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Sensor Localization Using Self-Organizing Map for Human Tracking

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Abstract

This article describes a sensor network suitable for human tracking and a sensor localization methodology using self-organizing map in indoor environments. We employed sensor nodes with passive binary infrared motion sensors, and characteristically implemented with functionalities for network configuration, time synchronization, and collision avoidance for transmitting data with accuracy. Using this sensor network, sensor localization for human tracking was examined from the viewpoints of physical space and logical space analyses. For the logical space analysis, we adopted the algorithm of the self-organizing map, that is able to acquire the neighbouring relation of nodes without physical positioning of them. We compared the analyses and concluded that the logical space analysis has great potentiality for human tracking application.

Keywords: sensor localization, human tracking, IR sensor, self-organizing map

1 Introduction

Advances in processor, memory, and wireless technologies have enabled the fabrication of small sensor nodes. The mass deployment of these nodes to form sensor networks offers an economically viable solution for a variety of applications. For example, applications include the sensing and control of air conditioning systems in the home and office. In other words, sensor networks are essential for creating smart spaces that embed information technology into home and office environments. In various scenes, the sensor nodes should establish a self-organizing sensor network when dispersed into an environment, and their positions are the keys to the creation of such networks.

The positioning of sensor nodes are very important for a variety of applications and for ad-hoc network routing protocols. Location information can provide a system with greater functionality, such as geographical routing and location-based information querying. It is also needed for labelling reported data. In the future, many protocols and applications will depend on location-aware sensing devices. However, accurate knowledge of sensor node locations in large sensor networks is often not available. When sensors are intentionally placed, their exact physical locations and orientations can be obtained. However, in other methods of sensor deployment, it is difficult, or impossible, to acquire such information. Many localization algorithms for sensor networks have been devised to estimate the positions of sensor nodes. There are two types: range-based and range-free. Range-based algorithms are characterized by protocols that use absolute point-to-point distances or angles to calculate location [1-4]. The range-free type makes no assumptions about the availability or validity of such information [5, 6]. This type is more suitable for the sensor nodes of very small, cheap, low-power devices because the range-based approach relies on extensive hardware and consumes a great deal of energy.

The sensor network discussed in this paper was developed for human tracking application. For this purpose, we implemented the following functions into the nodes: time synchronization, network configuration, and collision avoidance. These functions contribute to the efficiency of sensor data transmission. First, we demonstrate human tracking using this system. Next, we show sensor localization using self-organizing map (SOM). Our localization approach is based on the data of the sensor detection. We schematically illustrate in Fig.1 that how the SOM can construct a logical map of the sensor node deployment for human tracking.

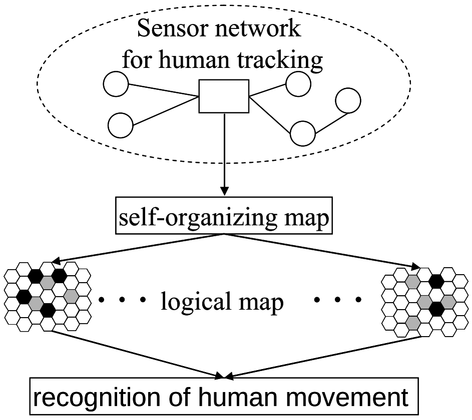

Figure 1: Schematic diagram of the system for human tracking and human movement recognition.

2 SOM for Sensor Localization

The SOM, with its variants, is the most popular artificial neural network algorithm in the unsupervised learning category [10]. There are many versions of the SOM; however, since even the basic algorithm is quite effective, and we applied it in this study.

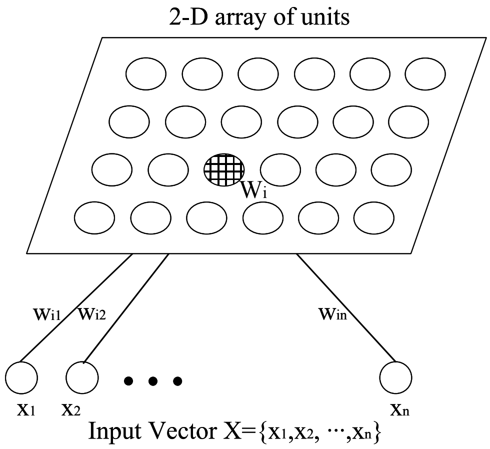

Figure 2: Topology of a self- organizing map with a 4×6 arrangement.

The SOM defines a mapping from the input data onto a two-dimensional array of units. The input pattern vector represents X, and the weight of unit i represents Wi. Vector X may be compared with all Wi in any metric. In many practical applications, the smallest of the Euclidean distances ||X – Wi|| is usually used in defining the best-matching node, signified by the subscript c;

$$\|X - Wc\| = \min_i \|X - Wi\| \tag{2}$$

The task is to define Wi in such a way that the mapping is ordered and descriptive of the distribution X. As a result, a set of values of Wi is obtained as the convergence limit of the following sequence;

$$W_i(t+1) = W_i(t) + h_{ci}(t)[x(t) - W_i(t)] : i \in N_c \tag{3}$$

where $h_{ci}(t)$ is the neighbourhood kernel, which is a function defined over the lattice points.

To apply SOM to sensor localization, we consider that the input vector is defined by the sensor detection. Since human movement is continuous, there is correlation between the sequence of sensor detection in time-series data and the position of sensor nodes. We consider that the number of vector elements can be defined by the number of sensor nodes and that the value of vector elements is defined by the sensor detection data, which produces a time-series across an interval period. When the server receives a sensor node's response, let the input vector of the sensor node be

(s1, s2, …, sn),

where si is the sensor response of sensor node i before and after that time and n is the number of sensor nodes. The si can be the response count or binary.

Since it is important to define the length of an interval period, the length which changes with situations is defined. In this paper, we simply consider the order relation of sensor detection. For example, when a person walks from sensor A to D (Fig. 3), the sensor B detects before sensor C and after sensor A. In this situation, the components of the input vector are binary and sensor B's input vector X_B is (1, 1, 1, 0). In the same way, sensor C's input vector is (0, 1, 1, 1).

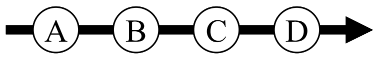

Figure 3: Sensor positions and human trajectory.

After the input data has been presented to the SOM, self-organization results in a topographic map. On the map, similar data points are likely to be projected to neighboring units. The map can be used to show the spatial relationships amongst data with respect to the nodes; hence, different grid structures can reveal different relationships.

3 Experimental

3.1 Sensor Node

As a base device, we adopted the Mote (MICA2DOT), developed by Crossbow Technology, Inc. [7]. The Mote is equipped with a radio (315 MHz), a processor, memory, and a small battery pack. Onto this device, we added a sensor head of passive binary infrared motion sensor (Matsushita Electric Works, Ltd) as shown in Fig. 2. The sensor detects differential changes in the infrared window that occur when humans or objects that have a different temperature from the surroundings move. This sensor node was set to work at intervals of 0.5 seconds, and transmitted the sensing data.

The Mote runs on a small event-driven operating system called TinyOS [8].

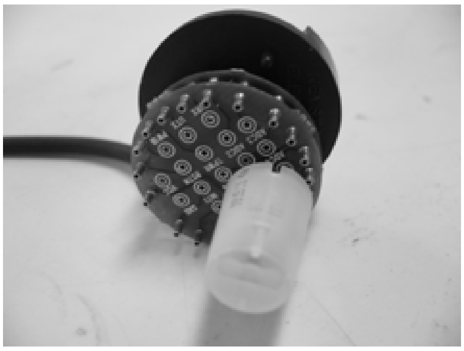

Figure 4: Mica2dot with an IR sensor.

3.2 Human Tracking System

The system proposed in this study is based on that designed by Surge [9]. However, we have made additional modifications to the hardware design of the nodes, the design of the sensor network, and the capabilities for remote data access and management. Thus, our system has the following characteristic functions:

▪Network configuration: The terminal is able to manage static and dynamic network configurations. In the static network, if a node receives a message of linking a new parent node, it changes the parent node as indicated in the message.

▪ Time synchronization: All sensor nodes reset their counter to zero when they receive the reset message from the terminal.

▪Collision avoidance: Each sensor node transmits a packet after waiting for time (1), defined as

$$Td = \left(ID\%N\max\right)\times\left(T\max d \big/ N\max\right) \quad (1)$$

where, Td is delay time, ID the ID of the node, Tmaxd the maximum possible delay time, and Nmax the maximum permissible number of nodes.

In addition, sensor nodes have the following useful functions:

▪The interval of sensing is changed when the nodes receive a reset message from the terminal.

▪The packet data structure transmitted by the nodes includes a destination address, active message handler ID, group ID, message length, source mote ID, counter, and sensor readings (six readings).

Since our localization model depends on the detection capability of sensor nodes, as the first step in the experiments, we checked the validity of our assumption in indoor environments. We placed 12 sensor nodes, three hopping nodes, and one terminal in our lab room as shown in Fig. 5. With this arrangement, this network is composed a static wireless one.

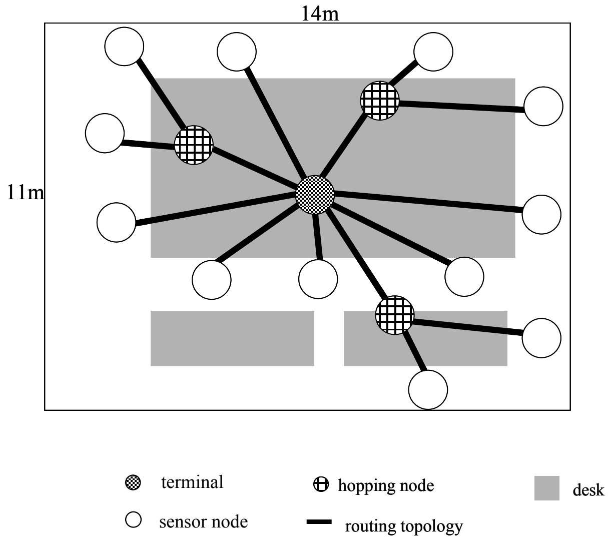

Figure 5: Location and route map.

4 Results and discussions

4.1 Human Tracking

First, we performed the physical space analysis. A person walked for one minute in the room to test the human tracking system. Figure 6 shows the deployment of the sensor nodes and the person's walking trajectory. In this experiment, the physical positions of all the sensor nodes were known.

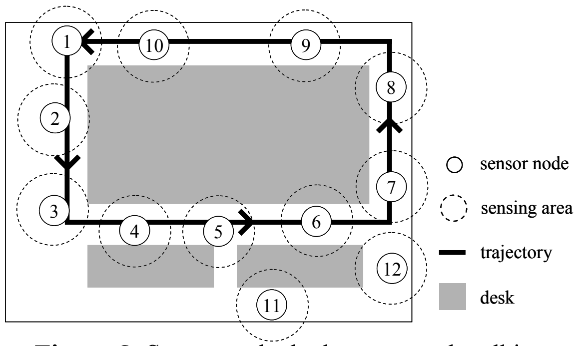

Figure 6: Sensor node deployment and walking trajectory.

The results of this experiment are shown in Fig. 7. We identified that the sensor nodes clearly and sequentially responded to the moving person. Because of the additional functions described in experimental section, there is very little missing data. The several points in this figure where data is lacking were caused by the detection characteristics of the IR sensor head. As these sensors detected the person's motion, the periods of each sensor detection corresponded to the one time through in each sensing area. Accordingly, we could obtain the positional information and average moving speed of the person with spatial and time resolutions of each sensing range and data acquisitions interval, respectively.

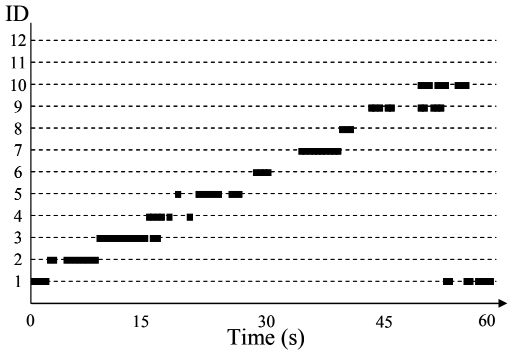

Figure 7: Sequence of sensor nodes' responses for a moving target.

4.2 Self-Organizing Map Formation

Next, we performed the logical space analysis, using the sensor localization with the SOM. Figure 8 shows walking trajectories and sensing area. In this experiment, the positions of the 12 sensor nodes were unknown.

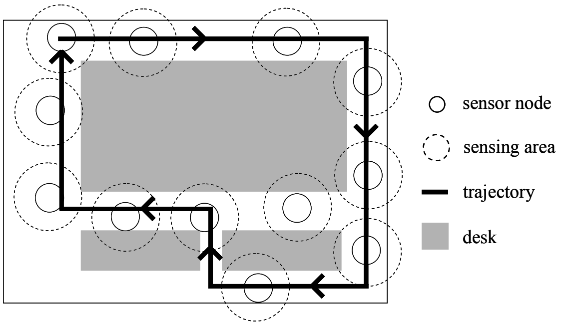

Figure 8: Person's trajectory.

The results are shown in Fig. 9.

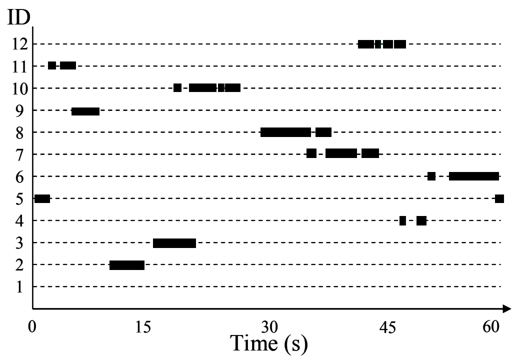

Figure 9: Sequence of 12 sensor nodes' responding to the moving person.

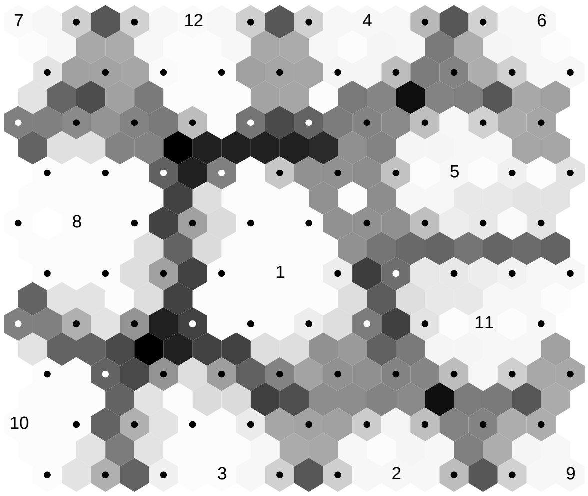

Figure 10: SOM obtained from sensor network responses for human tracking.

Figure 10 shows the SOM obtained from the results. The map size is 10 x 10, h(t) is constant 0.5, and the number of iterations is 10000. The grey level corresponds to the distance between the units. This map shows not the physical position of sensor nodes but the logical position of sensor nodes. Since the sensor detections are continuous, it is possible to recognize the neighbouring relation of the nodes in this map.

The answer of the physical positions of the sensor nodes are shown in Fig. 11. When Fig. 10 is compared with Fig. 11, it can be seen that the neighbouring relations of all nodes except node #1 in these maps are almost the same. For example, node #6 is between node #5 and 4 in Fig. 6 and Fig. 7. In Fig. 11, the node #1 is near nodes #3, #7 and #10, but node #1 is surrounded by the other nodes. Because there are no observed data for node #1 in Fig. 9, the SOM could not precisely determine its relation with other nodes. When the positions of some sensor nodes are known, the SOM is likely to be a physical position map. In addition, if the response count of response is used for the input vector, the resultant SOM has information about the distance between the sensor nodes, although the components of the input vector are binary in this paper.

5 Conclusion

This paper proposed the system architecture for a sensor network for human tracking and stressed the benefit of the sensor localization using self-organizing map (SOM). All results presented were prepared from experimental data obtained Mote-based IR-sensor nodes. To make the system suitable for human tracking, we have implemented: time synchronization, network configuration, and collision avoidance functions. These functions contribute to the certainly transmission.

From the comparison between the physical space analysis and logical space analysis using SOM, we found similarity between the actual map and resulting neighbouring-relation map as far as applicable data exist in SOM.

If we consider a future scene where the human tracking is applied in rather large-scale or public circumstances, SOM will be one of the most promising approaches. This is because physical positioning data will not always be prepared in such a scene, and because the logical position or meanings of the place are sometimes more meaningful than the physical position.

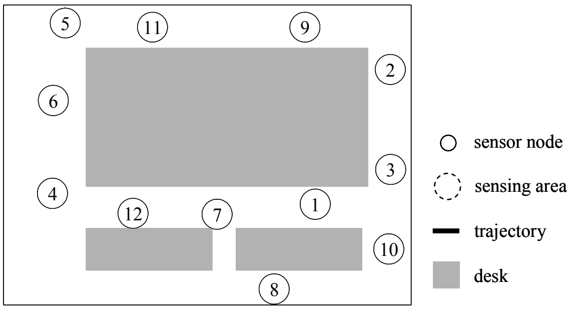

Figure 11: Actual deployment of sensor nodes.

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