이동센서노드를 이용한 환경감시 시스템에서의 커버리지 최대화

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Coverage Maximization in Environment Monitoring using Mobile Sensor Nodes

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요 약

다수의 이동센서노드를 이용한 환경감시 알고리즘을 제안한다. 제안하는 알고리즘은 사전 정보가 없는 개활 지역에서 이동센서노드들을 배치하여 센싱 커버리지를 최대화 하는 것을 목적으로 한다. 이동센서노드는 보다 높은 센싱 커버리지를 획득하기 위하여 최대의 센싱 커버리지를 획득할 때 까지 반복적으로 재배치된다. 커버리지 최대화를 위하여 ILP(Integer Linear Programming) 기반의 최적화 문제를 구성한다. 시뮬레이션 결과에 의하면 제안된 알고리즘은 이동센서노드들을 보다 높은 관심 지역으로 이동시킬 수 있으며 최대의 센싱 커버리지 획득이 가능함을 시뮬레이션을 통하여 검증한다.

ABSTRACT

In this paper we propose an algorithm for environment monitoring using multiple mobile sensor (MS) nodes. Our focus is on maximizing sensing coverage of a group of MS nodes for monitoring a phenomenon in an unknown and open area over time. In the proposed algorithm, MS nodes are iteratively relocated to new positions at which a higher sensing coverage can be obtained. We formulated an integer linear programming (ILP) optimization problem to find the optimal positions for MS nodes with the objective of coverage maximization. The performance evaluation was performed to confirm that the proposed algorithm can enable MS nodes to relocate to high interest positions, and obtain a maximum sensing coverage.

키워드

Mobile Sensor Network, Coverage Maximization, Environment Monitoring, Integer Linear Programming

Ⅰ. Introduction

In this paper, we consider the task of using a group of mobile sensor (MS) nodes (e.g., mobile robots, unnamed aerial vehicles) in various applications, such as search and rescue operations, disaster recovery, military surveillance, and environmental monitoring [1-3]. MS nodes are deployed in an open and unknown area. They move cooperatively with each other to cover the phenomenon of interest, and form a mobile sensor network (MSN) to collect information on the phenomenon over time.

For example, in search and rescue operations for disaster management, MS nodes are developed to explore the unknown area that is dangerous or not accessible for human, such as earthquakes, fires, floods, storms, and terrorist attacks. They localize, monitor the surrounding in the low visibility area, and collect task-related data (e.g., videos and photos) for further analysis. In addition, after the disasters occur, the environment may dynamically change over time, MS nodes must be able to both quickly and reliably locate and follow victims in the searching area.

Due to the limitation of MS nodes in terms of sensing and communication capabilities, and unpredictable change of sensing environment, designing an MSN for phenomenon monitoring involves many challenges including the control of movement of MS nodes towards high interest area such that a maximum sensing coverage can be achieved over time. Also, when any change of phenomenon in distribution and position is detected, MS nodes should be relocated to positions at which they can closely keep monitoring the phenomenon and maintain the maximum sensing coverage.

There have been several works in [4-6] that studied the problem of maximizing the sensing coverage for phenomenon monitoring in an open and unknown area. For example, the authors in [4] proposed a cluster creation-based monitoring algorithm using MS nodes, called Causataxis, that organizes nodes in a hierarchical network architecture over the interest area. Causataxis expands the network towards the high interest area by creating new clusters, and dissolves clusters at low interest area. In [5], three variants of VirFID algorithm (Virtual Force (VF)-based Interest-Driven moving phenomenon monitoring) were proposed to control the movement of MS nodes using virtual forces that are determined based on the local information on neighbor's sensed values and positions, and the global information sharing among nodes.

In this paper, we propose a motoring algorithm that iteratively relocate MS nodes to new positions at which a higher sensing coverage can be obtained. More specifically, in proposed algorithm, a root node is assigned to learn and collect the interest information on the uncovered regions around the current coverage area of MS nodes. Based on the interest information on the newly learned and covered areas, optimal positions of MS nodes are determined such that a maximum sensing can be obtained. Then, each optimal position is assigned to a MS node with the objective of minimizing the total travelling distance of nodes to move new positions. This relocation process is continuously performed until the optimal distribution is achieved. In addition, to find optimum positions for MS nodes, we formulate an integer linear programming (ILP) optimization problem with the objective of coverage maximization.

The rest of the paper is organized as follows. In section II, we describe our algorithm in more detail. Finally, we conclude the paper in section III.

Ⅱ. An Optimization-based Phenomenon Monitoring Algorithm

In this section, the proposed monitoring algorithm is detailed. We consider a group consisting of N mobile sensor nodes (hereafter referred as nodes) which are deployed into an open area to form an MSN for monitoring and collecting information on the phenomenon of interest. The goal of proposed algorithm is to control movements of nodes in the area of interest such that the maximum sensing coverage can be achieved over time.

In proposed algorithm, nodes are iteratively relocated to new positions to obtain a higher sensing coverage. More specifically, in each iteration, firstly a special node, called root, is assigned to explore uncovered regions around current coverage area of MSN. Then, the information of interest on the uncovered area is used to expand the network toward the high interest area.

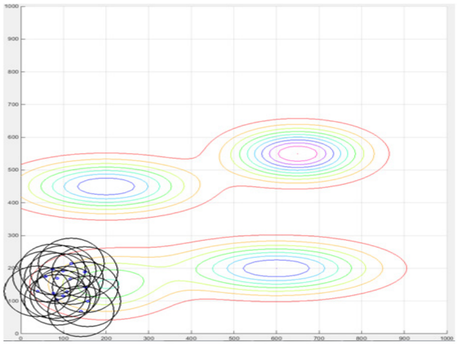
An integer linear programming (ILP) problem is formulated to find optimal positions for nodes such that a maximum sensing coverage can be obtained in the given explored area. Let denote A as the area which includes the newly learned region and the region currently covered by nodes. It is assumed that A is divided into M square cells. The square centers are candidates for placing sensors. Let $C=\{c_1, c_2..., c_M\}^T$ denote interest vector i.e., c_i is interest value at the center point i. Similarly, the vector $X=\{x_1, x_2..., x_M\}^T$ represents the centers at which sensors are placed i.e., $x_i=1$. The problem is to find N positions among M center positions for sensor such that the total obtained interest value is maximum.

Also, let $D_j=\{d_j^1, d_j^2..., d_j^M\}^T$ denote the connectivity vector of center j where $d_j^i=1$ if distance between two center points i and j is equal to or less than sensing radius of node, and becomes 0 otherwise. Then, the ILP problem can be formulated as follows

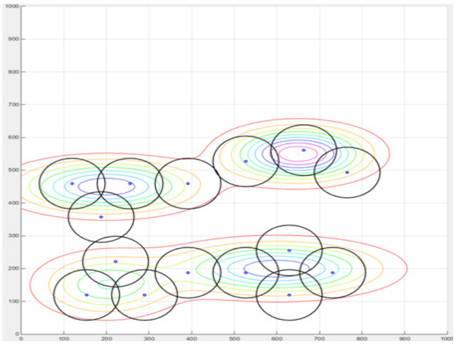
$$\max C^T X \tag{1}$$

subject to

$$e^T X = N \tag{2}$$



(a) Initial deployment



(b) Final distribution

Fig. 1. Snapshots for initial deployment and final distribution of mobile sensor nodes

$$D_j^T X \leq 1 \qquad j = 1,2,...,M \qquad (3)$$

where $e = \{1, ..., 1\}^T$ and $|e| = M$.

The objective function (1) is for maximizing total interest values obtained at selected points. Constraint (2) ensures that only N center points in C are selected for positions of N nodes. Constraint (3) eliminates coverage overlapping between nodes located at selected points.

The solution of above ILP problem is the set of N optimal positions at which nodes can obtain maximum sensing coverage without coverage overlapping. Then, on given set of selected positions, an assignment algorithm [7] can be used to assign each position to a node such that total traveling distance of all nodes to move from their current positions to new positions is minimized. Finally, the root sends position information to all nodes in the network. Upon receiving the position, each node moves to new position. This relocation process is periodically repeated to expand the network toward high interest area.

Note that, since the objective of ILP formulation is to maximize the total sensing coverage, the node may remain its position even new relocation process is performed. Thus, when the sensing coverage gain by relocation process is negligible, the size of area will be increased such that higher interest position may be found.

Figure 1 demonstrates the operation of proposed algorithm by showing initial deployment and final distribution of MS nodes achieved. As many as 15 MS nodes are initially deployed in the lower left corner of the area, and the interest phenomenon is presented by colored lines. As shown in Fig. 1, from initial deployment, the proposed algorithm can enable MS nodes to move to cover the highest interest area of phenomenon.

III. Conclusions

In this paper, we have proposed an optimization-based phenomenon monitoring algorithm for controling movements of MS nodes in an open area of interest. In proposed algorithm, we formulated an integer linear programming (ILP) optimization problem to find the optimal positions for MS nodes with the objective of maximizing sensing coverage. Then, each MS is assigned to move to an optimal position such that the total travelling distance of nodes is minimized. This relocation process is iteratively performed to move MS nodes towards positions at which a higher sensing coverage can be achieved. The simulation result confirms that the proposed algorithm can enable MS node track and cover the highest interest area of phenomenon.

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