A Cost-effective Mobile Sensor Network for Target Area Detection

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Abstract*-An application model of a mobile sensor network is presented to explore an unknown target area. The proposed SensorGroup (SG) network can reduce the operation cost since only few mobile sensors are required to be organized into a group. The members of the sensing group always move following the center node. They will spread out to perform efficient detection when the center node crosses the boundary of the target area. In order to discover the target area, an S-shaped sensing mechanism is designed for the SG network structure. The detection performance is evaluated by detection completeness for different scenarios in a 100m*100m environment.*

Keywords: Mobile sensor network, GPS, Localization.

1. Introduction

Due to the advances of the robot and wireless transmission systems, mobile sensors (MSs) are able to provide mobility for wireless sensor networks. MSs can move to collect information in the environment under their own control or under the control of the environment [1]. Mobile sensor networks can be formed through various wireless interfaces [2][3]. One of the applications for mobile sensor network is to detect and to localize specific target areas such as the detection of oil spoiled area in the ocean. Traditional sensor networks detect the environment by randomly deploying immobile sensors. Due to the higher cost of MSs than that of immobile sensors, it is inappropriate to organize the mobile sensor networks as the traditional sensor networks. Hence, decreasing the number of MSs to detect target area efficiently becomes an important issue. It is required to design an application model for both a small mobile sensor network and a sensing mechanism.

The location information of sensing data in a wireless sensor network provides significant values [4][5]. In mobile sensor networks, each MS node moves and operates according to its current location. So the combination of a wireless localization system and a mobile sensor network is essential for the construction of mobile sensor network. A satellite localization system locates target objects by using the signal from satellites surrounding the earth [6][7]. A global positioning system (GPS) allows users to collect the signals from at least four satellites through GPS receivers at any time and anywhere. GPS can then calculate the locations of users by triangulation [8]. For the large number of sensors deployed in the environment randomly, it is not cost effective to equip GPS receivers on all sensors. Hence, anchor nodes were added into sensor networks to support the localization.

Anchor nodes are the nodes whose locations are known prior. The locations of anchors can be set by labor or by equipping devices which can get global coordinates. After anchor nodes are set, each sensor can calculates its location with triangulation by receiving signal from at least 3 anchors and by measuring the distance to each anchor through the distance measuring technologies such as time of arrival (TOA) and received signal strength indication (RSSI) [9][10]. However, if the sensor network is scaled large, it becomes complicated for the setting of anchor nodes.

An RSSI using mobile anchor (RSSIUMA) localization system was presented to solve the problem [11]. Mobile anchor localization systems allow each mobile anchor to move and broadcast its location information to all sensors periodically. Each sensor can get number of circles after receiving signals from mobile anchor many times. The possible location based on the intersection area of all circles can be calculated.

Because the detection range of the mobile sensor network is changed dynamically, it is inappropriate to set fixed anchor nodes in the environment. A novel localization algorithm in our mobile sensor network structure is constructed by the concept of mobile anchor localization system.

2. SensorGroup Network Structure

To detect the targets using less number of expensive sensors with GPS devices, the mobile sensors should be formatted into a network and operate as a group called SensorGroup (SG). A number of mobile sensors are gathered within circle area with a certain radius. Each MS equipped with GPS device has the ability of obtaining the coordinates. MS can achieve the position and the shape of the target area by the movement of SG in the detection environment.

As shown in Fig.1, the circle with radius r is a SG composed by several MSs. During the time interval while MS moving through the border of the target area, the position will be localized and recorded. While leaving the target area, the border can be detected by the collected records of all MSs and shown as the bold black line in Fig.1. Then, the movement of SG is changed to the next detection position.

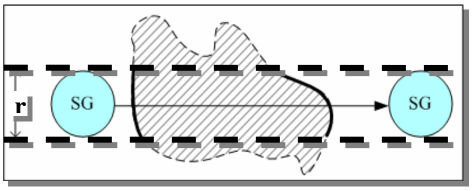


Figure 1. Concept of SG detection

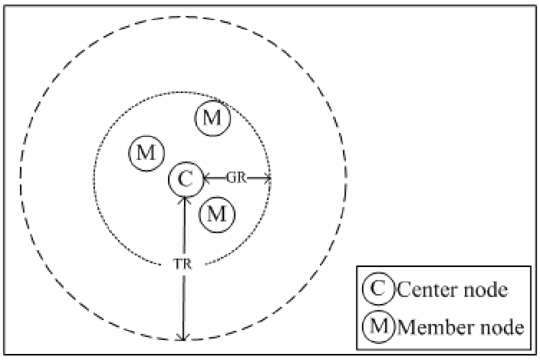


Figure 2. SG structure

SensorGroup
1. Set initial location of CSG
2. C moves with speed V_c
3. **Iterate** every T period
4. $L_c \leftarrow$ GPS location of C
5. C RPGMbroadcast(L_c)
6. **for** each M do
7. Receives L_c form C
8. $L_{m\_init} \leftarrow$ GPS location of M
9. $L_{m\_dest} \leftarrow$ Random destination within GR
10. M moves with speed V_m
11. **end for**
12. **end iterate**

SG : SensorGroup
C : Center node of a SG
M : Member node of a SG
V_c : Speed of Center node
V_m : Speed of Member node
GR : Radius of a SG
TR : Transmission range of a mobile sensor

Figure 3. Operation of SensorGroup

2.1. SG network structure

The movement of MSs in SG is based on Reference Point Group Mobility (RPGM) [12]. According to the function of MS in SG, there are two roles called Center node (C node) and Member node (M node). As shown in Fig. 2, C node is the MS allocated in the center of SG network. It is responsible of controlling all operations of SG and broadcasting its location to all M nodes within its transmission range (TR) periodically. M nodes are deployed surround C node. They move randomly surround C node within the range of group range (GR).

The operation of SG is illustrated in Fig. 3 along with the parameter defi. In the initial operation, SG is set to the initial location (step 1). Then C node starts moving with speed V_c and leads SG to detect targets (step 2). SG iterates step 3-12 with a period of T seconds, this periodical process is called a “RPGM round”. C node gets its GPS location L_c and broadcast L_c with an RPGM broadcast packet to all M nodes (step 4-5). This packet is a signal for SG to end (n-1)th RPGM round and to start nth RPGM round. An M node receives RPGM broadcast from C node (step 7) to end (n-1)th RPGM round and to start nth RPGM round. Then it gets the current location as its initial location L_{m_init} (step 8). A random destination L_{m_dest} is decided within GR around Lc in nth RPGM round (step 9). After the L_{m_init} and L_{m_dest} are decided, M node calculates a moving vector based on this two coordinates and move along this vector with speed V_m (step 10). During each RPGM round, both C node and M nodes should store the sensing records when they detect the border of target areas.

2.2. Parameter definition

In SG network structure, there are four parameters including TR, GR, V_c, and V_m need to be defined. These parameters are set based on the requirements of the operation of SG.

There are two requirements in the operation of SG. One is the node communication requirement. In SG, C node should broadcast its location to all M nodes in every RPGM rounds. The possible longest distance between C and an M node is V_c*T. To keep all M nodes can receive every broadcasts from C node, (V_c*T+GR) should be smaller than the TR of a node and TR can be set as large as TR_{max}.

The other requirement is the group movement requirement. To let M nodes keep moving around C node, the speed of C node V_c should be slower than speed of M node V_m. The maximum speed of a node can be set as fast as V_{max}. And to keep all M nodes move within the range of SG, the distance that an M node can move in every RPGM round V_m*T should be larger than (V_c*T+GR). Based on the requirements above, there are four parameter setting rules in SG:

$$TR \le TR_{max} \ , \tag{1}$$

$$V_c * T + GR \le TR \ , \tag{2}$$

$$V_m \le V_{max} \ , \tag{3}$$

$$V_c \le (V_m * T - GR) / T \ , \tag{4}$$

According to these rules, there is a trade off between the speed of center mode V_c and the range GR. The faster SG can move the smaller GR should be set and vice versa.

2.3. Localization algorithm

In wireless sensor network applications, location information is important for detection the activity of the environment. While sensor collecting the environment data without the location information, users can not obtain their position correctly when analyze the detection result. Hence, using wireless location technology to confirm the position of the sensors is one of the important issues for constructing wireless sensor networks. In mobile sensor network, mobile sensors should be able to aware their current position in order to move to the next position. The localization algorithm affects not only the values of the detection results but also the successful implementation of the mobile sensor networks.

In the SG structure, all MSs should be equipped with GPS devices. C node acts as a mobile anchor and other M nodes can exchange their locations through wireless localization algorithm. One of the localization algorithm used in SG was proposed while all mobile nodes within a group exchanging their information with each other [13].M node calculates its location based on the information provided by C node and other M nodes. Their local coordinates can be calculated in the group according to the information so as to keep their group moving. The previous algorithm is modified by us and combined with SG structure which simplifies the operation.

3. S-shaped Sensing Mechanism

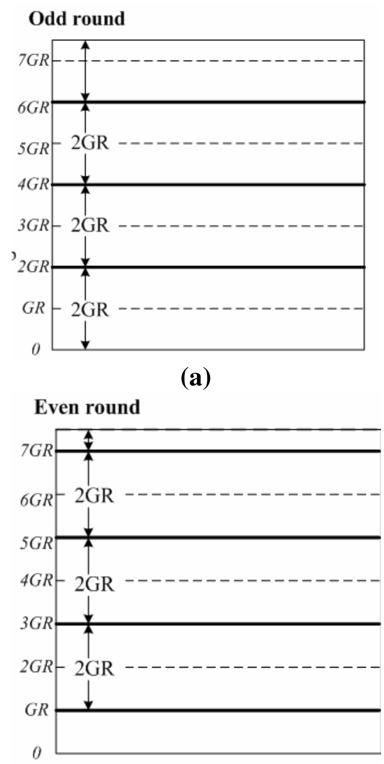
An S-shaped sensing mechanism (SSM) for evaluation is provided. In this mechanism, target areas can be detected by executing an S-shaped movement in the environment under the assumption of no obstacles. There are two states in a round of SSM operation. The first state is "complete detection state". The environment is spilt into several regions. Each region is scanned sequentially. The second state is "enhanced detection state". The doubtful regions are found by the sensing records collected in first state.

The operation of complete detection state is depicted in Fig. 4. In the initial state, C node splits the square sensing environment into number of rectangle regions with the width of GR*2. The centerlines of the regions are moving paths of C node (step 1). It is possible that SG can not detect the borders of each region. So, C node splits the regions with an interlaced style in odd and even round of SSM to achieve enhanced detection as depicted in Fig.5. Then C node starts the detection by scanning each path in RL with an S-shaped movement (step 3-14). Both C and M nodes detect border of target during SG movement (step 5-7).

Complete detection state

1. Creates RL by splitting area into rectangle regions with width of GR*2
2. Initialize location of SG
3. for each region r in RL
4. C moves along r
5. if C or M senses border then
6. Save location
7. end if
8. if C senses border then
9. C changes SG into scan mode
10. end if
11. if C reach destination of last r then
12. Enter next state
13. end if
14. end for

Figure 4. Operation of complete detection state



(a) **(b)**

Figure 5. Region splitting (a) Odd (b) Even round

The location is stored as a sensing record when it meets the border. If C node detects the border, it changes the mode from normal mode to scan mode and executes the process of step 8-10. ID of recent region is stored in a Region Index Record List (RIRL) by C node. C node stops moving for s seconds and asks all M nodes to expand their moving range from GR to TR at the initial of next RPGM round under the assumption of continuous border. The sensing records are collected effectively if it expands its detection range around the location of C node. The stop time s is set to TR*2/V_m seconds for SG. After s seconds, C node changes the normal mode. C node waits w seconds for all M nodes to back to the range of GR after asking them to gather. w is set to TR/V_m seconds for SG to insure all M nodes to move back from any location in range of TR. After C node waits for w seconds, C node continues the S-shaped movement until the destination of the last r in RL is reached (step 11-13).

The process of complement detection state is shown in Fig.6. C node checks whether RIRL is null (step 1). If RIRL is null, C node can not detect target with the paths used in first state, so C node directly enters the next round of SSM to detect with interlaced paths (step 8). If RIRL is not null, C nodes constructs SecondRegionList (SRL) based on the records in first state (step 2). SRL is constructed with two parts of paths. The first part is the set of path constructed on the records of RIRL. C node groups all continuous ID records and sets the neighbor regions of each group as doubtful regions. Then, the centerlines of these regions are added in to SRL.

Complement detection state

```
if RIRL is not empty then
    Finds doubtful regions and creates SRL
    C moves along each region in SRL by
executing step 3-14 in 1st phase
    if C reaches the destination of last region
in SRL then
        Enters next round
    end if
else
    Enters next round
end if
```

Figure 6: Operation of of complement detection state

4. Simulation Results

The sensing environment for the simulation is a 100 m*100 m square area. There are two types of target area deployed in the sensing environment. One is a single large target area. As shown in Fig 7(a), the large target area is a polygon and the coordinates are the locations of apexes. The other one is a discrete small target area. As shown in Fig.7 (b), each target is a small rhombus with the width and the height of 2m and the coordinates are the cancroids of each target.

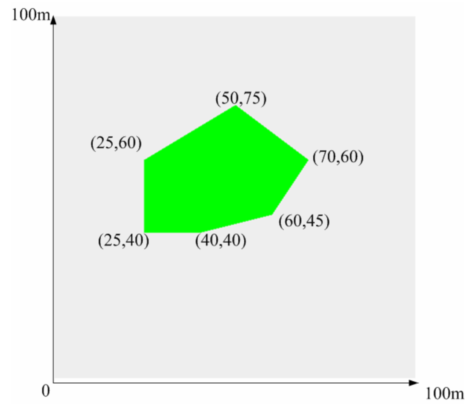
NS2 is used as a simulation platform. The simulation time is 6000 seconds. In SG structure, one C node and three M nodes is composed of an SG network. All parameter are set based on the upper bound in each rule. T is set to 1 second; V_m and TR are set to be V_{max} and TR_{max}. V and GR are set based on equation (4).The minimum execution time required for a round of S-shaped sensing mechanism.

Hence, TR is 15m. The period T for C node to broadcast RPGMbroadcast packet is 1 second. The moving speed of M node V_m is 5 m/s. When (V_c, GR) set to be (1,4), (2,3), (3,2), and(4,1)，the execution time for SG are 1373s, 882s, 851s and 1250s, respectively. While (V_c, GR) set to be (3,2), the execution time is the shortest than others. Hence, V_c and GR are selected to be 3 m/s and 2 m, respectively.

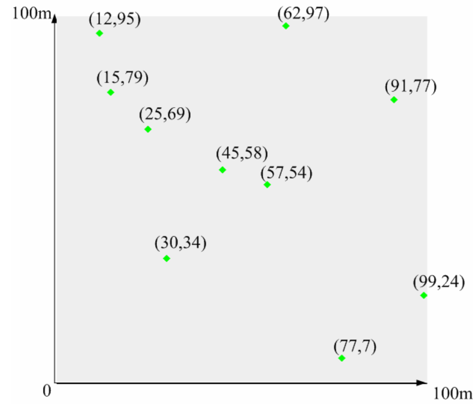
To simulate the interferences from the environment, random distance error and angle error are added into the localization process to analyze the effect of different level of interferences. Beside, it is assumed the localization of GPS is always accurate.

The parameter, detection completeness, is employed to analyze the detection performance. Due to all M nodes in SG are equipped with GPSs, the average error of records collected by SG is 0m. So no evaluation of the detection accuracy of SG is made.

The relationships between detection completeness and detection time of SG are evaluated in two scenarios with zero distance error and zero angle error. Fig. 8 (a) is the relationship of detection completeness and detection time in a single larger target scenario. The average time of a round in SSM is 1117 seconds. The average detection time required to achieve 80% detection completeness is 3325 seconds. Figure 8 (b) is an 80% detection completeness graphic result of the sensing records collected in one simulation. The detection time is 3268 seconds.

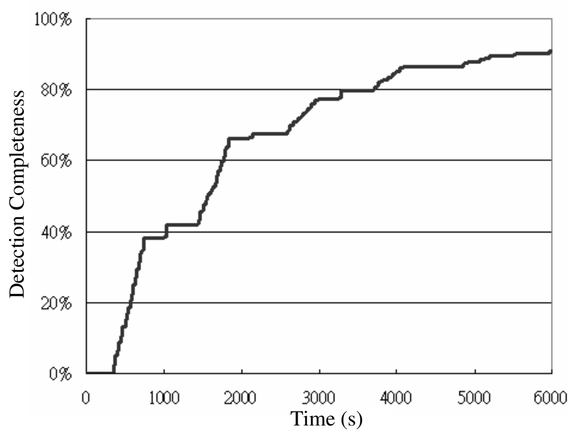


(a)

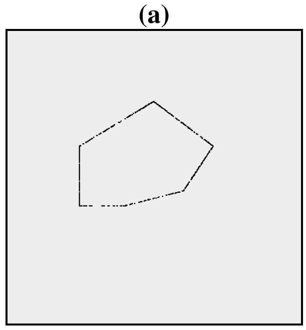


(b)

Figure7. Scenario setting (a) large target area (b) small target area



(a)



(b)

Figure 8. (a) Detection completeness a large target area (b) 80% detection completeness graphic result

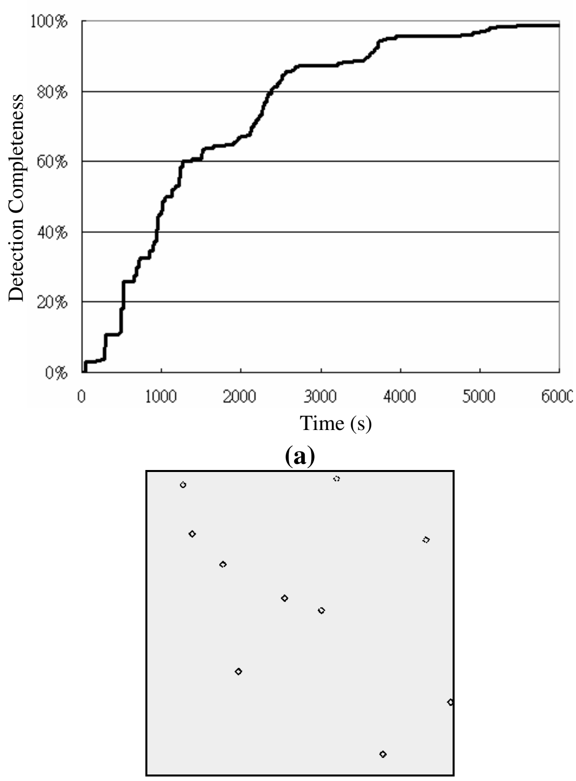


Figure 9. (a) Detection completeness a small target area (b) 90% detection completeness graphic result.

Figure 9 (a) is the relationship of detection completeness and detection time in discrete small targets scenario. The average time of a round in SSM is 1387 seconds and the average detection time required to achieve 90% detection completeness is 3649 seconds. Figure 9 (b) is a 90% detection completeness graphic result of the sensing records collected in once simulation. The detection time is 3671 seconds.

However, because the total length of borders in a small target scenario is shorter, it only requires relatively fewer records to achieve the same detection completeness in a large target scenario. Also the borders of a small target scenario are denser than a large target scenario, each M node in SG can detect the target in one movement with higher possibility and C node can easily change SG into the scan mode. Hence, SG can collect the sensing records much more active. Thus, SG can achieve higher detection completeness in a small target scenario under the same level of environment interferences.

5. Conclusion

SensorGroup (SG) network structure is proposed with an S-shaped sensing mechanism for detecting the border of the target area. Few mobile sensors are needed since they are grouped together and moved according to an effective sensing mechanism. The center node acts as a mobile anchor and other member nodes follow the leading of the center node. The detection performance is evaluated by detection completeness for different scenarios in a 100m*100m environment. The average detection time required to achieve 80% detection completeness is 3325 seconds for polygon scenario. Also the average detection time required to achieve 90% detection completeness is 3649 seconds for discrete rhombus scenario. Simulation results show that the integration of SG and S-shaped sensing mechanism achieve the goal effectively and efficiently

Due to the independent of mobile sensor network operations and the sensing mechanism, both the proposed techniques can be applied to other systems without reconstructing the whole application models.

References

[1] Y. Liang et al., "A Review of Control and Localization for Mobile Sensor Networks," in Pro. of the Intelligent Control and Automation, Vol.2, pp. 9164-9168, June 2006.

[2] J. Clark and R. Fierro, "Cooperative Hybrid Control of Robotic Sensors for Perimeter Detection and Tracking," in Proc. of American Control Conference, Vol. 5, pp. 3500–3505, June 2005.

[3] D. W. Casbeer, D. B. Kingston, and R. W. Beard, "Cooperative Forest Fire Surveillance Using a Team of Small Unmanned Air Vehicles," International Journal of Systems Sciences, Vol. 37, pp. 351-360, May 2006.

[4] N. Patwari et al., "Locating the Nodes: Cooperative Localization in Wireless Sensor Networks," Signal Processing Magazine, Vol.22, No.4, pp.54-69, July 2005.

[5] F. Franceschini, M. Galetto, and D. Maisano, "A Review of Localization Algorithms for Distributed Wireless Sensor Networks in Manufacturing," International Journal of Computer Integrated Manufacturing, pp. 1-19, June 2007.

[6] A. S. Zaidi and M. R. Suddle, "Global navigation satellite systems: a survey," in Proc. of the Conference on Advances in Space Technologies, pp. 84-87, Sep. 2006

[7] J. Ray, D. Crump, and M. Chin, "New Global Positioning System Reference Station in Brazil," Journal of GPS Solutions, Vol. 11, No. 1, pp. 1-10, 2007.

[8] J. G. McNeff, "The Global Positioning System," IEEE Transactions on Microwave Theory and Techniques, Vol.50, No.3, pp. 645-652, Mar. 2002.

[9] R. Reghelin and A. A. Frohlich, "A Decentralized Location System for Sensor Networks Using Cooperative Calibration and Heuristics," in Proc. of the 9th ACM International Symposium on Modeling Analysis and Simulation of Wireless and Mobile Systems, pp. 139-146, 2006.

[10] N. Priyantha et al., "Anchor-free Distributed Localization in Sensor Networks. Technical Report TR-892," MIT LCS, Apr. 2003.

[11] M. L. Sichitiu and V. Ramadurai, "Localization of Wireless Sensor Networks with a Mobile Beacon," in Proc. of IEEE International Conference on Mobile Ad-hoc and Sensor Systems, pp. 174-183, Oct. 2004.

[12] X. Hong, M. Gerla, and G. Pei, "A Group Mobility Model for Adhoc Wireless Networks," in Proc. of the 2nd ACM International Workshop on Modeling, Analysis and Simulation of Wireless and Mobile Ssystems, pp. 53–60, 1999.

[13] H. Akcan, V. Kriakov, and H. Brönnimann, "GPS-Free Node Localization in Mobile Wireless Sensor Networks," in Proc. of the 5th ACM International Workshop on Data Engineering for Wireless and Mobile Access, pp. 35-42, 2006.