Position Tracking | System Architecture | Sensor System

Technology Reports

Object Tracking System for Mobile Terminals: Prototype System Using Cameras and Position Measurement Sensors

A prototype system that tracks objects such as persons or things and acquires information on the object state (position data and still images or video) is constructed using sensor network middleware that implements cooperation between a mobile terminal and a sensor network.

Tomoyuki Osano, Takeshi Kato, Maximilian Michel and Qing Wei

1. Introduction

In recent years, progress in microprocessors and wireless communication technology has stimulated R&D of sensor networks, in which multiple sensors that are equipped with wireless communication functions are connected in a single network, and advancement toward practical use. Sensor networks allow unified control of many sensors via a network, and their range of applications is steadily expanding. For example, vibration sensors, brightness sensors, smoke sensors and other such sensors that are placed in various locations and connected via a network are being applied to remote monitoring of landslides, building security, and fire prevention. Applications that have attracted attention in recent years include the Global Positioning System (GPS) for location measurement, Radio Frequency IDentification (RFID)[*1], and systems that use image information acquired from cameras to track objects such as moving persons or things. Various methods for measuring object position have been devised, including hybrid position measurement systems that use the Round Trip Time (RTT)[*2] from GPS and the base station of a mobile communication network, RFID, wireless LAN Receiver Signal Strength Indicator (RSSI)[*3], the Time Difference Of Arrival (TDOA)[*4], which is the difference in the times that a signal is received by multiple base stations, or other such measurements. Object tracking systems in development that use these position measurement techniques include a child safety system that uses mobile terminals equipped with a GPS function to monitor kindergarten and elementary school pupils on the way to and from school, distribution systems that perform freight tracking, quality control and stock management of products by placing RFID readers and temperature sensors in stores, distribution channels and trucks, etc., and office security systems that use RFID readers placed at office entrances and exits to monitor the movement of PCs that contain confidential information and so on. Such systems use various kinds of sensors, and even when the same type of sensor is used, the sensor control and position data format differs, so the system is sensor-dependent. Considering that future applications may involve the cooperation of many small sensors, the conventional centralized sensor data management may not be efficient. For that reason, technology for realizing applications that work through the interaction and cooperation of sensor nodes and technology for managing the huge amount of sensor data is required.

In this research, we investigated technology for implementing a system for the real-time tracking of moving

*1 **RFID**: A scheme for wirelessly obtaining ID information embedded in small IC chips to identify and manage people and objects.

*2 **RTT**: The delay time for round-trip transfer between machines. For resends, it is the time from the initial transmission to the retransmission.

*3 **RSSI**: Level indicator of the signal power of the received signal at a receiver terminal.

*4 **TDOA**: A method for determining the position of a mobile terminal that periodically transmits a beacon signal, taking multipath signal propagation at a mobile terminal or wireless LAN access point such into consideration.

objects such as persons or freight by using a mobile terminal to control a sensor network that connects indoor and outdoor position measurement sensors and cameras. We also investigated a sensor data search method that allows the mobile terminal to be used for efficient search of object position data and other such log data that is distributed over the sensor network. To verify the method proposed from these investigations, we constructed a prototype object tracking system using a mobile terminal and wireless LAN position measurement sensors and cameras.

This research was conducted jointly with DoCoMo Communications Laboratories Europe GmbH. Concerning the system architecture and protocol, please refer to another article, "Object Tracking System for Mobile Terminals: Architecture, Protocol and Its Evaluation."

2. Requirements for Object Tracking from a Mobile Terminal

An object tracking system is configured by using a network to connect many sensors such as position measurement sensors and cameras that are positioned in the tracking range. An example of the sensor network is shown in **Figure 1**. Each sensor observes the state of the object and stores the observation data in the sensor node. The sensor node has functions for observation data management and communication, allowing it to respond to requests from the user's mobile terminal for data search. The requirements for this kind of system include the following.

- Object position data retrieval for any type of position measurement sensor (GPS, RFID, etc.)
- Sensor control that allows acquisition of object state, including position data (videos and other environ-

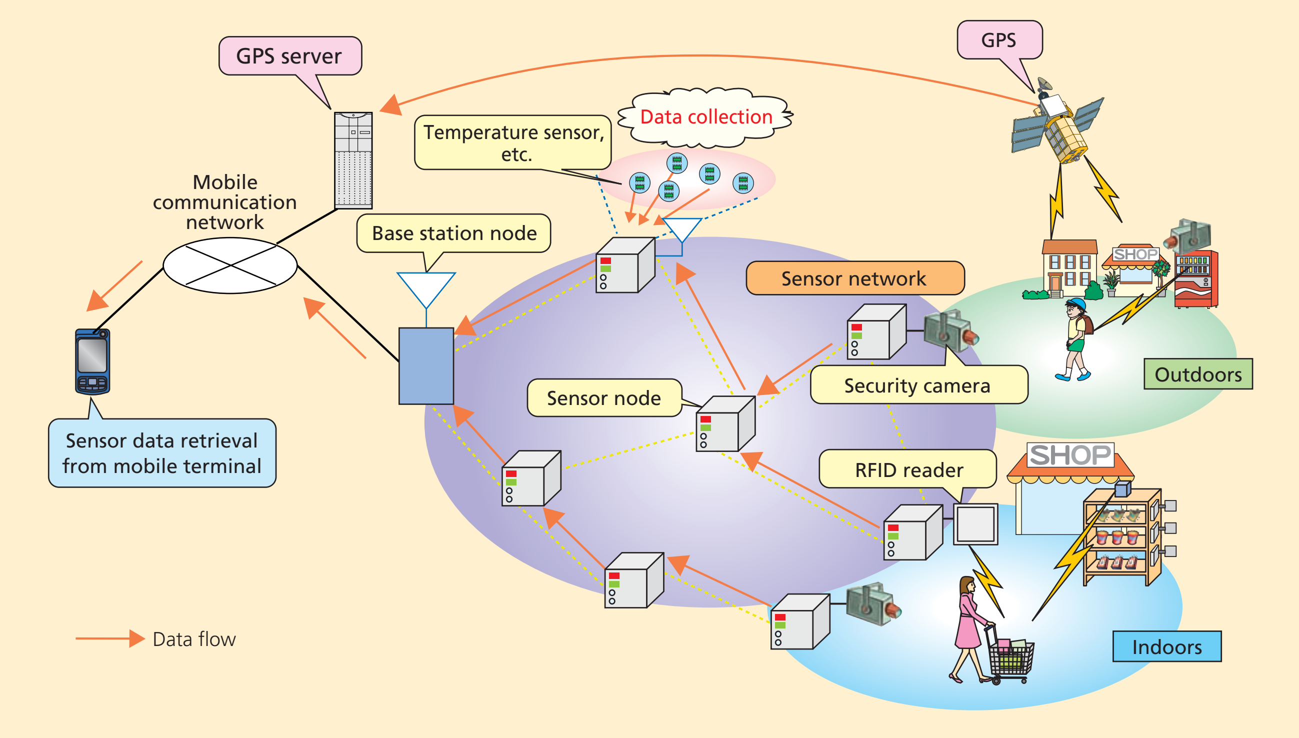

Figure 1 Sensor network

mental information)

- Scalable object search

These requirements are described in detail below.

2.1 Acquiring Seamless Object Position Data

The position data used when tracking objects such as persons or things generally comprises multiple elements, such as a coordinate system*5, coordinates, an object shape for screen display, and measurement time. For unified processing of position data by mobile terminals, car navigation systems and others, the standardization of the format for representing position data is in progress. Concerning the position data format for GPS and other systems that handle outdoor position data, standards have been set for representation as URL parameters by the Mobile Office Promotion Association (MOPA)*6[1] and for representation in eXtensible Markup Language (XML)*7 by Point Of Interest eXchange language (POIX)*8[2]. Furthermore, standardization that integrates these standards, such as the POIX_EX*9 [3], is in progress. In object tracking systems, however, position measurement is assumed to involve indoor position measurement using indoor RFID or wireless LAN as well as outdoor GPS measurements. Accordingly, a format for representing position data that allows the seamless handling of indoor and outdoor position data is required.

2.2 Acquiring the Object State

Maintaining the quality and freshness of the products (draft sake, for example) being transported in product distribution systems requires the management of information on object state (temperature, videos, etc.) in addition to position data. Therefore, the object tracking system must be capable of acquiring comprehensive information on the object state, including information on the object's peripheral environment, as well as position data.

2.3 Scalable Object Search

When a huge amount of data is managed centrally by means of a database, scalablity issues such as delay in response to a search arise. Particularly in object tracking, where massive amounts of observation data are created in real time, that issue strongly affects system performance. Therefore, scalablity that allows a stable response regardless of the number of search items or the type or amount of data is required.

In the child monitoring system, for example, many sensors such as RFID readers and monitoring cameras are located along the child's route to school, so it is necessary to manage hundreds of sensors. Furthermore, when hundreds of children are being monitored, there are also hundreds of monitoring adults, and the time of access is concentrated in the time frames of the children going to and coming from school. In that kind of environment, fast and efficient search of the child's position data from the mobile terminal is required.

3. Design and Implementation of the Object Tracking System

The overall configuration of this system is shown in **Figure 2**. Object position measurement in this system adopts a wireless LAN position measurement system that can also be used as a wireless LAN access point. As a wireless LAN position measurement system it detects position on the basis of the times at which signals transmitted periodically from special radio tags are received at multiple access points (TDOA). Although there is another position measurement method that uses RSSI, that system generally requires calibration to damaged items for operation. We selected TDOA position measurement sensors for the system described here because they do not require calibration to each change in environment and can thus meet the demand for position measurement even in dynamically changing environments such as a warehouse. For the cameras that provide video of the object to the mobile terminal, we used cameras that can output Joint Photographic Experts Group (JPEG) images and Moving Picture Experts Group phase 4 (MPEG-4)*10

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*5 **Coordinate system**: A system of an origin and coordinate axes for representing arbitrary coordinates. The combination of coordinates and coordinate system allows representation of unique points.

*6 **MOPA**: A format established by the Mobile Office Promotion Association that represents position data as a URL for position data services offered via mobile terminals and other mobile devices.

*7 **XML**: A mark-up language for information handled on the Internet released in February 1998.

*8 **POIX**: XML data format specifications for position data defined by the MObile Information Standard TEchnical Committee (MOSTEC), an organization of automobile and car navigation manufacturers.

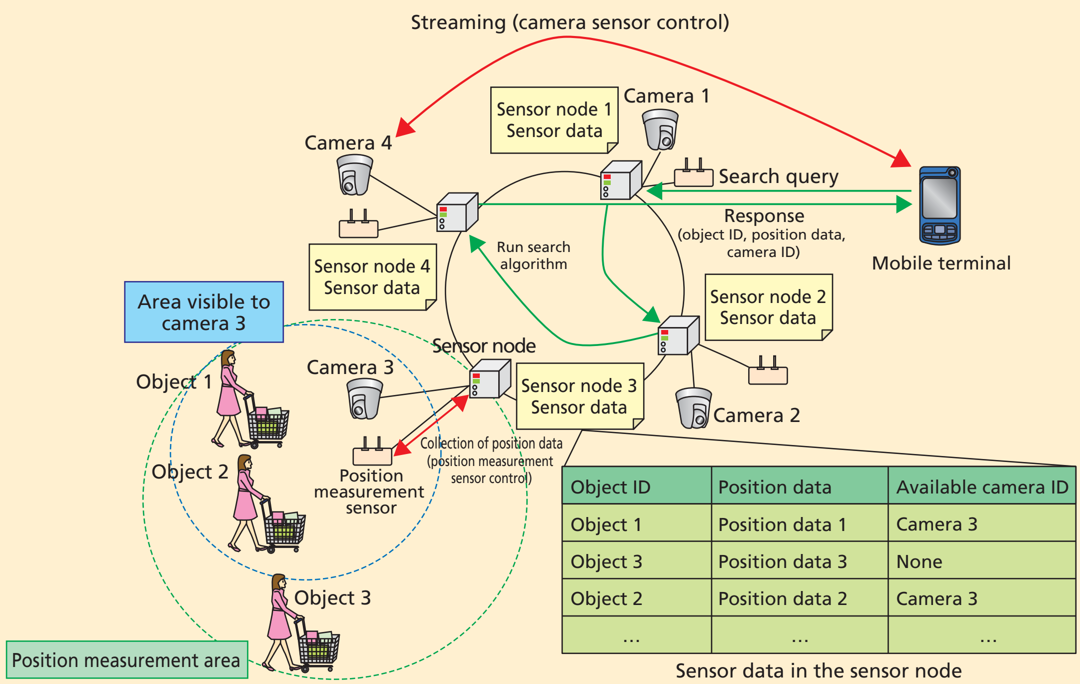

Figure 2 System configuration

video and which have a LAN interface. Multiple small, embedded Linux terminals[*11] that run the Linux OS[*12] served as the sensor nodes that control the position measurement sensors and cameras. The mobile terminal we used was also wireless LAN capable.

A design policy for satisfying the above requirements is described below.

3.1 Position Data

As a format that can represent both the indoor position measurement information from the wireless LAN and the outdoor position measurement information from the GPS, we specified an extension of the POIX_EX standard. An example of the position metadata used in this system is shown in **Figure 3**. The position data comprises a coordinate system definition, a representation of the object coordinates in that coordinate system, a representation of the object shape, and the time of measurement. In the example of Fig. 3, the Japanese standard Japanese Geodetic Datum 2000 (JGD2000) is used as the geodetic system[*13] for specifying the conditions for the measurements. Because the object coordinates obtained from indoor measurements are represented with a coordinate system that is specific to the site of installation, we specified a reference point. The reference point represents coordinates that relate the origin of the indoor-specific coordinate system to the origin of Japan Plane Rectangular Coordinate System IX (jprcs9), a rectangular coordinate system that divides Japan into 19 regions. This makes it easy to use the reference point to convert indoor position measurement information from RFID, etc. that is represented with a local coordinate system and outdoor position measurement information from GPS, etc., thus achieving seamless position data representation. In addition to the local coordinate system coordinates, measurement error, object shape, and measurement time are described in the position data.

3.2 Sensor Control Protocol

The protocols for controlling sensors such as the acquisition of position data and video data from the cameras

*9 **POIX_EX**: A position data representation standard that integrates the POIX standards defined by MOSTEC and the MOPA standard. Unlike the POIX standard which uses XML to describe position data, and the MOPA standard which describes as a URL, POIX_EX specifies the structure without specifying the description method itself.

*10 **MPEG-4**: A coding system for moving-picture data used for delivering video over relatively slow communication circuits as in mobile terminals.

*11 **Embedded Linux terminal**: A kind of special-purpose device that is incorporated into mobile data terminals, digital appliances and other such products and has a CPU and software that runs on the Linux OS (See *12).

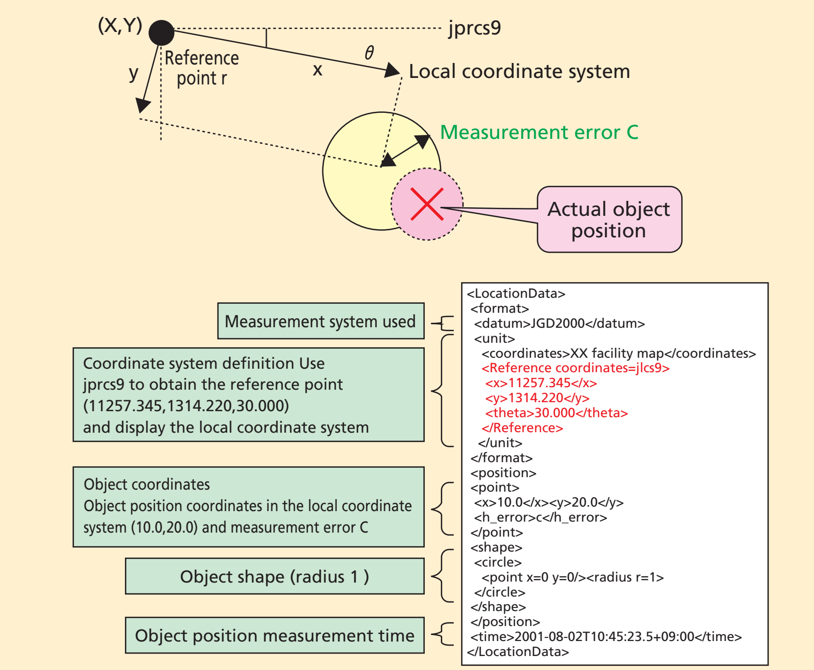

Figure 3 Position metadata

are specified independently by the manufacturer. Thus, control of the various sensors from the mobile terminal requires the design and implementation of a protocol for each sensor. To solve this issue, we implemented sensor middleware[*14] that provides a unified control interface for the various types of sensor nodes that coexist in this system. This allows unified control of different types of position measurement sensors and camera sensors from the mobile terminal via sensor middleware. Concerning the R&D of the sensor middleware, see Ref. [4].

3.3 Ensuring Scalability in Object Search

In sensor networks to which many sensors are connected, the management of the sensor data is generally distributed over the sensor nodes. This system also uses distributed management of sensor data (object position data) (Fig. 2). The mobile terminal sends a search message to a sensor node, and the sensor node that receives the search message passes it on successively to the nodes around it. When search requests are thus made from multiple mobile terminals, the network is flooded with messages. To solve this issue, we investigated the use of a Distributed Hash Table (DHT)[*15], which adopts a hash function[*16] for efficient search for sensor data from a mobile terminal in a distributed environment of many sensor nodes. In this system, we introduced an object search algorithm using Chord[*17][5], a method derived from DHT that is being studied by DoCoMo Communications Laboratories Europe GmbH.

4. Prototype System

4.1 Functions

The configuration of the prototype system is shown in **Figure 4**. A camera and a position measurement sensor are connected to each sensor node. The sensor nodes and the mobile terminal are connected to the sensor network, and the mobile terminal acquires information (position and streaming[*18] video) on the objects (wireless LAN position measurement tags) that move within the position measurement area. This system implements the following functions.

- Function for obtaining a movement history from the object position data

  This function compiles a history of the movement of an object specfied with the mobile terminal from the object's position data collected by the sensor nodes.

- Real-time object video acquisition function

  This function searches for cameras that can acquire images of the object, and obtains streaming video data from those cameras in real time.

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*12 **Linux OS**: An open-source Unix-type OS that can be freely redistributed under GNU Public License (GPL).

*13 **Geodetic system**: Assumed conditions for representing location on the earth as coordinates. The shape of the earth is represented as a ellipse.

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

*15 **DHT**: A data structure for storing paired data comprising a search key and a value over multiple nodes, without requiring a central node to manage the data.

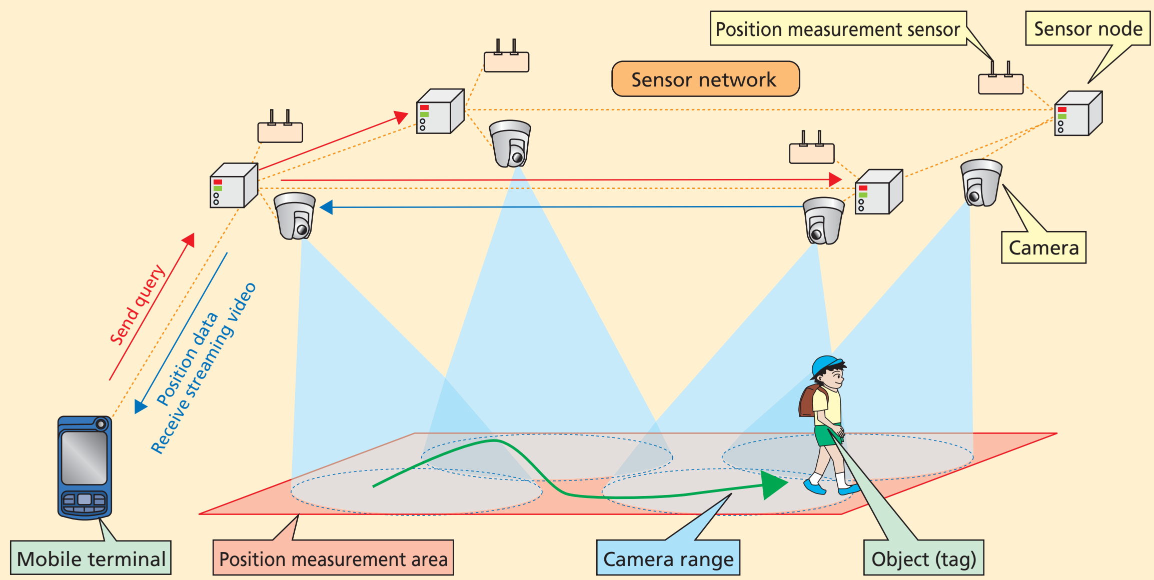

Figure 4 Prototype system

4.2 Protocol Sequence

The operation sequence of the two functions described in Section 4.1 are shown in **Figure 5**, and the screen transitions of the mobile terminal are shown in **Figure 6**.

1) Object Movement History Function

First, each sensor node requests object position data from the position measurement sensor (Fig. 5 (a) (1)). The sensor node appends information on whether the camera can photograph the object in question to the position data obtained from the position measurement sensor (object ID, position data), and saves the data (Fig. 5 (a) (2)). The mobile terminal uses the object ID of the search target as the search key (Fig. 5 (a) (3)) and retrieves the object position data as the search results (Fig. 5(a) (4)). The collected position data can be used to construct the object's movement history. The interval for retrieving the movement history can be set arbitrarily.

2) Real-time Video Function

The operation sequence for sensor node position data acquisition and saving (Fig. 5 (b) (1), (2)) is common to the sequence for acquiring the movement history (Fig. 5 (a) (1), (2)) from the object position data.

The mobile terminal uses the ID of the object being searched for as the search key (Fig. 5 (b) (3)) and retrieves information on the cameras that can photograph the object as the search results (Fig. 5 (b) (4)). The mobile terminal can inspect the object video in real time by selecting a camera from the most recent of the retrieved information and retrieve streaming video from it (Fig. 5 (b) (5), (6)). A streaming protocol developed for mobile terminals is used [6].

4.3 Evaluation

Operation of the prototype system confirmed that a sensor network that connects multiple position measurement sensors and cameras can be used to search for an object from a mobile terminal and to receive object position data and real-time video as the search results. With this system, the object ID of the search target is used in the search, but compositive search such as the "temperature of the room Mr. A is in" are difficult. In future work, we must apply Semantic Web technology or other such techniques for attaching semantic information to sensor data to

*16 **Hash function**: A reproducible method of mapping some kind of data to a (small) value of fixed length. It has the property that it is difficult to infer the original data from the hash value.

*17 **Chord**: An algorithm to construct an overlay, which organizes nodes in a virtual ring (one dimensional logical space).

*18 **Streaming**: A method for simultaneous downloading and playback of voice, video or other multimedia files, with a greatly reduced waiting time.

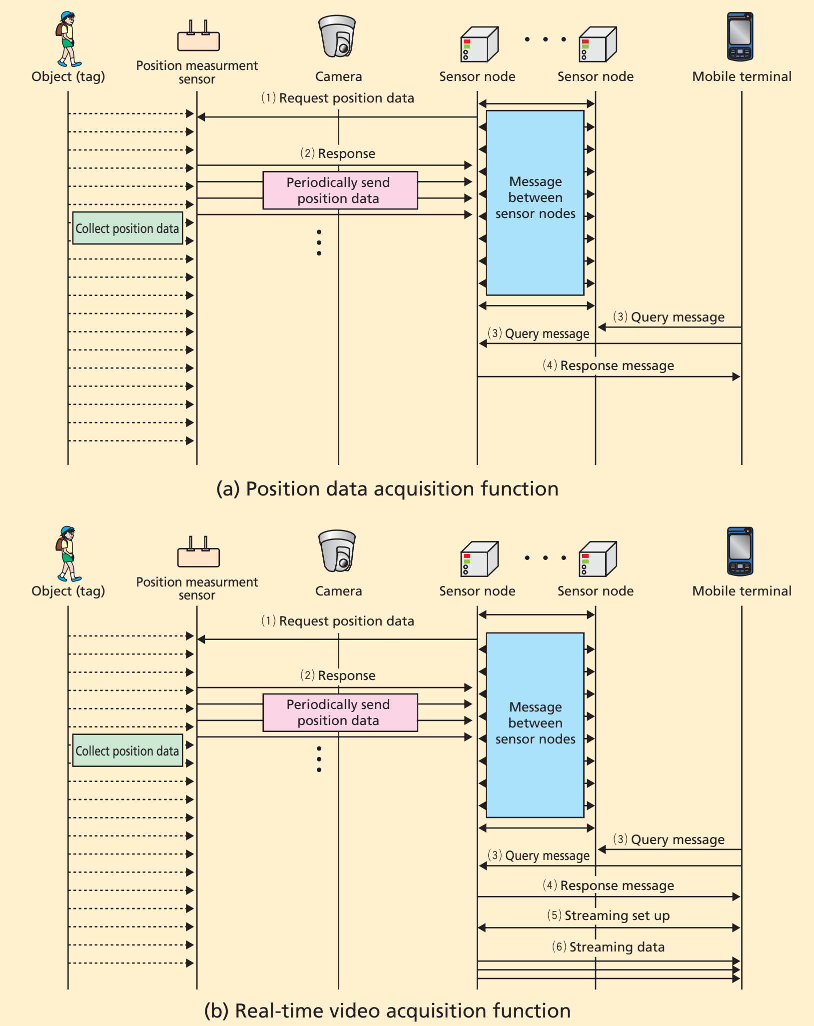

Figure 5 Operation sequence

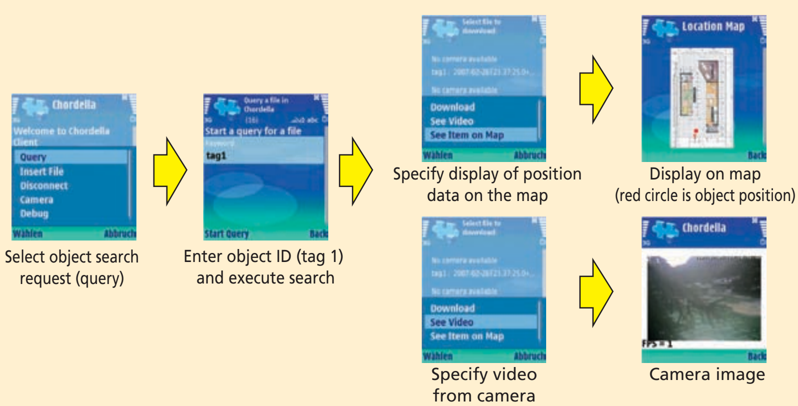

Figure 6 Screen transitions

make this kind of sophisticated search possible.

5. Conclusion

We have described an object tracking system using a network of position measurement sensors and cameras, a position data representation format, sensor control middleware, and distributed data search technology. In future work, we will investigate privacy protection and other security systems with practical application in mind, and study methods of system operation. In addition, we will investigate application of this technology to the use of a sensor network and mobile terminals in advertisement distribution, in-store navigation and other such applications, and conduct experiments to verify and prove this technology.

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