MOBILE SENSORGROUP WITH SMART PATH FOR DETECTING TARGET AREA

Kuen-Liang Sue and Jing-Wei Lin
Department of Information Management, National Central University, Taoyuan, Taiwan

Keywords: Mobile Sensor Networks, Incremental Clustering, Exploration.

Abstract: The aim of this study is to design an intelligent mechanism for exploring unknown target areas in a plant, such as oil pollution in ocean. To explore the target area efficiently, a smart sensing mechanism based on Incremental Clustering algorithm is proposed to cooperate with a small sensing network structure named Centralized SensorGroup (CSG). The operation processes and detection phases are provided and verified in the investigation. System performance is evaluated by observing the detection completeness and accuracy in different scenarios within a square experimental area of 100m*100m. No matter when large or small scenarios are explored, simulation results demonstrate that CSG cooperated with the smart sensing mechanism has quite good detection accuracy and efficiency and can achieve the purpose of exploring target area efficiently and effectively.

1 INTRODUCTION

With the development of robot and wireless transmission technologies, mobile sensors (MS) can provide mobility for wireless sensor networks and mobile sensor networks can be formed through various wireless interfaces (Liang et al, 2006; Dantu et al, 2005; Hu and Evans, 2004). Mobility of mobile sensor networks brings some significances and potentials. Mobility can let the sensor network moves to collect information in the environments that traditional fixed sensor networks can not be deployed (Clark, 2005; Casbee et al, 2006; Wang et al, 2005). One of the application issues of mobile sensor network is to detect and localize specific target areas in the sensing environment, for example, the detection of oil spoiled area in the ocean environment. Traditional sensor networks detect environment by random deployment. However, due to the higher cost of MS, it is inappropriate to use mobile sensor network by the same way. Hence, how to use few MS nodes to detect unknown target areas efficiently is a key issue in this application. The aim of this study is to design an intelligent mechanism for exploring unknown target areas in a plant, such as oil pollution in ocean. To detect the targets efficiently, a smart sensing mechanism based on Incremental Clustering algorithm is proposed to cooperate with a small sensing network structure named Centralized SensorGroup (CSG).

The remainder of this paper is structured as follows. Because we use incremental clustering algorithm to improve the efficiency of detection, the related data clustering techniques is introduced briefly in section 2. The proposed mobile sensor network structure and sensing mechanism are described in section 3. Simulation method and numerical analyses are described in section 4. Section 5 provides conclusion for the investigation.

2 BACKGROUNDS

In this study, we propose a sensing mechanism designed for a small mobile sensor network to detect the unknown target areas in the environment. The proposed mechanism utilizes a skill for data mining called cluster analysis to offer sensor network the ability to analyze the distribution of target area from sensing records and adjust the movement of CSG dynamically by using data clustering algorithms. Hence, the exploration job can be performed more efficiently and effectively.

Cluster analysis is an unsupervised machine learning technology. Clustering algorithms' operation is based on the concept of grouping the similar data into a cluster and making the data in different clusters dissimilar (Jain et al, 1999). The

Sue K. and Lin J. (2010).
MOBILE SENSORGROUP WITH SMART PATH FOR DETECTING TARGET AREA.
In *Proceedings of the International Conference on Wireless Information Networks and Systems*, pages 36-41
DOI: 10.5220/0002981100360041

traditional techniques are mainly designed for static databases environment. For example, the K-means algorithm is one of the traditional partitioning clustering algorithms (Law and Jain, 2005). The general objective is to obtain a fixed number of clusters and minimizes the total square errors of the all clusters.

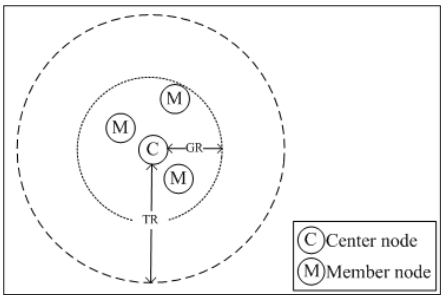


Figure 1: CSG structure.

However, with the increasing requirements of data clustering, the limits of traditional data clustering algorithms exist due to that they usually need to load all data into memory while analyzing. To solve the problem, incremental clustering algorithms are proposed for the dynamic database environments (Ester et al, 1998; Pons-Porrata et al, 2005). Incremental clustering algorithms executes clustering analysis whenever a data enters the database, thus these algorithms can cluster all data by executing simple calculations instead of loading all data into memory and executing complicate analysis. That is, incremental clustering algorithm needs fewer requirements for computation resource and ability. The proposed exploration mechanism is supposed to cooperate with mobile sensors which are usually assumed to have limited computing resources. Therefore, incremental clustering algorithm is appropriate to be used for activating the sensing mechanism in the proposed sensing networks.

3 EXPLORATION SCHEME

To detect the targets efficiently, the mobile sensors should be formatted to a network and operate as a group basing on a systematic sensing mechanism. Thus this study is composed with two parts - mobile sensor network structure and sensing mechanism.

3.1 Centralized SensorGroup

Centralized SensorGroup (CSG) is a mobile sensor network structure constructed with number of MS nodes crowded within a specific range. The concept of CSG is to let CSG keeps moving in the environment. MS nodes in a CSG keep detecting targets while moving. If a MS detects the border of target, then it records its current location as a sensing record. Finally, the location of targets' borders can be known by using the sensing records.

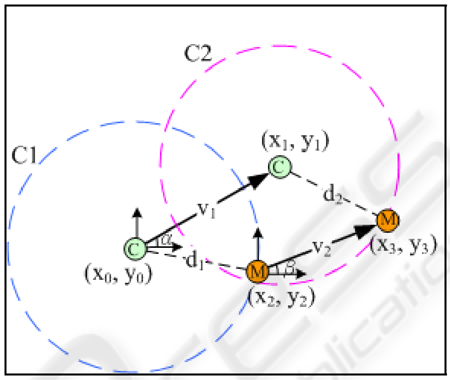


Figure 2: Initial phase.

In the following parts, we introduce the CSG structure and CSG's operation process.

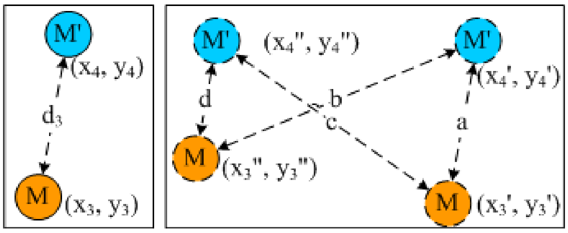
3.1.1 CSG Network Structure

The movement of MS in CSG is based on Reference Point Group Mobility (RPGM) (Hong et al, 1999). According to the functions of MS in CSG, there are two roles of MS in CSG called Center node (C node) and Member node (M node). As shown in Fig. 1, C node is the MS allocated in the center of CSG. It is responsible of controlling all operations of CSG and broadcasting its location to all M nodes within its transmission range (TR) periodically. M nodes are the other MS deployed surround C node. They move randomly surround C node within the range of group range (GR). In CSG structure, only C node requires GPS ability. C node acts as a mobile anchor in the network and other M nodes can calculate their locations by using a wireless localization algorithm. We assume that all MS in CSG should be equipped with a compass to measure the direction of its movement and have the ability to measure the distance of its movement.

3.1.2 Localization Algorithm of CSG

The localization algorithm used in CSG is modified from the algorithm proposed (Akcan et al, 2006). In this algorithm, all mobile nodes within a group exchange their information with each other and calculate their local coordinates in the group basing on the information to keep their group moving. In this study, we modify this algorithm and combine it with CSG structure. There are two phases in the modified algorithm, the "initial phase" and the "verification phase".

In the initial phase, C node broadcasts its location with packets Loc1 and Loc2 at time t1 and t2 sequentially. As shown in Fig. 2, C node adds its



(a) (b)

Figure 3: Verification phase.

location (x0, y0) into Loc1 and broadcasts it to all M nodes at time t1. An M node can measure the distance to C node d1 by TOA (Time Of Arrival) when it receives Loc1. After t1, C node and M nodes start moving along the directions they decided. At time t2, C node then broadcast its location (x1, y1) with Loc2 again and an M node measures the distance to C node d2 when it receive Loc2. After the above process is finished, an M node can calculate two circles C1 and C2 by using the coordinates (x0, y0), (x1, y1) and the distance d1, d2. These two circles define the sets of possible locations of an M node at t1 and t2. Because M node can calculates it displacement vector from t1 to t2, it can calculates a new circle C1' by displacing C1 with the vector (v2cosβ, v2sinβ). Because both C1' and C2 define the set of possible locations of M node at t2, M node can get its t2 candidate locations by calculating the intersection of C1' and C2.

In the verification phase, each M node exchanges its t2 candidate locations with each other by broadcasting a VeriInfo packet. When an M node receives VeriInfo from other one, it firstly measures the distance to the sender, then verifies an answer from its candidate locations by using this distance. Finally, M node calculates a weight for the verified answer. For example, as shown in Fig. 3 (a), M receives a VeriInfo packet from M'. M firstly measures the actual distance d3, and then uses d3 to verify the most possible candidate. As shown in Fig. 3 (b), M can compose at most four sets of candidate location by using the t2 candidate locations of M and M'. Then M compares the distances of four candidate sets a, b, c and d with d3 and chooses the set which has smallest difference with d3 as the verified answer. Then M gives this answer a weight value by calculating the inverse of the difference of the chosen candidate set distance and the actual distance d3. As shown in Fig. 3 (b), the candidate set with the distance value "a" has the smallest difference with d3, so M chooses (x3', y3') as the verified answer of the VeriInfo packet from M' and gives (x3', y3') a weight by calculating 1/|d3– a|. An

Centralized SensorGroup procedure

```
1.  Set initial location of CSG
2.  C moves with speed Vc
3.  iterate every T seconds period
4.     Lc ← GPS location of C
5.       C RPGMbroadcast ( Lc )
6.       for each M do
7.          Receives Lc form C
8.          Location determination
9.          Records conversion
10.         Lm_init ← initial location
11.         Lm_dest ←Random destination
12.         M moves with speed Vm
13.      CSG Localization process
```

Figure 4: CSG operation procedure.

M node can choose one of its candidates and gives the one a weight value whenever it receives a VeriInfo. The weight value for each candidate location is accumulated. Finally, M can get the t2 localization result by calculating the weighted mean of its candidate locations and can also get t1 localization result by using its displacement vector from t1 to t2 in the initial phase.

3.1.3 CSG Operation Process

The CSG operation procedure and communi-cation protocol between CSG members are shown in Fig. 4. In the initial of operation, CSG is firstly set to the initial location (step 1). Then C node starts moving with speed Vc and leads CSG to detect targets (step 2). CSG iterates step 4-14 with a period of T seconds, this periodical process is called a "RPGM round". In this process, C firstly gets its GPS location Lc and broadcast Lc with a RPGMbroadcast packet to all M nodes (step 4-5). When an M node receives a RPGMbroadcast (step 7), it firstly executes the process to end the n-1th RPGM round. This process includes the localization result determination of n-1th RPGM round (step 8) and the conversion of the temporary sensing records in n-1th RPGM round (step 9). In step 9, due to that M nodes in CSG can't get their current locations timely, all sensing record in n-1th RPGM round are temporarily stored as the displacement vectors from time t_1 to the time they detect the border of target. After the t1localization result is determined in step 8, M nodes convert the temporary sensing records in n-1th RPGM round to actual sensing record by adding t_1 localization result to all temporary records. M node then starts the process of nth RPGM round. It calculates the initial location L_{m_init} of nth RPGM round by adding t_2 localization result of n-1th RPGM round with the displacement form t_2 to the time it receive RPGMbroadcast of nth RPGM round (step 10).

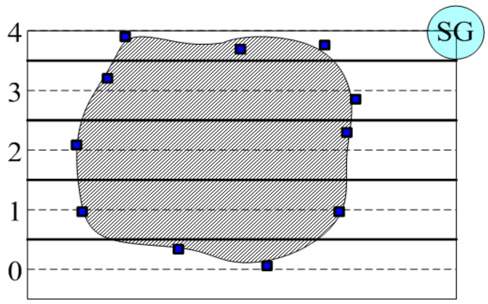


Figure 5: Concept of data collection phase.

Then M node decides a random destination L_{m_dest} around L_c within range of GR (step 11) and starts its movement with speed V_m (step 12). CSG then executes the localization process of nth RPGM round (step 13), C node sends Loc1 after RPGMbroadcast immediately at t_1. After T seconds, C node broadcasts RPGMbroadcast again to end the nth and start the n+1th RPGM round.

3.2 Sensing Mechanism

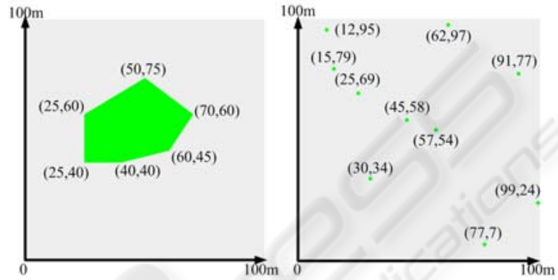
To detect the unknown targets in the environment, C node need a systematic sensing mechanism to control the moving path of CSG. An Incremental Clustering Aided Sensing Mechanism (ICASM) is proposed in this study. In this mechanism, we assume that there is no obstacle in the environment.

There are two phases in a round of ICASM's operation. The first phase is "data collection phase". CSG executes a quick scan of the whole environment to analyze the rough locations of the targets' borders. The second phase is "Detailed detection phase". CSG make a detailed detection along the rough location of targets' borders according to the analysis of the first phase.

In the data collection phase, C node splits the whole square sensing environment into number of rectangle regions with the width of GR*2. The centerlines of the regions are the C node's moving paths in this phase. C node leads CSG to scan the environment along these paths. Because it is possible that CSG can't detect the borders of each region effectively, C node splits the regions with an interlaced style in odd and even round of ICASM.

According to the split regions, the border of unknown target can also be split into number of deformed lines. We expect that all sensing records collected in this phase should be clustered basing on these lines, each lines can own one or more clusters.

Finally, as shown in Fig. 5, C node can catch the rough location of the target's border by using the



(a) Single large area (b) Discrete small area

Figure 6: Scenario setting.

centroid of each cluster. To reduce the load of C node to cluster records, a simple incremental clustering algorithm is used as the clustering method in this mechanism.

4 SIMULATIONS

4.1 Scenario Settings

The environment in the simulation is a 100 m*100 m square area. There are two types of target area deployed in the sensing environment. The first is "single large target area", as shown in Fig. 6 (a), the coordinates are the apexes of target. The other is "discrete small target area", as shown in Fig. 6 (b), each target is a rhombus with width and height of 2 m and the coordinates are the centroid of each target.

4.2 Parameter Settings

We use NS2 as the simulation platform. The simulation time is 6000 seconds. A CSG network is composed of one C node and three M nodes; the transmission range of a node is 15 m, the period of a RPGM round is 1 second, the speed of C node and M nodes are 3 m/s and 5 m/s and the range of CSG is 2 m. In the localization algorithm of CSG, the execution time of initial phase and verification phase in a RPGM round are 0.9 and 0.1 second.

In the localization algorithm of CSG, each MS uses wireless signals and compass to measure the distance between each them and their moving directions. Both of them may be influenced by interferences in environment. To simulate the interferences from environment, random distance error and angle error are added into the localization process to analyze the effect of different level of interferences. The range of distance error is -10% to 10% and range of angle error are -10 to 10 degrees. Accuracy of GPS is assumed always accurate.

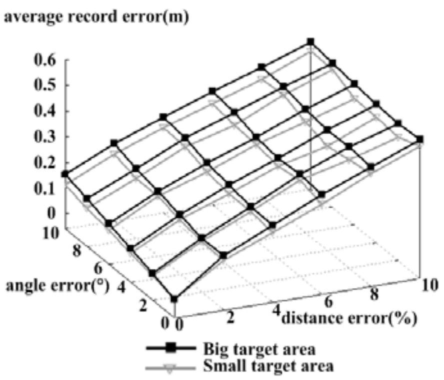


Figure 7: Detection accuracy.

4.3 Simulation Analysis Methods

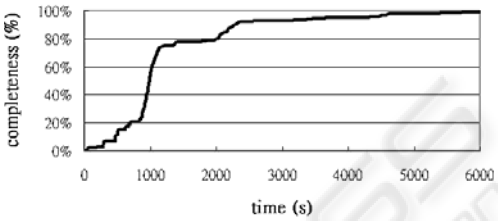
We use “detection accuracy” and “detection completeness” to analyze the detection performance of CSG. The detection accuracy is evaluated by calculating the average error of all sensing records collected by CSG. We define the error of a sensing record as the shortest distance for the record to the border of target area.

To evaluate the of detection completeness are set anchor coordinates on the border of target per 0.2m. If one or more sensing record exists around an anchor within 0.2 m, we set the status of the anchor to “sampled”. Hence, we evaluate the detection completeness by calculating the ratio of the number of sampled anchor and the total number of anchor after matching the anchor coordinates with all sensing records.

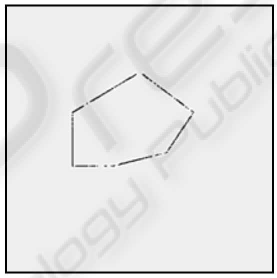
4.4 Simulation Results

4.4.1 Detection Accuracy

Because the sensing records are mainly collected by the M nodes, the detection accuracy is decided by the localization accuracy of M nodes. The average detection accuracy of CSG structures using ICASM in two target area scenarios is shown in Fig. 7. We can see that the increasing localization error of M nodes in CSG lifts the error of sensing records and decreases the detection accuracy. The average error of sensing records in single large target scenario and discrete small targets scenario are 0.52 m and 0.48 m when the distance error and angle error are set to 10% and 10 degrees. In both scenarios, the higher level of interferences is, the lower detection accuracy in CSG becomes.



(a) Detection completeness with time



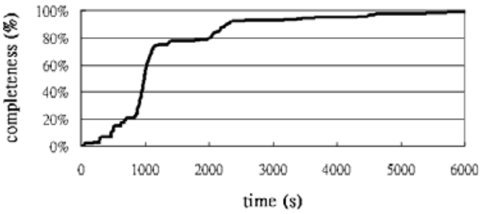
(b) Detection result for 80% completeness

Figure 8: Detection completeness in large scenario.

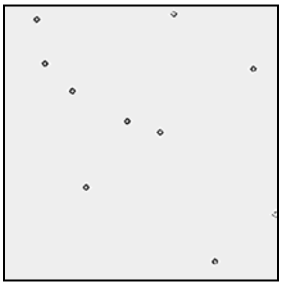
4.4.2 Detection Completeness

In this part, we evaluate the relationship of detection completeness and detection time of CSG using ICASM in both two scenarios without interferences (0 distance error and 0 angle error). Fig. 8 (a) is the relationship of detection completeness and detection time in single larger target scenario. The average time of a round in ICASM is 1195 seconds and the average detection time required to achieve 80% detection completeness is 2258 seconds. During the first round, because ICASM only detects the targets roughly in the first phase, so the trend of detection completeness increases slowly. However, in the second phase, ICASM can let CSG to make a detailed detection according to the analysis of first phase. Thus the detection performance of ICASM increases significantly in this phase. Beside, the trend of detection completeness in ICASM can still increase efficiently after the first round. This means that ICASM can adjust the movement of CSG and achieve the purpose of efficient detection. Fig. 8 (b) is a 80% detection completeness graphic result of sensing records collected by CSG in once simulation. The detection time is 2234 seconds.

Fig. 9 (a) is the relationship of detection completeness and detection time in discrete small targets scenario. The average time of a round in ICASM is 1139 seconds and the average detection time required to achieve 90% detection



(a) Detection completeness with time



(b) Detection result for 90% completeness

Figure 9: Detection completeness in small scenariois 2353 seconds. Fig. 9 (b) is a 90% detection completeness graphic result of sensing records collected by CSG in once simulation. The detection time is 2215 seconds.

5 CONCLUSIONS

To identify target areas automatically is an important application of mobile sensor networks, especially in abnormal environment such as oil pollution in oceans. The research investigates the problem by utilizing small mobile sensor network. Centralized SensorGroup (CSG) organized with several sensor nodes, only one of them called center node needs to be equipped with GPS functionality. During the exploring process, GPS-free member nodes can localize themselves by computing information from center node and their historic data. Hence, the sensor network is rather cost-effective. Furthermore, a sensing mechanism based on the incremental clustering algorithm is also proposed to adjust the moving direction of CSG dynamically according to the distribution of the target area. The proposed sensing mechanism can achieve the target area exploration more efficiently.

The detection performance is evaluated by detection completeness and accuracy for different scenarios in a 100m*100m square environment. The simulation results show that. The average detection times to achieve 80% detection completeness are 2258 seconds for large polygon scenarios. In discrete small target scenarios, the average detection times to achieve 90% is 2353 seconds. The average record errors which represent the detection accuracy in different scenarios vary between 0.48m and 0.52m. To sum up, simulation results demonstrate that CSG cooperated the ICASM has quite good detection accuracy and efficiency.

ACKNOWLEDGEMENTS

The research was supported by the National Science Council, Taiwan, under the contract NSC 98-2410-H-008-004.

REFERENCES

Liang, Y. et al. (2006). A Review of Control and Localization for Mobile Sensor Networks. *Proceedings of Intelligent Control and Automation*, 2, 9164-9168.

Dantu, K. et al. (2005). Robomote: enabling mobility in sensor networks. *Proceedings of Information Processing in Sensor Networks*, 404-409.

Hu, L. and Evans, D. (2004). Localization for mobile sensor networks. *Proceedings of the 10th conference on Mobile computing and networking*, 45-57.

Clark, J. and Fierro, R. (2005). Cooperative hybrid control of robotic sensors for perimeter detection and tracking. *2005 American Control Conference*, 5, 3500–3505.

Casbee, D. W. et al. (2006). Cooperative forest fire surveillance using a team of small unmanned air vehicles. *International Journal of Systems Sciences*, 37(6), 351-360.

Wang, G. et al. (2005). Sensor relocation in mobile sensor networks. *Proceedings of the 24th IEEE Computer and Communications Societies*, 4, 2302-2312.

Jain, A. K. et al. (1999). Data Clustering: A Review. *ACM Computing Surveys*, 31(3) 122-130.

Law, H. C., Jain, A. K. 2005. Data Clustering: A User's Dilemma. *Proceedings of Pattern Recognition and Machine Intelligence*, 3776, 1-10.

Ester, M. et al. (1998). Incremental Clustering for Mining in a Data Warehousing Environment. *Proceedings of Very Large Databases*, 24-27.

Pons-Porrata, A. et al. (2005). An Incremental Clustering Algorithm Based on Compact Sets with Radius α. *Proceedings of Progress in Pattern Recognition, Image Analysis and Applications*, 3773, 518-527.

Hong, X. et al. (1999). A group mobility model for ad hoc wireless networks. *Proceedings of the 2nd international workshop on Modeling, Analysis and simulation of wireless and mobile systems*, 53–60.

Akcan, H. et al. (2006). GPS-Free node localization in mobile wireless sensor networks. *Proceedings of the 5th international workshop on Data engineering for wireless and mobile access*, 35-42.