the VFA algorithm. For a n by m grid with a total of k sensors deployed, the computational complexity of the VFA algorithm is $O(nmk)$. Table 1 shows the results of the proposed localization algorithm based on the VFA algorithm sensor placement result with 20 sensors in a 50 by 50 sensor field grid, as shown in Figure 4. Target trace starts at t_{start} from its initial location marked as

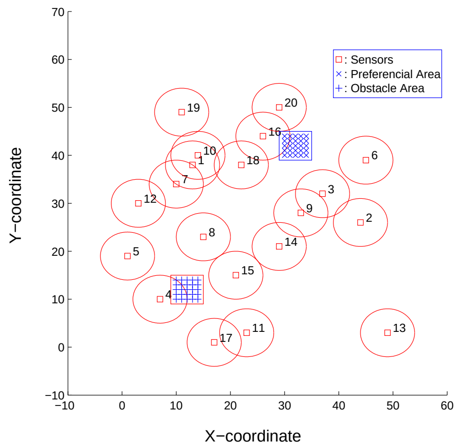

Figure 1: Initial sensor positions after random placement.

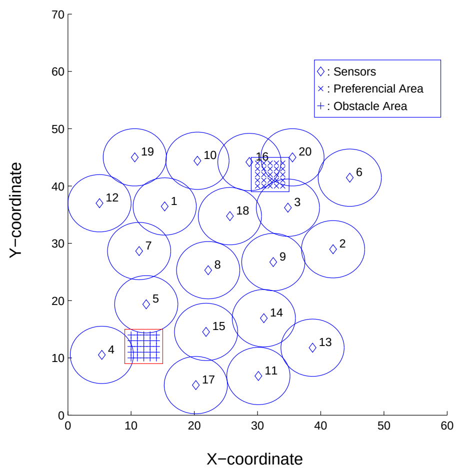

Figure 2: Sensor positions after the execution of the VFA.

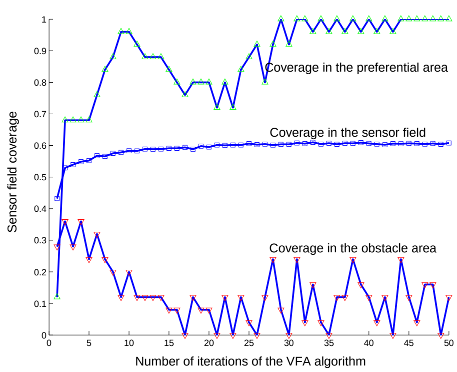

Figure 3: Sensor field coverage achieved using the VFA.

"Start". The computational complexity of the probabilistic localization algorithm is $O(nm2^k)$. Table 1 presents the results at time t=1-3, 41-43 and 80-82. $S_{rep}(t)$ indicates sensors that have reported the detection; $S_q(t)$ are sensors selected for querying by the cluster head; $\Delta E(t)$ is the energy saved by the localization algorithm for the detection

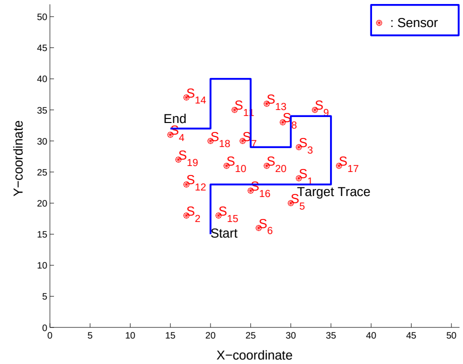

Figure 4: Sensor field with sensors deployed by the VFA.

event in units of an energy evaluation constant C.

t	$S_{rep(t)}$	$S_q(t)$	$\Delta E(t)$
01	S_2, S_6, S_{15}	S_2, S_{15}	C
02	$S_2, S_6, S_{12}, S_{15}, S_{16}$	S_2, S_{12}	$3C$
03	$S_2, S_6, S_{12}, S_{15}, S_{16}$	S_2, S_{12}	$3C$
...	...	...	...
41	S_3, S_8, S_9, S_{13}	S_8, S_9	$2C$
42	$S_3, S_7, S_8, S_9, S_{11}, S_{13}$	S_8, S_{13}	$4C$
43	$S_3, S_7, S_8, S_9, S_{11}, S_{13}, S_{20}$	S_{13}, S_8	$5C$
...	...	...	...
80	$S_4, S_7, S_{10}, S_{11}, S_{14}, S_{18}, S_{19}$	S_{18}, s_7	$5C$
81	$S_4, S_{11}, S_{14}, S_{18}, S_{19}$	S_4, S_{18}	$3C$
82	$S_4, S_{14}, S_{18}, S_{19}$	S_4, S_{19}	$2C$

Table 1: Sensors selected for querying by the cluster head.

ACKNOWLEDGEMENTS

This research was supported in part by DARPA under grant number N66001-00-1-8946, in part by Office of Naval Research under grant number N00014-01-1-0712, and in part by DARPA and Army Research Office under award number DAAD19-01-1-0504. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the DARPA and ARO agencies.

REFERENCES

Howard, A., Matarić, M. J. and Sukhatme, G. S., "Mobile Sensor Network Deployment Using Potential Field: a distributed scalable solution to the area coverage problem", *Proc. 6th International Conference on Distributed Autonomous Robotic Systems (DARS02)*, pp. 299-308, Japan, 2002.

Locateli, M. and Raber, U., "Packing equal circles in a square: a deterministic global optimization approach", *Discrete Applied Mathematics*, vol. 122, pp. 139-166, October 2002.