Sensor Information Processing System for Flexible Ubiquitous Services

We describe ubiquitous gateway technology for achieving ubiquitous services using sensor networks, and the future role of mobile terminals. This research was conducted jointly with the Aoyama Morikawa Laboratories (Professor Tomonori Aoyama, Graduate School of Information Science and Technology; Associate Professor Hiroyuki Morikawa, Graduate School of Frontier Sciences), The University of Tokyo.

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1. Introduction

In the future, we can expect the spread of a "ubiquitous computing environment" with omnipresent sensors and computers and the provision of "ubiquitous services" based on the user and surrounding conditions (such as the names, owners, and locations of things as seen by the user). A wide variety of ubiquitous services can be imagined, such as a service that detects that the user has dropped something and informs the user of that, or a service that determines the user's destination from something that he/she is carrying on leaving the house and then provides directions to that destination. The user and surrounding conditions are commonly called "context," and technologies that handle context are called "context awareness technologies." These technologies are vitally important for achieving ubiquitous services, and they can be broadly dividend into three types: technology for obtaining information on the user and the state of things around the user (real-world information) using sensors; technology that uses that information to determine the user's current situation (e.g., boarding the bus arriving three minutes from now will get the user to his/her destination with the shortest transfer wait time); and technology that selects a service appropriate to that situation and acts on the user accordingly via an actuator[*1].

A sensor network that interconnects sensors and an actuator network that interconnects actuators each consist of things that move in unison with the user and things that are embedded in the environments that the user moves to (house, buildings, etc.). This implies a mixture of various types of networks. Under these conditions, a mobile terminal that is always moving with the user becomes an important element of context awareness technologies.

As a first step toward the realization of such a ubiquitous computing environment, we propose in this article a system consisting of a sensor network, an actuator network, and a Ubiquitous GateWay (UGW), consider the role of future mobile terminals, and describe the elemental technologies and collaborating methods of each of those components. In addition to the technologies described here, the provision of actual services will require system technologies such as middleware[*2]. For information on those technologies, refer to the article "R&D Toward a Connecting Service Between Mobile Terminals and Sensor Networks."

2. Requirements and Issues in the Provision of Ubiquitous Services

We can expect sensors to be very small and be attached to daily commodities in the years to come. But collecting the measurement results of such a huge number of sensors would result

*1 Actuator: In contrast to a sensor that detects light, sound, etc. in the outside world and converts them to signals, an actuator is a device that generates light, sound, etc. or physical motion as in a motor based on internal signals and acts on the outside world.

*2 Middleware: Software positioned between the OS and actual applications, providing common functions for diverse applications thereby making application development more efficient.

in a massive amount of data, and communicating that data would consume a large amount of power. To resolve these issues, a technology to select and integrate data within the sensor network is required. To date, however, there has been little progress in research on what kind of information should be processed and in what way to enable a sufficient amount of data to be collected with a minimal amount of power consumed.

In addition, it is necessary to understand the user's situation from the real-world information collected by sensors. Real-world information might be an analog value representing voltage or ID information consisting of a sequence of numbers. Converting such information to an abstract expression like "carrying purse" constitutes "understanding". This requires intelligent processing, which is a difficult problem in itself. Providing sufficient processing capability and securing autonomy during communication downtimes are also issues that need to be addressed.

Finally, it is necessary to provide a suitable service according to the user's current situation. This will require a means of judging the suitability of individual services given current conditions, and a means of selecting a method for providing the service in accordance with the state of actuators near the user.

3. UGW-centered Architecture for Providing Ubiquitous Services

Sensor network technology and actuator network technology play an important role in solving the technical issues described above and satisfying the aforementioned requirements. However, the processing capability of each node is limited, which means that external support is required. A function to collaborate the above two types of networks is also required. The device to provide this support and perform this function is the UGW. **Figure 1** shows the proposed system centered around the UGW, and the following section describes this system overview.

3.1 Sensor Network for Finding Similar Things

As a first step toward solving sensor network issues, we proposed a "sensor network for finding similar things" and its algorithm with the aim of finding things that have similar output patterns from attached accelerometers [1]. A sensor network of this type makes it possible to determine, for example, that several things are being carried by the same person, or that several things are in the same drawer. In short, it would be able to obtain information on real-world things.

The conventional approach to achieve the above is to gather

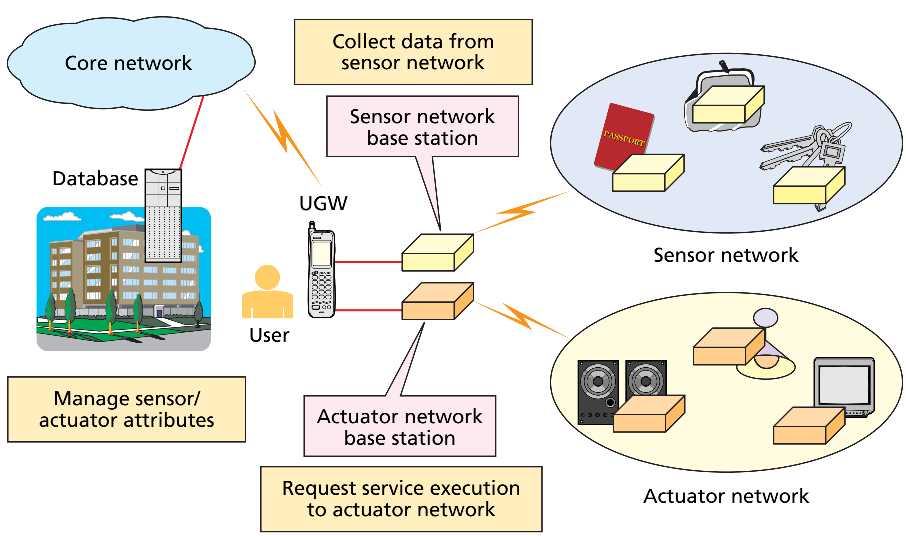

Figure 1 System overview

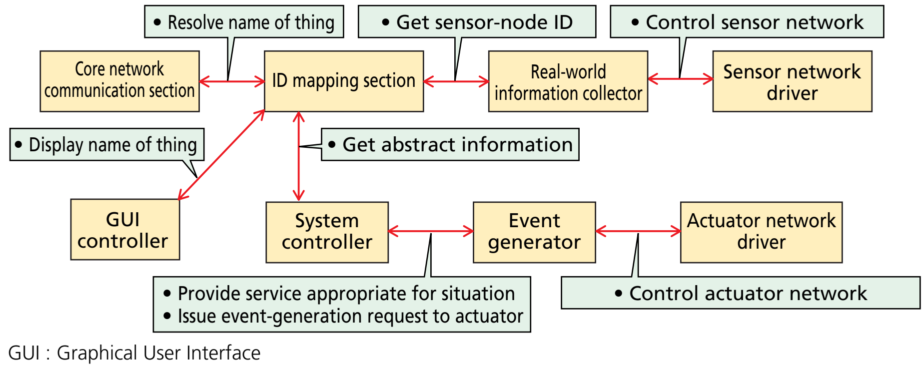

Figure 2 UGW components

all acceleration data in one place and compare them, but has a defect of high communication load. To resolve this issue, we introduce the concept of a cluster and propose the following cluster generation algorithm.

1) Determine Cluster Head (CH)

Using the occurrence of some physical phenomenon as the starting point, each sensor node enters a wait state. The wait time of each sensor node is inversely proportional to its remaining battery power. The first node to complete its wait time becomes the CH.

2) Determine Cluster Membership

The CH broadcasts the sensor signal pattern of that physical phenomenon to all sensor nodes. Each node compares the received data with its own measured signal pattern, and if similar, notifies the CH of that fact.

The advantages of this method are twofold. First, the node with the most remaining battery power is automatically selected by step 1) so that battery power is consumed in a balanced manner among all nodes. Second, as the task of each node here is to receive data from the CH and only return to it the result of similarity judging (one-bit YES/NO answer), communication load is reduced compared to the sending/receiving of the measurement results of all nodes. With the proposed algorithm, the CH can determine the sensor-node group similar to itself. This group is called a "cluster." The CH sends the list of nodes belonging to the cluster to the UGW as real-world information.

3.2 UGW

The UGW [2] is a device equipped with a battery, information processing capability, and interfaces for communicating with the sensor network and actuator network. **Figure 2** shows the components of the UGW, and key components are described below.

The real-world information collector collects real-world information sent from the sensor network, corrects data errors caused by limited sensor processing capability, and handles communication cutoffs with the sensor network. The method adopted here to correct data errors in the system is to introduce a filter, which treats a one-time change as a data error in the sensor network that should be ignored considering the temporal continuity of cluster information. The method used to handle communication cutoffs is to transmit Keep Alive messages so that communication ability can be periodically checked. In the event that a disconnection continues for a long period of time, the system determines that the UGW and the target thing are far apart and informs the event generator of that condition.

The ID mapping section consists of a correspondence table between obtained sensor-node IDs and the things that those nodes are attached to. This table serves as a list of cluster members. The names, photo, etc. of things corresponding to the IDs are stored in the database on the core network. The UGW accesses the database as needed and saves accessed data on itself to reduce unnecessary communications with the database.

The event generator decides on a service corresponding to the current situation and generates a corresponding event with respect to the actuator network. The UGW can understand the situation by combining abstract information based on the ID mapping section. The correspondence between the understood situation and the event depends on the service application. In this system, a change in the combination of things is taken to be an event. However, to let individual users specify such combinations, this would detract from the convenience of the service. For this reason, the system is equipped with the mechanism described later that semi-automatically establishes situation-event correspondences using functions of the sensor network for finding similar things.

3.3 Actuator Network

We use ANtennary THings (ANTH)[*3] [3] in the actuator network. Activating an actuator managed by an ANTH node is called an "action." In ANTH, establishing correspondences between events generated in the real world and actions can achieve the most basic level of ubiquitous services in the form of "if A happens, B executes." While much research has been concerned with automating the setting of such correspondences or with having users describe them, ANTH features a specialized device that enables the user to establish event-action correspondences by actually pointing out the devices that correspond to "A" and "B." Establishing correspondences in this way by having people perform actions in the real world is called "real-world programming."

3.4 Overall System Operation Overview

Using a lost-item-detection service as an example, the following gives a brief description of system operation.

1) Initialization

Before starting the service, the following two instructions are necessary. First, we let the service system monitor target things for determining an event. We accomplish this by shaking the UGW and the target things simultaneously so as to give them the same degree of vibration. The UGW now finds the things with the same acceleration pattern as itself and registers those things with the event generator. Second, we let the service system specify what to do when a lost-item event occurs. This is done by real-world programming. For example, the user may bring the UGW close to the built-in vibrator of an ANTH module so that the connection between the event and actuator is registered within ANTH.

2) Walking

If the user begins to walk while carrying the above registered things, each of them detects the vibrations associated with acceleration causing the system to execute the clustering algorithm. The UGW receives the result of clustering and the event generator checks whether all registered things are included in the cluster.

3) Lost Item

If the user lose something, the ID number of the sensor corresponding to the thing will drop out of that cluster. This causes the event generator to send this event to ANTH, which associates an actuator (vibrator) with the event. The vibrator carried by the user notifies the user that he/she has lost something.

4. Evaluation

To evaluate sensor network protocol, we performed simulations comparing our sensor network with Low-Energy Adaptive Clustering Hierarchy (LEACH)[*4] [4], a typical system in sensor network research. **Figure 3** shows a comparison between our sensor network and LEACH. The horizontal axis of the graph represents the operating time of each sensor network. The vertical axis represents the number of surviving nodes in each sensor

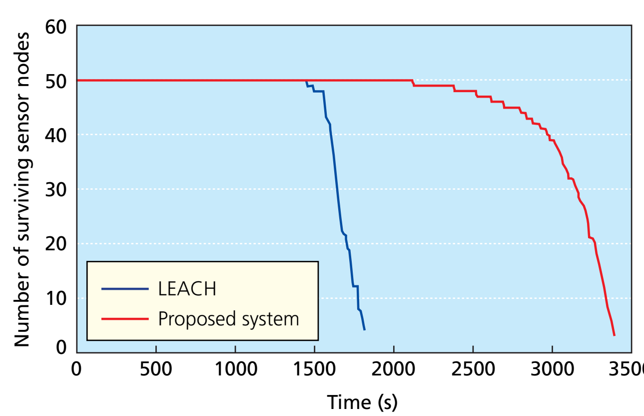

Figure 3 Change in number of sensor nodes for LEACH and proposed system

*3 ANTH: A real-world programming framework developed by the Aoyama Morikawa Laboratories, Graduate School of The University of Tokyo. In ANTH, all functions are abstracted into events that detect a state and actions that are generated toward outside. A user can describe a service by establishing correspondences between events and actions.

*4 LEACH: A hierarchical routing algorithm for a sensor network using multihop communication. It features dynamic determination of a cluster head for collecting sensor information to distribute node load.

network that configures clusters at fixed intervals. In our system, all sensor nodes consume battery power equally and the total communication load for cluster generation is small. This feature ensures that the operating time of our system is about twice as long as that of LEACH.

5. Future Role of Mobile Terminals

We can expect that a future mobile terminal which functions as a UGW will have the following functions:

- Acts as a real-world programming device that can indicate a physical object by shaking together or moving close
- Receives information from the sensor network and supports processing difficult for the sensor network to perform by itself such as handling of data errors
- Understands the user's situation and state of surrounding things using network information (in this system, using a database of IDs and object attributes)
- Determines what has to be performed in accordance with the current situation and specifies an action for providing a service

6. Conclusion

We proposed a system composed of a sensor network, actuator network, and UGW and described the elemental technologies and interfacing methods of each of these components.

The feasibility of the proposed system is now being verified, but it has already been confirmed that the sensor network section is twice as efficient as existing systems.

In this research, we have focused on sensors attached to things. We are going to expand the system to sensors and actuators embedded in buildings, sensors installed outdoors, etc. with the aim of providing an even wider variety of ubiquitous services in the near future.

References

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