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Continuous Location Sensing and Analysis System in Hospital

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Abstract— **In this paper, we describe an indoor location sensing system. It senses and analyzes continuous locations of indoor workers, such as hospital staffs (doctors, nurses, care workers, etc.) The system is used for a field experiment at a hospital so as to improve their collaboration of work based on their location data, such as physical proximity of them. In the experiment, each staff brings a small sensor device that has a wireless communication module (IEEE 802.15.4). It receives beacon signals from other network devices installed in the hospital floor and senses 3-axis acceleration of body movements of the staff. Based on integration analysis of the sensing data and received signals of the sensor devices, the system can estimate locations of the staffs and visualize them in synchronized manner. We describe overview of the system and analytic results of the location data of hospital staffs. We confirm that the continuous locations of the staffs show the difference of working styles of each occupational category, such as doctor and care worker. We also show an analysis result of the proximity frequency data of the staffs.**

Keywords- indoor location system; wireless sensor networks; 3-axis acceleration; hospital

I. INTRODUCTION

As aging population in most countries has been increasing, there is a necessity of getting more workforces who support the aging population, such as hospital staffs. Therefore the cost of the workforce is becoming severe financial stress in many countries. It is an important social issue how a limited number of workforces can provide high quality services for elderly people.

In this study, we propose a system that senses and analyzes continuous locations of staffs in a hospital. The system visually shows the continuous locations and analyzes the proximity frequency of the staffs. The purpose of the system is enabling the manager of the hospital to obtain the overview of staffs' activities in the hospital and improving the medical service based on such quantitative data.

This paper describes the system and the field experiment at a hospital so as to obtain continuous locations of care worker and medical staffs (doctors, nurses, caregivers, therapists, etc.) In the experiment, each staff brings a small sensor device that has a wireless communication module. It receives beacon signals from other network devices installed in the hospital floor and senses 3-axis acceleration of body movements of the staff. Based on integration analysis of the sensing data and received signals of the sensor devices, the system can estimate locations and movements of the staffs in the measuring area.

The rest of the paper is organized as follows: First, we describe related work of this study. Then, we describe the overview the system. Last, we show the analytic results of the field experiment. The results include continuous locations, body movements, and physical proximity of hospital staffs.

II. RELATED WORK

In recent years, researches of activity recognition in indoor space, such as hospitals, have been proposed [1] [2]. These studies focus on recognizing detailed activities of hospital staffs by using various sensors. In this research, we focus on sensing and analyzing the location of multiple hospital staffs using simple sensing devices.

Some vision based systems are also used for tracking multiple humans in indoor space [3] [4]. These systems can precisely track the locations of the humans. But it is difficult to track humans who move beyond its field of vision. Our system is designed to be used for tracking multiple humans who move around in a wider area and records the overview of the activities of hospital staffs.

Sensing social relations based on the physical proximity derived from sensor devices have been proposed [5] [6]. In the scenario of the indoor space, Olgui'n [7] has proposed a methodology to investigate social interactions of office workers by using wearable badges. The badge includes multiple sensors (e.g., motion, IR, audio, etc.) and records social interactions of the staff who brings the badge. Our system aims at obtaining overview of the staffs' physical activities based on estimating accurate indoor locations comparing with these systems.

III. LOCATION SENSING AND ANALYSIS SYSTEM

We propose a continuous location sensing and analysis system in hospital. It consists of two steps: *Sensing phase* and *Analysis phase.*

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A. *Sensing Phase*

In the sensing phase, a hospital staff brings a small sensor device and works as usual. The sensor device that works with indoor location system [8] has consists of two parts: *main unit* and *wireless communication module*.

1) *Main Unit*

The unit is stored in a staff's chest pocket and senses his/her body movements. It includes a MPU, a flash memory, 5 kinds of sensors (electrocardiograph, 3-axis accelerometer, barometer, thermometer, and hygrometer) and a lithium ion battery. To detect the body movements, we use the 3-axis accelerometer.

Its size and weight are as follows: size 6x4x1.5 cm; weight 22g (without batteries). Continuous operating time is about 6–8 hours. The sensing data are recorded in the device with timestamps (sensing time). The main unit has a USB port by which sends the recorded data to a personal computer.

2) *Wireless Communication Module*

The module is a small IEEE802.15.4 module connected to the main unit with a cable. Using the cable, the module can be attached at clothes of the staff to avoid the communication troubles. The module receives multiple beacon signals emitted by environmental nodes installed in the hospital.

The environmental node is a small IEEE802.15.4 device and can be directly attached to the wall using gummed tape. The beacon signal is recorded with received signal strength (RSS), received time, and ID of the environmental node emitting the signal.

Based on the sensing data, the analysis system estimates the locations and body movements of the staff who has the sensor device.

B. *Analysis Phase*

In the analysis phase, our system estimates the locations and body movements of the staffs and visualizes them in synchronized manner. The analysis process is divided into four sub processes: *data transfer*, *location estimation*, *body movement recognition*, and *visualization*.

1) *Data Transfer*

The process reads the data recorded in the sensing device connected to the computer's USB port. Its output is a text file which includes acceleration value, barometer value, location data (RSS, node id, etc.,) and time-of-day information.

2) *Estimating Locations*

As the locations of the network nodes are known beforehand, a location of a sensor device can be estimated by using strengths of received beacon signals.

The location estimation algorithm of the system is based on a particle-filter algorithm [9] [10]. In this algorithm, each particle has a hypothesis about a current location of the device and a weight which represents a confidence value of the hypothesis. The weight is updated by calculating a likelihood of the hypothesis according to observation data (strengths of received beacon signals). Based on the weights and hypotheses of particles, we can calculate probabilities of candidates of the current location and infer a most likely one.

The input data of this process are derived from the transferred sensing data file. The output data are continuous locations of the senor device. The data are represented as 2-dimensional spatial-temporal format (x, y, t).

3) *Recognizing Body Movements:*

The process recognizes body movements and postures of the staff based on the 3-axis accelerometer data. It classifies the accelerometer data into the following 7 physical statuses of the staff every second. The statuses are standing, *walking*, *moving*, *lying face down*, *lying face up*, *lying face right*, and *lying face left*. In addition, *unclassified* status is used when the any of the 7 statuses are not classified. The status is recorded with a time-stamp.

This process consists of two sub processes: recognition process of staff's movements and recognition process of staff's postures.

Recognizing Movements: First, the algorithm identifies a gravity vector based on the moving average value of 3-axis acceleration sensor. Then, it calculates the inner products of current value of the acceleration sensor and obtains projection of the current sensor value to the direction of gravity vector.

As the fluctuations of the projection represent the vertical movements of the human body, the algorithm can detect the walking status based on the continuous and periodic fluctuations. When the fluctuation value exceeds a certain threshold, the algorithm classifies the physical status as "*moving*". When the value does not exceed it, the algorithm performs the posture recognition process described below.

Recognizing Postures: First, the algorithm identifies a gravity vector based on the moving average value of 3-axis acceleration sensor. Because this vector represents the direction of gravity in the coordinate system of the acceleration sensor, we can calculate a roll angle and a pitch angle of the sensor device by an inverse conversion. However, these angles do not directly represent the inclination of the human body but the inclination of the sensor device.

Therefore, our algorithm estimates the inclination of the human body by correcting with the angles obtained when "*walking*" status is detected. As the angles reflect the inclination of the sensor device when the posture of the human is upright, it can estimate the posture of the human based on the sensing data. Here we suppose that the sensor device is seldom moved in the pocket.

4) *Visualization*

The process analyzes continuous locations of the multiple staffs and visualizes them. In the process, continuous locations and movements shown by the system are automatically adjusted based on some heuristics, e.g., smoothing the movements by calculating moving averages and removing anomalous moves when beacon signals were not received correctly.

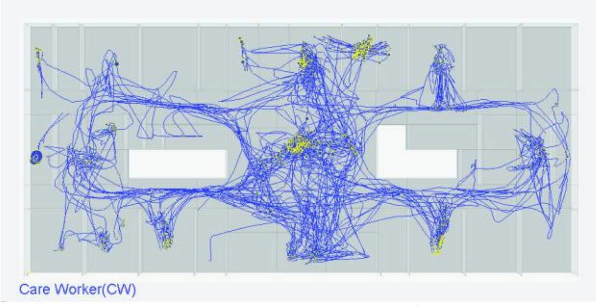

Figure 1 Estimated continuous locations of a care worker

Figure 2 Estimated continuous locations of a doctor

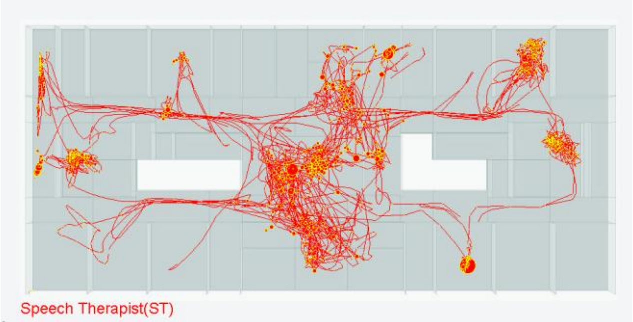

Figure 3 Estimated continuous locations of speech therapist

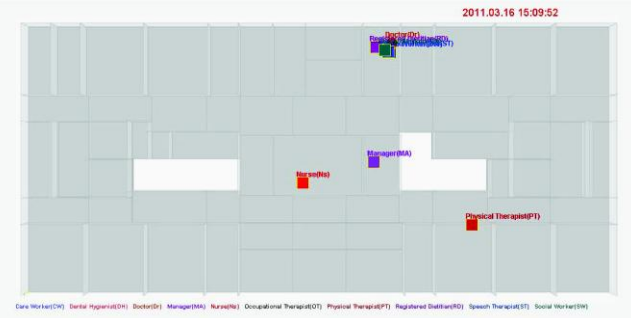

Figure 4 A snapshot of estimated locations of multiple staffs

IV. FIELD EXPERIMENT AND ANALYSIS

We have conducted a field experiment to obtain locations and body movements of staffs in Nagasaki Rehabilitation Hospital. In this field experiment, each staff brings a sensor device in his/her chest pocket and does his/her work as usual. In the experiment, the sensor device records 3-axis acceleration, and location data (e.g., beacon signals). We investigated the locations of staffs in a floor from 11:00 to 17:00. When the staffs go out of the floor, it records only 3-axis acceleration data. The participants were 10 staffs who have different occupations: dental hygienist, registered dietitian, social worker, doctor, manager of the floor, speech therapist, physical therapists, nurses, occupational therapists, care worker.

A. Continuous Locations of Staffs

The exemplary results of the estimated continuous locations are shown in Fig. 1-3: Fig. 1 shows the locations of a care worker, Fig. 2 shows the locations of a doctor, Fig. 3 shows the locations of a speech therapist.

The background image in the figures shows an overview of the measurement area. Hospital rooms, rest rooms, meeting rooms, etc. are shown in the image. A staff station room is in the center of the floor and it is surrounded by a corridor.

In the figures, circles represent stationary points where the staff continuously stayed. The longer they stayed at one point, the bigger the circle became. To estimate the stationary points of a staff, our system analyzes body movements of the staff. When the system recognizes his/her motion is not "*walking*," it assumes the staff was staying around the points and estimates the average point of them as a stationary point.

These figures show difference of the working style by the occupation based on the pattern of the continuous locations. For example, while the care worker shown in Fig. 1 moved in most of rooms in the floor, the doctor in Fig. 2 stayed in a nurse station room and sometimes moves in other rooms. In addition, the continuous locations of the speech therapist in Fig. 3 show two stationary points around the both sides of the figure. The voice guidance training of the therapist intends to be done with looking at the mirrors. Therefore the locations where the mirrors of the sinks exist tend to be stationary points of the therapist. By estimating and visualizing continuous locations of the hospital staffs, the system enable us to easily understand the movement patterns of the staffs.

B. Proximity of Staffs

The visualization process has a "play back mode" that displays the locations of the multiple staffs in synchronized manner. Therefore, it is possible to observe the staffs' location from bird's eye view over the sensing period. In other words, locations and movements of the multiple staffs are easily observed in chronological order. Fig. 4 shows a snapshot of the play back mode that displays locations of multiple staffs in chronological order. Square dots in the figure represent the locations of the staffs at the time. The figure shows that the staffs (doctor, registered dietitian, speech therapist, and social worker) are discussing medical treatments of patients in a meeting room (the top of the center.) It is important that a team of different experts takes care of a patient with his/her effective medication. Using our system, we can observe the proximity frequency of different experts in the hospital.

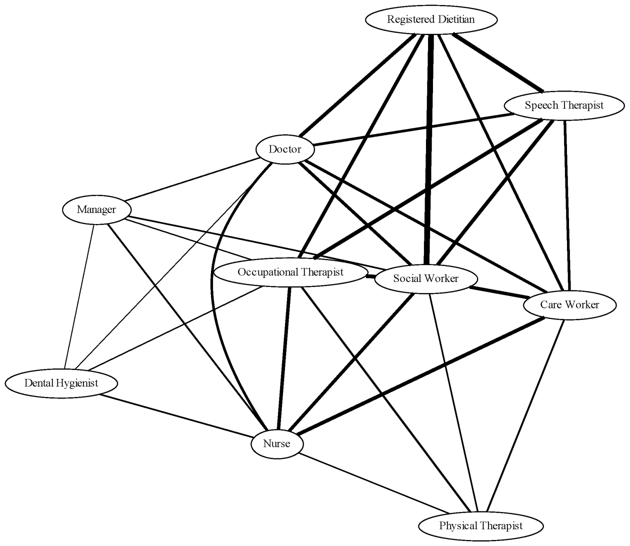

Figure 5 Analysis result of proximity frequency data of hospital staffs

Our system recognizes and records staffs staying in the room at the same time. Fig. 5 shows an analytic result of the proximity frequency data of the staffs based on their locations. The figure is visualized by using Graphviz[1]. In the analysis, we divide the floor into 67 regions and count how often a staff is with another staff in the same region. Based on the data, we calculates Jaccard similarity coefficient [11] of the each staff. The Jaccard similarity coefficient: J is a statistical measure of similarity between two sample sets.

$$J(A,B) = \frac{|A \cap B|}{|A|+|B|-|A \cap B|} \qquad (1)$$

In this analysis, the coefficient J(A,B) represents how often staff A and staff B stayed in the same region in the floor. |A| means number of counts when staff A are detected in the regions. |B| means number of counts when staff B is detected in the regions. $|A \cap B|$ means number of counts when staff A and staff B are detected at the same region.

In the figure, a node represents a staff and an edge represents the Jaccard similarity coefficient between the staffs. The thickness of edge represents how large the coefficient value is; thicker line represents larger coefficient. This figure only shows the edges which have large coefficients. For each staff, we select top 4 edges that have large coefficients. We suppose that we roughly estimate collaboration frequency of the staffs based on such location proximities. The figure shows that the social worker was the person who frequently collaborated with other staffs in the day. We can see that the staffs (doctor, registered dietitian, speech therapist, social worker) who participate the meeting shown in Fig. 4 have thick edges.

V. CONCLUSION

In this paper, we have proposed a system that senses continuous locations of staffs in a hospital. The purpose of the system is enabling the manager to recognize the way the staffs work in the hospital so as to improve the nursing care service based on such quantitative location data.

We confirm that the locations and movements show difference of the working style by occupation. These locations reflect the ways staffs wok in a day. In addition, we describe an analysis result of the collaboration frequency of the staffs based on physical proximity.

As estimation process of the system consists of sensing phase and analysis phase, there is a delay in obtaining the locations. Our future work will be developing a system that can simultaneously sense and analysis continuous locations of staffs in a hospital.

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