Developing Mobile Physiological Sensor that Works with Indoor Positioning System

Akio Sashima, Takeshi Ikeda, Akira Yamamoto,
Mitsuru Kawamoto, Takafumi Kuga, and Koichi Kurumatani
National Institute of Advanced Industrial Science and Technology (AIST)
2-3-26 Aomi, Koto-ku, Tokyo, 135-0064, Japan
Emails:{sashima-akio, ikeda-takeshi, akira-yamamoto, m.kawamoto, t.kuga, k.kurumatani}@aist.go.jp

***Abstract*—In this paper, we propose a mobile physiological sensor that works with an indoor positioning system based on a wireless sensor network. The physiological sensor is a small, mobile, multi-sensor device which includes electrocardiograph, 3-axis accelerometer, barometer, thermometer, and hygrometer. In addition, the device is a network node of a wireless sensor network and receives beacon signals from network nodes installed in an indoor space. Obtained physiological signals and Received Signal Strength Indication (RSSI) of the beacon signals are simultaneously recorded. Based on the data, user's physiological statuses and trajectories in the space are estimated. We describe design and implementation of the mobile physiological sensor device and the indoor positioning system. Then experimental results of the system are shown.**

I. Introduction

Recently, health-care services for elderly persons are drawn attention of researchers in the field of wireless sensor networks. By using wireless sensor network technologies, care-givers, family members, or doctors can remotely monitor health conditions of an elderly person and notice a change of his/her behaviors based on long term data collections.

So far, most researches of health-care services by using wireless sensor networks have focused on sensing physiological statuses of the person's body [1] [2] [3]. However, it is also important to sense the locations and trajectories of the person in an indoor space (e.g., hospital, nursing home, home) in order to understand ordinal physical/social activities (e.g., walking distance, spending time with friends) of the person.

To sense the physiological statuses and locations simultaneously, we propose a mobile physiological sensor that works with an indoor positioning system based on a wireless sensor network. The physiological sensor is a small, mobile, multi-sensor device which includes electrocardiograph, 3-axis accelerometer, barometer, thermometer, and hygrometer. We have implemented the device as a network node of a wireless sensor network which has an indoor positioning function. The sensor device receives beacon signals from the network nodes installed in an indoor space and stores the strengths of the beacon signals and the person's physiological signals at its internal storage (flash memory). By analyzing the stored data, we can know the person's ordinal health conditions and location trajectories which represent physical/social activities.

In this paper. we show the mobile physiological sensor that works with an indoor positioning system. At first, we describe the design and implementation of mobile physiological sensor device. Then, we show an indoor positioning system including the sensor device. We also describe an experimental result of the physiological sensor device and the positioning system.

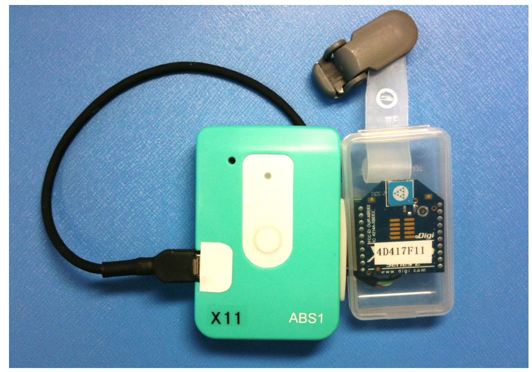

Fig. 1. Mobile physiological sensor

II. Mobile Physiological Sensor

Figure 1 shows a mobile physiological sensor which we have developed. The sensor device consists of two parts: one is a main unit (left side) and the other is a wireless communication module (right side).

A. Main unit

The main unit includes a MPU, a flash memory, 5 kinds of sensors (electrocardiograph, 3-axis accelerometer, barometer, thermometer, hygrometer) and a lithium ion battery. Its size and weight are as follows: size 6x4x1.5 cm; weight 34.5g (includes battery). Continuous operating time is about 6–8 hours when the sensing cycle is 50 Hz. It has a button and a color LED for the user interface. The actions are recorded when the button is pushed.

To sense electrocardiogram correctly, it is required to be tightly attached to user's chest by sticking electrodes of the device. Once it is attached to user's chest, it can detect his/her upper body by the 3-axis accelerometer. The device continuously senses current states of the user and records them in its internal data storage (flash memory) with the time stamps.

The user's locations and physiological statuses are estimated based on the obtained data. The process is performed by an

Fig. 2. A network node installed in an indoor space

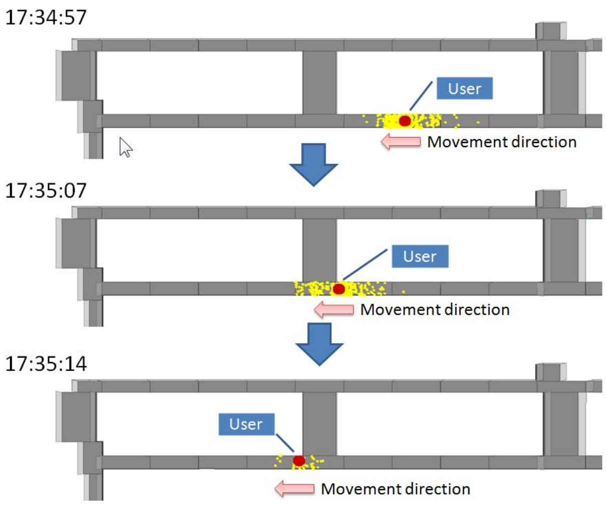

Fig. 3. Images of an analytic process (user's location)

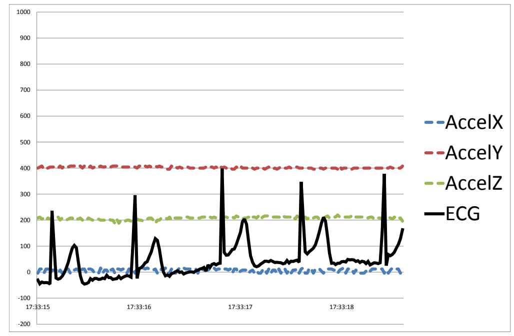

Fig. 4. Sensed ECG and acceleration data (standing)

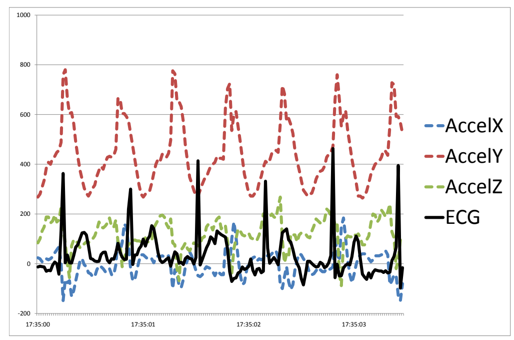

Fig. 5. Sensed ECG and acceleration data (walking)

analysis program on a personal computer. To send the obtained data to the PC, the USB (Universal Serial Bus) port of the main unit is used. By connecting the port and the PC, the program receives the data from the device.

B. Communication module

The communication module is connected to the main module via a UART (Universal asynchronous receiver/transmitter) port of the main module. We have developed some wireless communication modules (e.g., Bluetooth[1], IEEE 802.11, ZigBee[2]) connected to the UART port. Enabling the sensor device to work with an indoor positioning system, we adopt a ZigBee/IEEE 802.15.4 module[3] as the communication module.

The communication module has an extension cable connected with the main unit. It is clipped at the user's shoulder to correctly communicate with the other nodes without any interference of the human body.

The module has a function to receive the beacon signals from other network nodes installed in a targeted indoor space. Figure 2 shows an image of a network node. The node continuously broadcasts beacon signals. The signals are received by the communication module and sent to the main module. The main module stores strengths and senders (network nodes) of the signals with time stamps in the main unit. Based on the analysis of strengths of the signal and locations of the sender, we can obtain a trajectory of the locations where the signals are received. The trajectory represents movements of a user when he or she carries the sensor device.

III. Indoor Positioning System

We have developed an indoor positioning system based on a wireless sensor network. The communication protocol of the network is based on IEEE802.15.4 and ZigBee standards. The network nodes which periodically send beacon signals are installed in a targeted space in a building. The beacon signals are implemented with IEEE802.15.4 broadcast packets. As the locations of the network nodes are known beforehand, a location of a sensor device, which is also a mobile node of the network, can be estimated by using strengths of received beacon signals.

A. Location estimation algorithm

The location estimation algorithm of the system is based on a particle-filter algorithm [4] [5]. In the algorithm, each particle has a hypothesis about a current location of the device and a weight which represents a confidence value of the

[1] http://www.bluetooth.com/Pages/Bluetooth-Home.aspx/
[2] http://www.zigbee.org/
[3] XBee: http://www.digi.com/pdf/ds_xbeezbmodules.pdf

Fig. 6. An analytic result (user's heart rate (top), movement (middle), trajectory (bottom))

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.

In addition, our algorithm uses walking (or standing) data analyzed by acceleration data obtained by the sensors. In the algorithm, the weights of particles are updated when user is walking. It means that current location is not updated when user is not walking. By applying this heuristics, the location estimate becomes more robust because the heuristics suppresses drifts of the estimated locations caused by fluctuations of observed RSSI values.

The analysis is processed on a personal computer. Figure 3 shows example images of the analytic process. The estimated location of the user (red circle) on a floor and particles (yellow circles) which represent candidates of the user's location are shown.

IV. Analytic results

A. Physiological signals

Figure 4 shows electrocardiogram (ECG) and acceleration data sensed by the device when user is standing; Figure 5 shows ECG and acceleration data sensed by the device when user is walking. In the figures, the dotted line shows 3-axis acceleration data. The black line shows ECG. As the device can sense the R-wave of the ECG regardless of the presence or absence of user's movements, user's heart rate variability can be continuously analyzed.

B. Location estimation

Figure 6 shows an analytic result of user's heart rates (top), Y-axes body movements (middle), a location trajectory (bottom) when a user with the sensor device walked on our laboratory floor in a clockwise direction. Top of the figure shows heart rates of the user. The middle shows user's body movements. The bottom indicates an estimated location trajectory (yellow line and red dot). Red circles in the middle and bottom figures show the periods when the user was standing (or slowly moving). In this result, the location estimation error is in 2–3 meters.

V. Conclusion

This paper has shown a mobile physiological sensor that works with indoor positioning system based on a wireless sensor network. The physiological sensor includes electrocardiograph, 3-axis accelerometer, barometer, thermometer, and hygrometer. In addition, the device receives beacon signals from network nodes installed in an indoor space. Based on sensed physiological signals and received beacon signal strengths, user's physiological statuses and location trajectories can be estimated.

Currently, this system cannot be used for real time monitoring of the user's physical conditions and locations. As a future work, we will develop the sensor device which can immediately send the sensed data to the analysis software on a remote server through the wireless sensor network.

Acknowledgment

This work was supported by the Grant-in-Aids for the Scientific Research by the Japan Society for the Promotion of Science, No.22500079.

References

[1] A. Sashima, Y. Inoue, T. Ikeda, T. Yamashita, M. Ohta, and K. Kurumatani. Toward mobile healthcare services by using everyday mobile phones. In *HEALTHINF (1)*, pages 242–245, 2008.

[2] P. Leijdekkers and V. Gay. Personal heart monitoring and rehabilitation system using smart phones. In *ICMB '06: Proceedings of the International Conference on Mobile Business*, page 29, Washington, DC, USA, 2006. IEEE Computer Society.

[3] N. Oliver and F. Flores-Mangas. Healthgear: A real-time wearable system for monitoring and analyzing physiological signals. In *Proceedings of the International Workshop on Wearable and Implantable Body Sensor Networks (BSN'06)*, pages 61–64, Washington, DC, USA, 2006. IEEE Computer Society.

[4] D. Fox, J. Hightower, L. Liao, D. Schulz, G. Borriello, Bayesian Filtering for Location Estimation. IEEE Pervasive Computing, pp. 24-33, July-September, 2003

[5] I. M. Rekleitis, A Particle Filter Tutorial for Mobile Robot Localization. Centre for Intelligent Machines, McGill University,TR-CIM-04-02,2004.