4-3 Research and Development of an RFID-based Disaster-relief System

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A portable system for assisting rescue personnel in disaster situations has been developed. The system consists of portable microwave terminals that function as message readers/writers/carriers and long-range, non-battery RFID tags that are ubiquitously placed along roadsides and function as information-storage units. Information such as location of refuges and the safety assessments of damaged buildings is remotely downloaded onto or uploaded from the tags by the terminals.

Keywords
RFID, Damage information, Disaster relief, Disaster prevention, Disaster mitigation, GIS

1 Introduction

In the 1995 Great Hanshin-Awaji Earthquake, bills were widely posted as a means of distributing information in the disaster-afflicted area. Resident safety and evacuation information and emergent risk assessment results were directly posted on damaged buildings, and in this manner information was communicated within the disaster area. This example highlights the importance of establishing a system that can be used in rescue operations for the rapid collection of information scattered throughout an affected area; such a system could rely on manpower, rescue robots, or other elements that are independent of existing means of communication. This feature would prove particularly important in the event of a large-scale disaster that would likely cripple the communication infrastructure.

An RFID tag (for Radio Frequency Identification, a type of electronic tag) is a small device that can store, input, and output data through non-contact means. In addition to its wide use as a non-contact IC card, the RFID tag is on its way to becoming commercially feasible for attachment to merchandise and cargo in the logistics industry. In addition to logistics applications, a range of uses in other fields, including firefighting and disaster prevention, were recently highlighted in a report by a study group[1] organized by the Ministry of Internal Affairs and Communications.

Given the anticipated arrival of a "ubiquitous information society" in which RFIDs are embedded in large quantities in house walls, and in traditional utility poles along the road for normal use, the authors are moving ahead with development of an RFID writer/reader designed to write or read rescue-related information to or from an RFID. This device could serve as an information resource for rescue work in the disaster area and allow disaster victims or rescue workers outside of the disaster area to collect needed information instantaneously, in large quantities, and in a non-contact fashion, informing those outside the afflicted area of the conditions within the region. This paper describes the RFID writer/reader under development, followed by a discussion of an information sharing system using the device and thoughts on the further potential of an overall damage information collection system.

2 Development of an RFID writer/reader to collect damage information

This section outlines the RFID and provides a description of the development to date of the RFID writer/reader device based on anticipated application to the collection of damage information.

2.1 Outline of the RFID [2]

The RFID consists of a small IC (Integrated Circuit) chip capable of storing information and responding to commands from an interrogator (the writer/reader), and a metal antenna. The interrogator can read information stored in the RFID in a non-contact fashion using electromagnetic waves or through electromagnetic induction. Figure 1 presents an example RFID.

Fig. 1 Example RFID

The basic IC is 0.1 to several square millimeters, with its own storage capacity ranging from around ten bytes to several tens of Kbytes. The IC also has memory and logic circuitry as well, allowing it to perform processes such as computation, authentication, and encryption. In Japan, two frequency bands—13.56 MHz and 2.45 GHz—are the main radio frequency bands assigned to RFID. The maximum communication distance between the RFID and interrogator is roughly 70 cm for the 13.56-MHz band and roughly 1.5 m for the 2.45-GHz band, in accordance with regulations under Japan’s Radio Wave Law. In Japan, frequencies from 950 MHz to 956 MHz will likely be available for use in the latter half of fiscal year 2004 as a result of deregulation, which is expected to enable the design of RFIDs capable of communication over longer distances.

RFIDs are classified into two types: an active type incorporating a battery, and a passive type that does not require a battery. A passive RFID modulates the carrier wave sent from the interrogator with the information written in the RFID’s storage area and returns the signal to the interrogator, transferring the information. With a rectifying circuit in the antenna, this type of RFID receives the power to reflect the signal by rectifying the electromagnetic wave received from the interrogator. While in areas such as logistics, the passive type is the mainstay device due to its lower cost and maintenance-free design, battery-driven RFIDs can extend the distance of communication with the interrogator and can actively transmit information—functioning as a beacon, for example.

An additional type of RFID has been developed that allows not only reading of data previously written to the RFID (as in read-only devices) using the interrogator, but also permits write operations to the RFID using the same interrogator.

RFIDs are characterized by better reading efficiency per unit time (relative, for example, to barcodes) thanks to the ability to read multiple RFIDs at once (so-called “multi read”). Moreover, the manufacturing cost of a single RFID has dropped to approximately several tens of yen, paving the way for further cost reduction through increased production volumes.

Fig.2 *RFID Writer/Reader for Collection of Damage Information (Left: Fiscal Years 2001 to 2002, Center: Fiscal Year 2003; Right: Fiscal Year 2004)*

2.2 Outline of the RFID writer/reader under development

The authors embarked on the development of a 2.45-GHz passive RFID writer/reader in fiscal year 2001, and from fiscal year 2002, moved the project forward as a joint research initiative with the National Institute of Advanced Industrial Science and Technology, the National Research Institute of Fire and Disaster, and the Kogakuin University Department of Architecture, with the coordination of the International Rescue System Institute, an NPO. Research thus evolved as one of the themes of the Special Project for Earthquake Disaster Mitigation in Urban Areas (hereinafter referred to as "the DDT Project") launched by the Ministry of Education, Culture, Sports, Science and Technology. To date we have developed three types of writer/readers: a cart-mounted device (fiscal years 2001 to 2002), a backpack-mounted device (fiscal year 2003), and a handheld device (fiscal year 2004).

Designed to be battery-driven and portable under the assumption that it will be carried into disaster-stricken areas, the writer/reader under development is comprised of an antenna section, handling write and read operations to and from an RFID; a main body; a notebook PC controlling the main body; and batteries supplying power to these devices. While some RFID writer/readers are already commercially feasible for use as hand-held inventory terminals, most such terminals can only read an RFID upto several centimeters away, as with barcodes. However, assuming the necessity of reading a difficult-to-reach RFID in the event of a disaster (such as one buried under rubble), extending the readable distance is an obvious necessity. The possible communication distance of the authors' system is roughly 2 m at present. At the beginning of the development process, a high-output stationary writer/reader requiring a private radio station license was modified and rendered portable by adding batteries, in an attempt to secure the longest readable distance with a passive RFID available in Japan today with a portable device. However, since reduced size is critical for mobile activities in disaster areas, a low-output device was adopted from fiscal year 2004, at the expense of readable distance. As mentioned in Section **2.1**, an RFID in the UHF band, soon to be available in Japan, is expected to provide communication over longer distances than the RFID in the 2.45-GHz band. We are therefore contemplating the eventual adoption of a low-output device in the UHF band for use in our system. We should note here that although they allow extension of readable distance, active RFIDs require periodic tag-battery replacement. This poses the difficult challenge of replacing large quantities of tag batteries to prepare for a disaster that could occur at any time. Further, many RFIDs are read-only (that is, they send only a fixed tag ID), rendering them unsuitable for collection of damage information.

RFIDs are generally used in a client/server configuration in which the RFID is commonly employed as an identifier (ID), and the server retrieves information from a database under its control via a network using the read ID as a key. The authors' system, in contrast, is designed to use the RFID for data storage, with all necessary information written to the RFID based on the assumption that the client/server system will not function at the time of a large-scale disaster.

The following sections provide an outline of developments in chronological order:

2.3 Outline of developments in fiscal year 2001

In fiscal year 2001, the first year, we tackled development of the following basic functions in writing and reading information to and from the RFID:

- Writing Japanese character strings to a single RFID (simplified write function)
- Reading Japanese character strings from an RFID and saving these to a control PC (read function)
- Voice synthesis of Japanese character strings read from an RFID in real time (read-out function)

Early in this development, we restricted the data to be exchanged to Japanese character strings (text data), assuming that damage information would be written and read in natural language. Figure 3 illustrates an example of a screen for the simplified write function, and Fig.4 shows an example of a screen for the read function.

For the successful deployment of this system in society, RFIDs must be ubiquitous, or present everywhere in high concentrations. To this end, it is important to be able to use this system for commercial purposes (e.g., proving store information) in ordinary periods and then to switch to damage information collection in the event of a disaster. Voice synthesis of information from RFID would represent an expansion beyond the range of ordinary commercial applications; accordingly, a function in which Japanese character strings are read in real time via voice synthesis was incorporated in the first year.

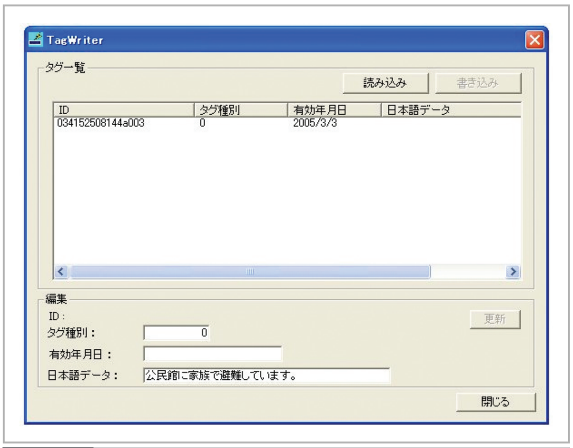

Fig.3 Screen Example for Simplified Write Function

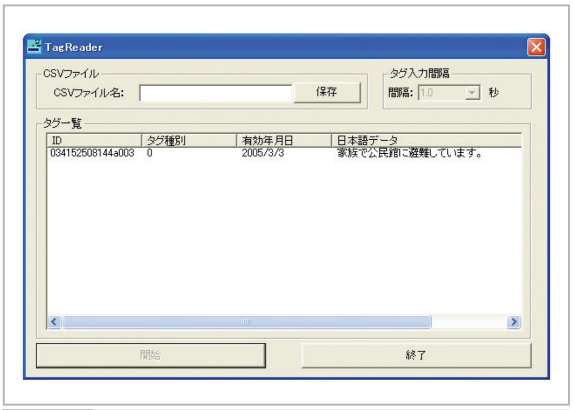

Fig.4 Screen Example for Read Function

The RFID ("Intellitag" from Intermec) memory consists of 128 bytes, and can be broken down as follows:

Thus, 100 bytes of Japanese character strings are writable to each tag (50 characters in two-byte character format).

2.4 Outline of developments in fiscal year 2002

In fiscal year 2002, the first year of the DDT Project, the following functions were developed, with an emphasis on the write function developed in the previous fiscal year:

- Automatic location of an empty tag among multiple RFIDs and writing of information to the tag (write function)
- Clearing a tag to an empty state by deleting read data from the RFID (retrieval

System ID	8 bytes (not rewritable)
Manufacture ID (manufacturer type information)	2 bytes (not rewritable)
Hardware tag type (tag type information)	2 bytes (not rewritable)
Software tag type (tag identifier 02 h, 53 h, 48 h)	3 bytes (not rewritable)
Software tag type (NICT global code 02 h, 00 h, *)	3 bytes (rewritable)
User area (User area breakdown)	110 bytes (rewritable) Tag type: 2 bytes Date of expiry: 8 bytes Japanese data: 100 bytes

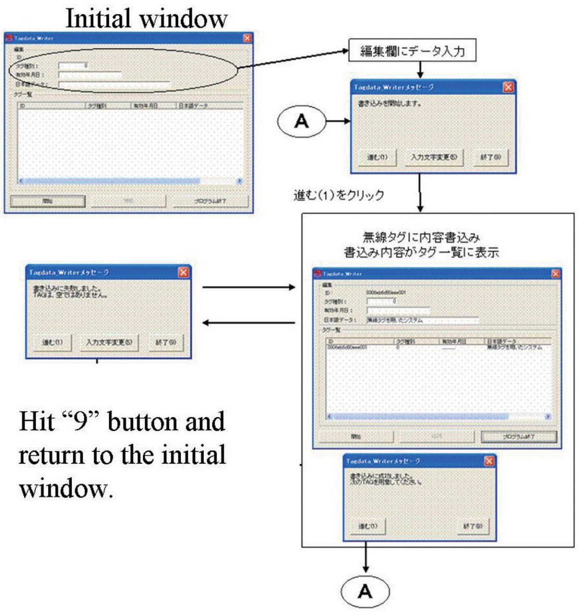

Fig.5 Screen State Transition Diagram of the Write Function

function)

The following describes the operational procedures for the writing and retrieval functions developed in fiscal year 2002, with reference to the screens of the control PC:

(1) Write function

This function consists of automatic selection, from within the antenna's field of view, of an empty tag (i.e., with no written information) followed by writing of information to the tag. Figure 5 presents a screen state transition diagram of the write function.

A specific example of processing is given below.

When the user enters “Test Writing”, a character string to be written in the Japanese Data field, from the keyboard and presses the Start button, the system enters the waiting state for numeric key input. Figure 6 illustrates the screen in this state. Here, the user uses a numeric key to select Proceed (to proceed with writing), Change Input Character String, or End.

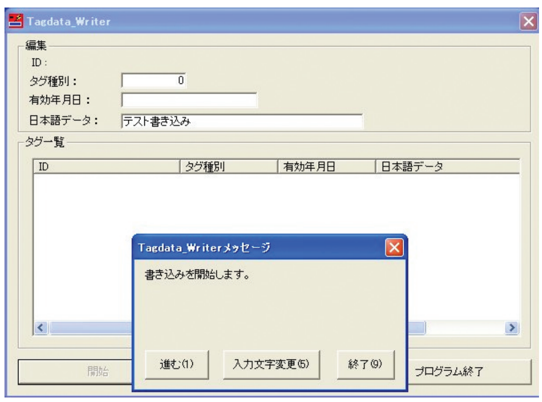

Fig.6 Write Function Screen (start of write operation)

When the user selects Proceed (to proceed

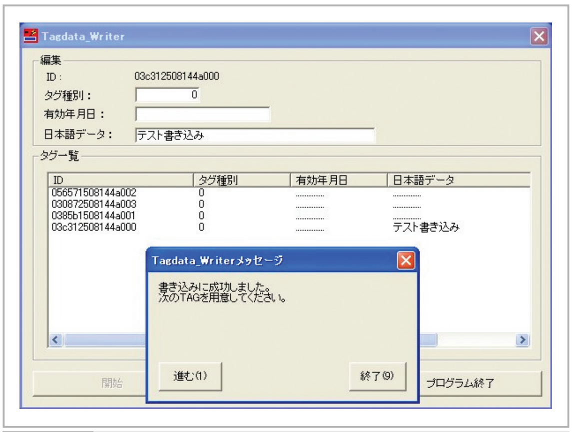

Fig.7 *Write Function Screen (After Writing to Tag)*

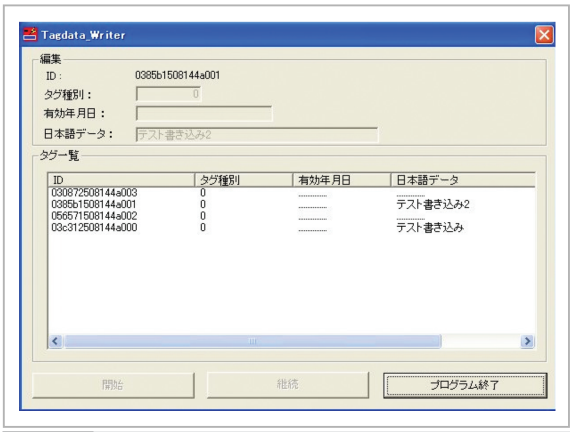

Fig.8 *Write Function Screen (after writing different character string to second tag)*

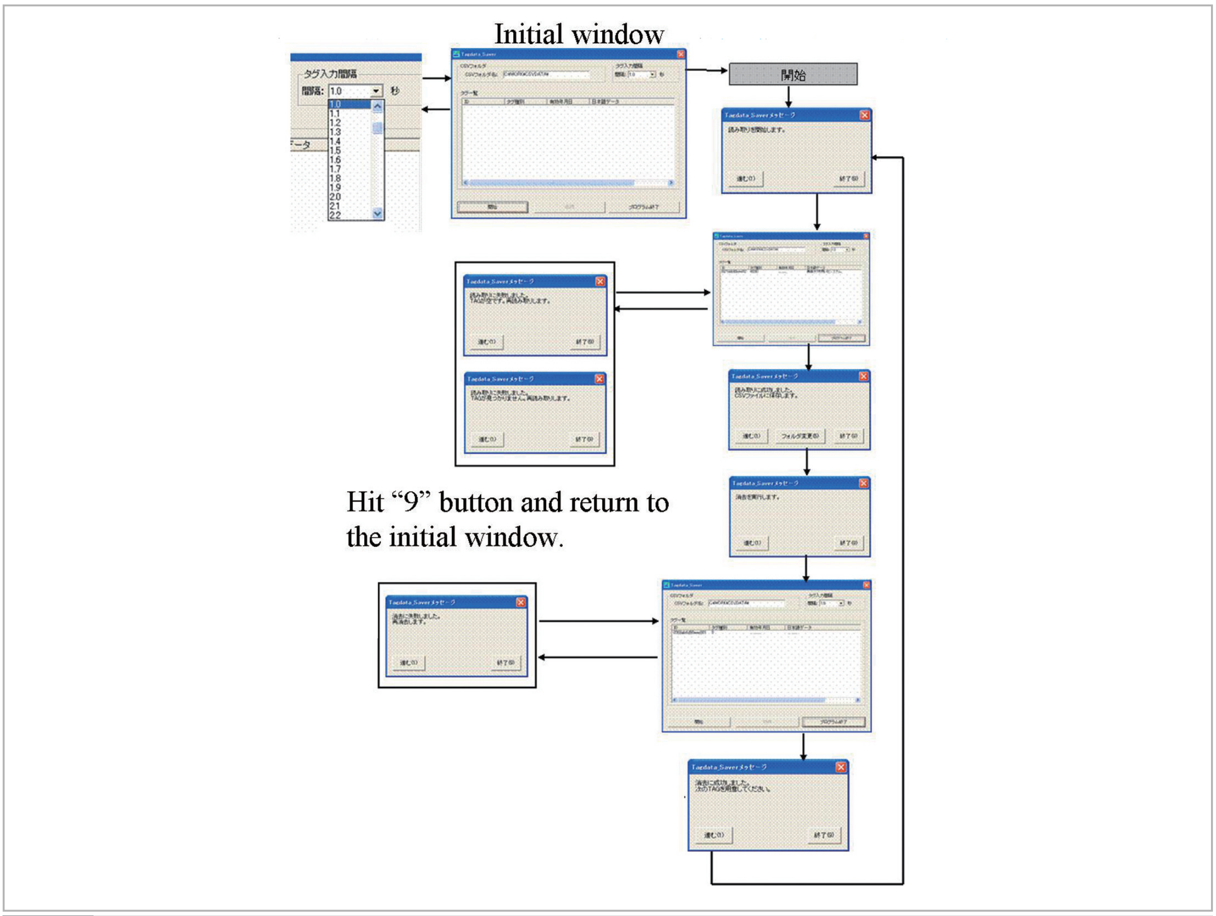

Fig.9 *Screen State Transition Diagram of the Retrieval Function*

with the write operation), the system reads tags within the antenna's field of view (Figure 7 shows that there were four tags in the field of view) and automatically selects one empty tag (i.e., a tag with a blank Japanese Data field) (Figure 7 shows that the tag with the ID "03c312508144a000" has been selected), writing the character string "Test Writing" to that tag. Figure 7 illustrates the screen after the character string is written.

Proceeding from the screen in Fig.7, the user returns to the screen in Fig.6. Here, if the user wishes to enter another character string, this is executed from the keyboard,

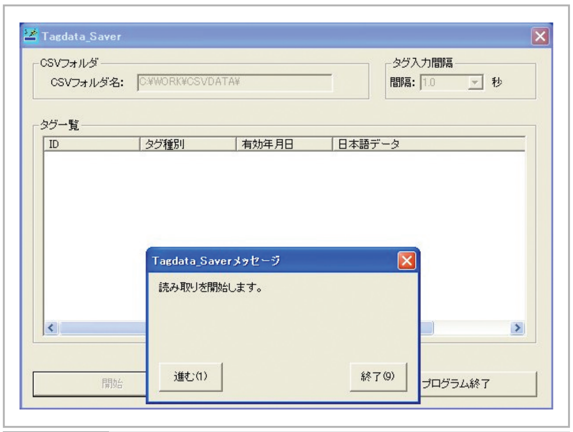

Fig. 10 Retrieval Function Screen (at the start of retrieval)

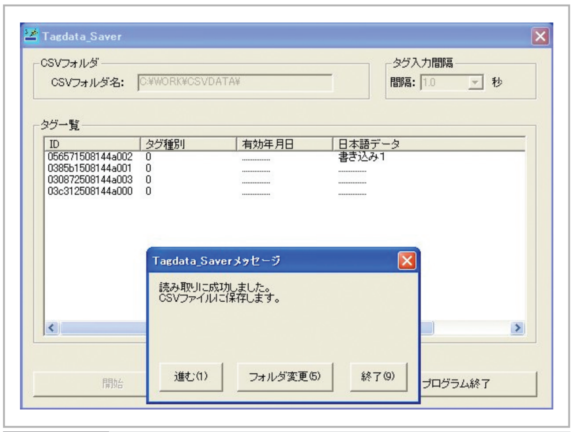

Fig. 11 Retrieval Function Screen (after reading tag)

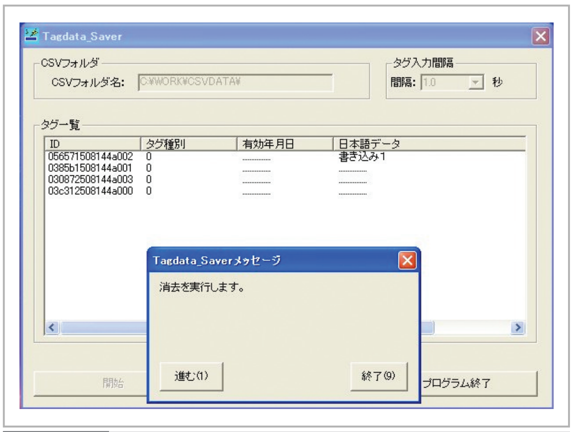

Fig. 12 Retrieval Function Screen (waiting for deletion processing)

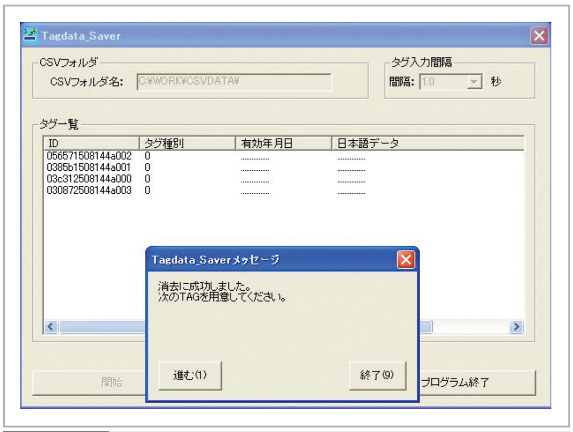

Fig. 13 Retrieval Function Screen (tag in empty state)

and the write process begins again. The system automatically selects one empty tag from among those in the antenna's field of view (Figure 8 shows that the tag with ID "0385b1508144a001" has been selected), and writes the character string "Test Writing 2" to that tag. Figure 8 shows the screen displayed after the character string is written.

(2) Retrieval function

This function consists of clearing a tag to an empty state by deleting previously read data from the tag; new data can then be written to the RFID. Figure 9 shows a screen state transition diagram of the retrieval function.

A specific processing example is given below.

When the user presses the on-screen Start button from the keyboard, the system enters the waiting state for numeric key input. Figure 10 shows the screen in this state. Here, the user selects Proceed (to retrieve data) or End, via numeric key.

Figure 11 shows the system as it waits for the read data to be saved to the control PC, after having read four tags within the antenna's field of view. The storage format is CSV (comma-separated values).

The user selects Proceed (to save), Change Folder to Save, or End.

When the read data is saved, the system enters the waiting state for a request to delete the data from the read tag. Figure 12 shows the screen in this state. The user selects Delete or Stop (end without deleting).

When the user selects Delete, the data that has been saved will be deleted from the tag with the ID "056571508144a002", emptying the tag. Figure 13 shows the tag in the empty state.

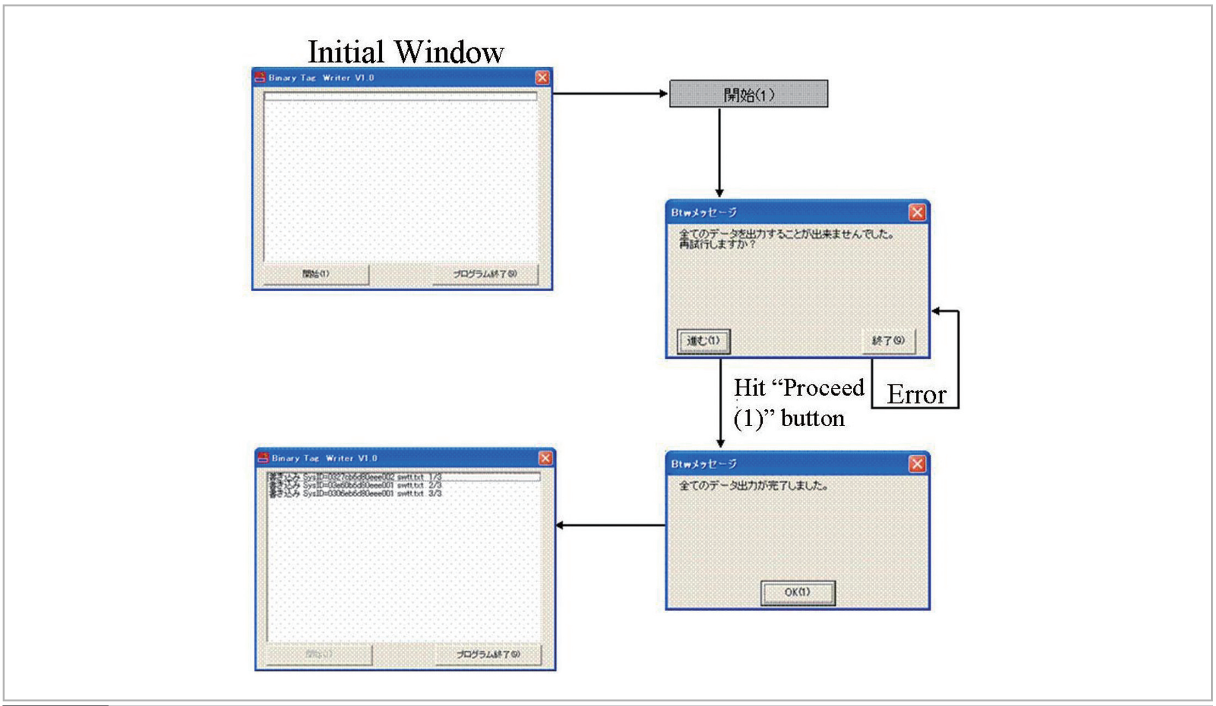

Fig. 14 *Screen State Transition Diagram of the Binary Data Division Write Functions*

2.5 Outline of developments in fiscal year 2003

The following four achievements were realized in fiscal year 2003:

- Announcement of operating conditions via voice synthesis
- Binary data division write and retrieval functions
- Control function via TCP/IP
- Wearable system
- Explanations are as follows:

(1) Announcement of operating conditions via voice synthesis

The developed system was geared toward eventual miniaturization to handheld size. The aim was therefore to enable the basic write and retrieval functions to be employed without viewing the screen and through operation of the buttons at hand. A function to announce screen status via voice synthesis was therefore added to those developed in fiscal year 2002. Since the function of reading out data via voice synthesis had already been developed in fiscal year 2001, the announcement function was realized through the incorporation of this read-out function.

(2) Binary data division write and retrieval functions

Functions have been developed to write binary data, available in advance in the control PC, to an empty RFID, together with a file name; binary data read from an RFID in the control PC can then be saved as a file. Here we should note that the data capacity of 100 bytes may be insufficient for binary data when this data becomes available. For this reason, a function has been developed to divide and write binary data automatically to multiple empty RFIDs within the system's field of view if target binary data size exceeds the capacity of a single RFID. Conversely, another developed function reads and merges partial data items stored in a divided manner in multiple RFIDs, thus restoring the data to the original file. These developments lessen the limitations of RFID capacity within the system. Figure 14 shows the screen state transition diagram of the binary data division write functions.

Figure 14 shows an example of dividing and writing binary data under the file name "swtt.txt" to three RFIDs. The user specifies the file name of the data to be written in advance in the initial setting file.

Next, a screen state transition diagram of

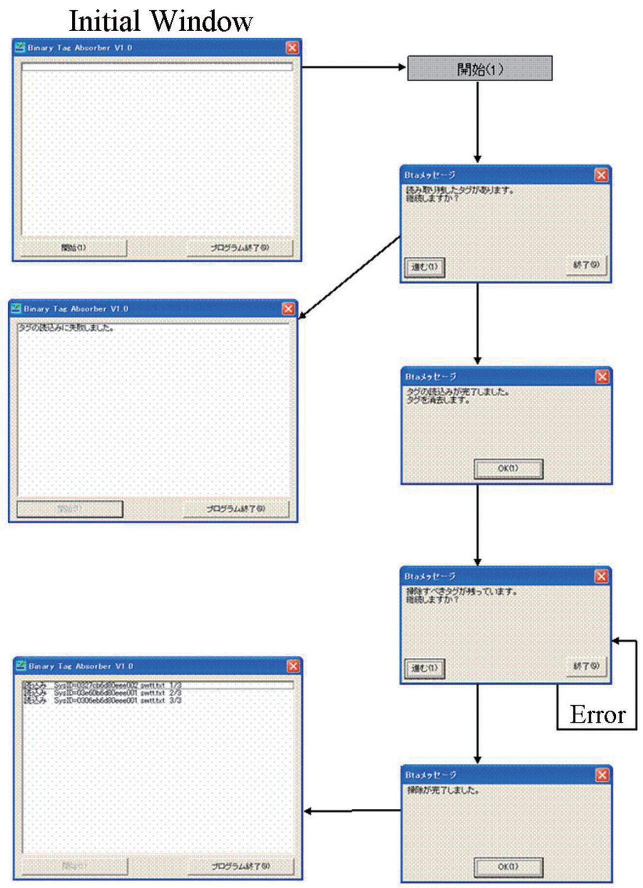

Fig. 15 *Screen State Transition Diagram of the Binary Data Retrieval and Merge Functions*

the binary data retrieval and merge functions is illustrated in Fig.15.

Figure 15 shows an example of reading binary data that has been divided and written to three RFIDs. This data is read one element at a time, with each data item deleted in sequence (in a process referred to as “clearing”) when all three pieces of data have been read. The three binary data items are merged to generate a binary file named “swtt.txt”; the data is then saved to the control PC. The user specifies the folder in which to save the generated binary file in advance in the initial setting file.

The tag memory for the binary data division write and retrieve functions described in the present section can be broken down as follows:

The present functions require that the file name of the original data before division, the division sequence, and additional data be written to each tag. The size of the binary data

System ID	8 bytes (not rewritable)
Manufacture ID (manufacturer type information)	2 bytes (not rewritable)
Hardware tag type (tag type information)	2 bytes (not rewritable)
Software tag type (tag identifier 02 h, 53 h, 48 h)	3 bytes (not rewritable)
Software tag type (NICT global code 02 h, 00 h, *)	3 bytes (rewritable)
User area (User area breakdown)	110 bytes (rewritable) File name: 8 bytes File name extension: 3 bytes Number of divided files: 1 byte Division sequence number: 1 byte Write size: 1 byte Binary data: 96 bytes

writable to a single tag is therefore 96 bytes, smaller than that of the Japanese character strings described in Section **2.3**.

The functions to handle binary data described in this section will be employed to develop applications designed to take advantage of RFIDs in various applications. Demonstrating the usefulness of RFID in a variety of applications in normal periods and at the time of a small-scale disaster (such as a normal fire), as well as in the event of a large-scale disaster, is expected to spur widespread use. For example, if binary data encrypted in advance—such as building position (precise GIS [Geographical Information System] coordinates), construction type, room arrangement, resident information (e.g., number of residents, contact information) and presence/absence of hazardous substances—is compressed and registered in an RFID attached to a building, then this information will be accessible from the RFID in the rescue team's command vehicle in the event of a normal fire, enabling rapid fire response and rescue. These application examples will be discussed further in Section **3**.

(3) Control function via TCP/IP

Interfaces controllable via TCP/IP have been provided in the writer/reader, allowing the device to be activated and operated from other applications within the control PC; this will also enable operation of the device from a remote PC via network.

(4) Wearable system

The conventional cart-mounted system has been redesigned to be wearable by someone on foot. The wearable system is shown at the center of Fig.2. With this system, the RFID writer/reader and the batteries are piggy-backed, with the control PC suspended from the shoulders like a drawing board.

On the other hand, as the use of RFID tags becomes more and more widespread, counter-measures against tampering (security issues) and unauthorized reading (privacy issues) will increase in importance. Accordingly, we also studied the possibility of access control through information encryption and using the unique IDs of RFID tags[3].

2.6 Outline of developments in fiscal year 2004

In fiscal year 2004, a specific application was developed to write binary data to RFID tags. In addition, the system was further reduced in size.

(1) Development of specific damage information collection application

A function has been developed to write and read assessment results to or from an RFID tag in coordination with an application that displays emergent risk assessments and accepts assessment results in binary data form. This function is intended to check previous building data against the current status for a rapid assessment of damage. Assessment results are electronically deposited on-site for use among other rescuers at the time of a large-scale disaster, thus avoiding duplicative investigation, streamlining relief subsidy and other formalities, and contributing to the timely establishment of a detailed disaster database. Figure 16 shows the entry application screen for the emergent risk-assessment results.

(2) Miniaturization of the system

Although wearable, the system up to fiscal

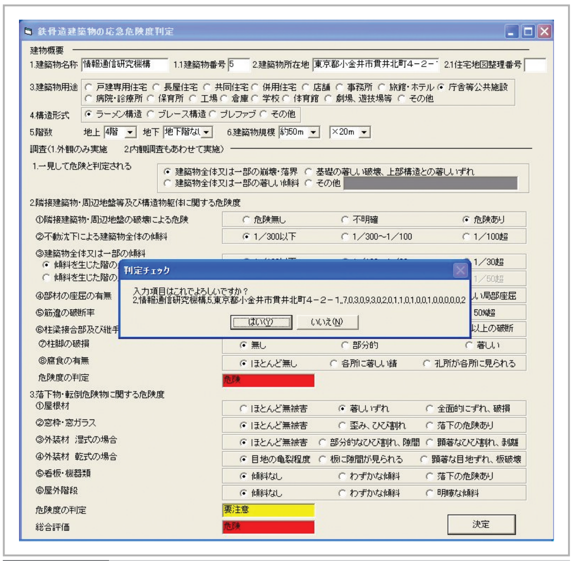

Fig.16 *Entry Application Screen for Emergent Risk-Assessment Results*

year 2003 was too large for mobile activities at a disaster site. We therefore developed a smaller writer/reader allowing use of the same RFID technology. The smaller device is illustrated at right in Fig.2. The main body of the writer/reader is of a size enabling insertion into the card slot of a notebook PC, with the antenna width reduced to roughly 1/4 of the original. Here we must note that the communication distance possible with the RFID shrank due to the weaker radio wave output of the writer/reader (relative to the device configuration used up to fiscal year 2003). An RFID system in the UHF band, soon to be available in Japan, is expected to provide communication over longer distances. The authors are thus contemplating eventually modifying the system to incorporate a low-output device in the UHF band.

2.7 Summary of RFID writer/reader for collection of damage information

As described in Section **2.2**, the authors' system is designed based on the concept that all necessary information must be written to and stored in an RFID. Therefore, we had to develop many unique functions unavailable in conventional RFID systems designed for logistics and similar applications. Once developed, these functions paved the way for deployment in the information sharing system and the damage information collection system described in the next section.

3 Information sharing system and damage information collection system using RFID [4]

3.1 Introduction

It is widely recognized that rescue efforts of fire departments, the police, the Self-Defense Forces, and others were not smoothly executed in the Great Hanshin-Awaji Earthquake. Among the causes for this unsatisfactory response were delays in the collection of damage reports and resultant improper assignment of personnel, an overall shortage of personnel, and delays in support activities of personnel outside the afflicted area (due to a lack of understanding of the geography of the disaster region). In contrast, examples were seen in which many people were rescued by the local community—neighbors, volunteers from disaster-prevention organizations, and volunteer firefighters—without the assistance of the fire department, the police, or the Self-Defense Forces, as witnessed in Hokutancho, Tsuna-gun, Hyogo. The efficiency of the search for survivors was enabled by information: these neighbors and volunteers knew how many people lived where, where the elderly were located, and so on. In urban areas, however, where community ties are weaker, few know their neighbors. To gain an accurate grasp of those in need of rescue under these circumstances, there must be some way to determine numbers of family members, the whereabouts of the elderly, and more. Even in local communities, there are limits to volunteer relief and rescue efforts in times of large-scale disaster.

Similarly, as we learned from the Great Hanshin-Awaji Earthquake, gathering on-site damage information is essential for public organizations such as fire departments, the police, and the Self-Defense Forces if they are to initiate strategic relief and rescue efforts and promote recovery through the appropriate deployment of personnel. At present, however, it is difficult to ensure sufficient numbers of personnel to cover an entire disaster area, leaving no alternative but to rely on estimates of earthquake ground motion and damage, as well as on information collected through the circulation of a small number of personnel.

As a possible solution, the present section discusses an information sharing system (involving individual building structures) theoretically in place before an incident and subsequently applied in large-scale disasters to recovery operations. We then discuss a damage information collection system based on the existing information sharing system. The systems described in the present section are to be developed based on the RFID writer/reader described in the previous section.

3.2 Information sharing system using RFID

3.2.1 Outline of the information sharing system

The information sharing system using RFID is designed to store information—on buildings, family identification, numbers of family members, and hazardous substance in the building—in normal periods. Each building would be equipped with such a system, enabling the sharing of information (both in normal periods and in times of disaster and recovery), ensuring efficient collection of information, and preventing on-site errors. The system will serve at normal times as a source of information for economic activities, such as those related to delivery, and as an information source for relief and rescue workers in the event of a disaster.

With client/server-based information sharing using conventional information communication networks, it is impossible to call up and acquire needed information if a large-scale disaster leads to breaks or congestion in the communication network. On the other hand, equipping the buildings themselves with RFID technology, a known reliable source of information, allows for the acquisition of information in the field and enables the establishment of a highly disaster-resistant system. Such a system, based on information gathered and managed in the field, will prove significantly useful in firefighting, disaster prevention, large-scale earthquakes, and other disasters that require an urgent response.

Moreover, in contrast to the client/server-based information sharing method, which raises the concern that an individual may not be able to control all of his or her information, including privacy information (in other words, the method is based on trust in the database administrator), an RFID system maintains information under the physical control of the individual, in effect assigning access control rights to the user. This is a considerable advantage in terms of privacy management. Enabling a choice between keeping information private (in normal periods) and disclosing it voluntarily (as in times of emergency or disaster) will provide ample reassurance to most users concerned with privacy.

3.2.2 Use of the Information Sharing System

Figure 17 illustrates a series of ways in which the RFID information sharing system can be used, from building construction to times of disaster and disaster recovery.

(1) Installation of “electronic nameplates”

An RFID is attached as an “electronic nameplate” to a new or existing building. This refers to an existing nameplate embedded with an RFID that stores a range of information, from building information to details on resident families. Examples of data that may be stored in an electronic nameplate are shown in Table 1. This data can be put to common use, both in normal periods and in times of disaster, as described later. Residents of the building can make any necessary changes to the stored information as the need arises. On the other hand, if the residents do not wish to disclose this information, they can forego installation of the electronic nameplate or restrict the information stored. On the other hand, measures will be taken to limit the number of the people having access to the information.

(2) Normal periods

In normal periods, the positional information stored in the electronic nameplate is used for mail deliveries and courier services. On the other hand, RFID can also be used as a guidepost for the visually disabled, thanks to its ability to convey information in a noncontact manner. Moreover, reading the owner’s name, address, device numbers, and other data stored in the electronic nameplate will ensure efficiency in utility meter readings, such as those for gas and electricity. Further, if electronic nameplates and equipment such as gas and electricity meters can function in a coordinated fashion, it will be possible to perform meter-reading process simply by accessing the RFID.

(3) In the event of fire

In the event of a fire in the building in nor-

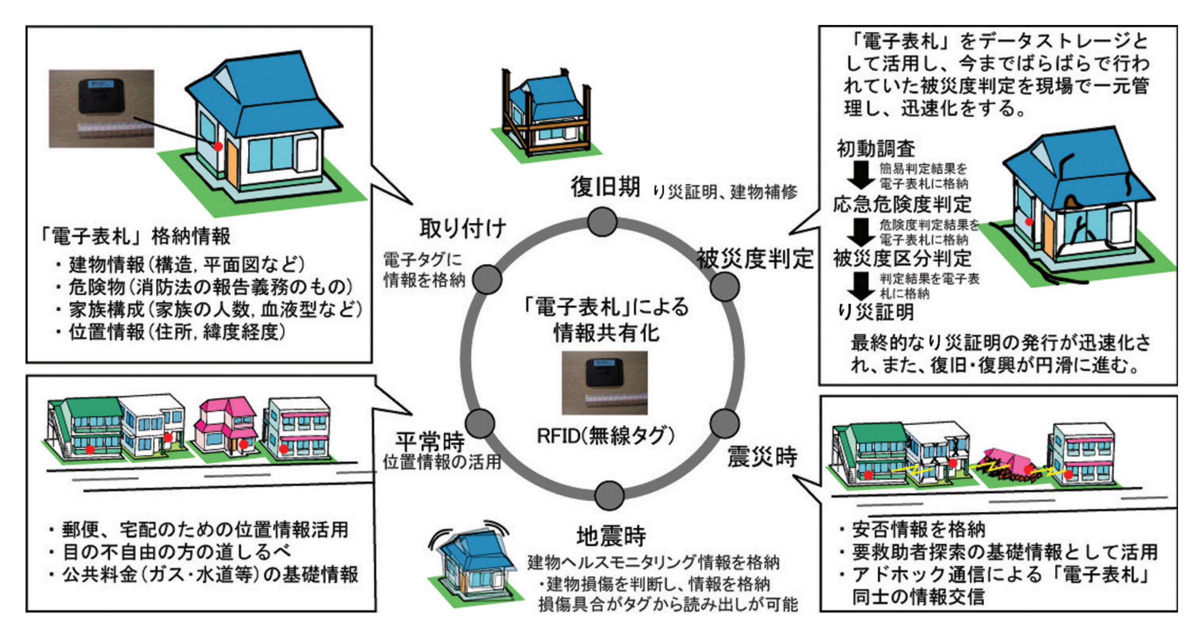

Fig.17 *Uses of the Information Sharing System, from Building Construction to Times of Disaster and Disaster Recovery*

Table 1 *Examples of Information Stored in Electronic Nameplates*

Item	Information Stored
Building position information	Address, latitude and longitude, etc.
Building information	Building floor plan, construction type, etc.
Hazardous substance information	Hazardous substances subject to mandatory registration under the Fire Services Law
Life-saving information	Family members, blood types, presence/absence of the physically disabled, information about elderly residents under care, etc.

mal periods, the information read from the electronic nameplate by a firefighter—such as the building's floor plan, resident family details, and information of hazardous substances—can improve life-saving in firefighting efforts and strategy. Meanwhile, if a resident is alone and injured, stored information on blood type, allergies, and other medical details will prove extremely useful during transportation of this person to hospital.

(4) In the event of an earthquake

In the event of an earthquake, a number of people may be trapped under collapsed buildings and in need of rescue. Yet most urban dwellers don't know their neighbors, and the resultant lack of information can unnecessarily impede rescue efforts. Searches can be accelerated, however, using the information from electronic nameplates. This feature will prove essential in the effective absence of a local community, listing residents who may be trapped within collapsed buildings. Further, if successful evacuees are registered as such on the electronic nameplate, those in need of rescue will be more readily identified, further reducing search times.

An alternative application would involve coordinated operation with a health monitoring system adapted to perform continuous assessment of the building at the time of an earthquake, determining damage to the building simply by reading the electronic nameplate and increasing efficiency in the survey of overall damage.

(5) Building damage assessment

Following an earthquake, various parties perform damage assessments to aid in recovery and reconstruction, including surveys to determine the distribution of government aid. Using electronic nameplates for such surveys would streamline the flow of needed information. Included among these earthquake-related surveys are emergent risk assessments for damaged buildings, particularly important in preventing life-threatening secondary disasters[5]; damage assessments for scientific purposes (i.e., assessment of whether a building is partially or fully collapsed); damage classification for the assessment of required repairs and reinforcements and the continued use of the building[6]; and victim's certificate (classification of victims) for purposes of awarding assistance. While these surveys and assessments share many common items, at present this data is not structured to flow smoothly among the various parties. Survey details stored in electronic nameplates, however, can be used by the next survey team. This ensures reduced assessment times, speeding recovery and reconstruction. Further, with surveyors sharing a variety of survey results, differences in focus and oversights will be eliminated, both offering surveyors more material for judgment and providing for greater accuracy in assessments.

(6) Recovery and reconstruction

During recovery and reconstruction, information relating to repair work can be added to a building's electronic nameplate, which would prove useful in future remodeling or a future disaster.

Given the foregoing considerations, it is clear that information sharing using electronic nameplates can form the basis for a system that will maximize efficiency in the field.

3.3 Damage information collection system using RFID

3.3.1 Outline of the damage information collection system

The damage information collection system is designed to collect damage information efficiently in the disaster-stricken area during and after an earthquake based on the information sharing system described above, in combination with IT-based digital information terminals and RFID writers/readers. Further, the system can be used to convey damage information to disaster response headquarters and elsewhere over existing communication networks and can help in the assessment of building damage for the phases of recovery and reconstruction. Moreover, the system can be used not only to help in the collection of damage information but can also be applied to information collection in normal periods.

Additional functions are possible: display of geographical information on a 3D screen to assist in surveys, fire simulations for firefighter reference, display of local geographical information and water resources (particularly the availability of water for firefighting), and simulation/analysis of ground motion and possible damage, for use in prediction or in the event of an actual earthquake or other disaster.

It should be noted that although the present damage information collection system may be built independently of RFID writers/readers, the system will provide a much wider range of functions when operated in coordination with these devices.

3.3.2 System configuration

The damage information collection system is comprised of a GPS (Global Positioning System), a notebook PC to operate the system, an RFID writer/reader, and a field damage information collection system[7][8] incorporating a simplified GIS developed by the authors. In addition to the above configuration, the system allows hands-free surveying when combined with a head-mounted display (HMD). The system configuration is illustrated in Fig.18.

3.3.3 Methods of use of RFID systems

(1) Identifying building position and collecting damage information using "electronic nameplates"

A number of systems have been researched and developed to support the collection of damage information in the field [9][10], with nearly all systems using a GIS, as this system enables entry of damage information while viewing a map. However, even with a map entry of building position information entry can be slow if the user is not aware of the local geography. On the other hand, even GPS positional information is accurate only to several tens of meters, making it difficult to identify a target building among a series of adjacent buildings. To save time and effort in entering positional information, therefore, information is drawn from the electronic nameplates within the information sharing system. Matching surveyed building information on latitude and longitude, owner's name, address, and so on to

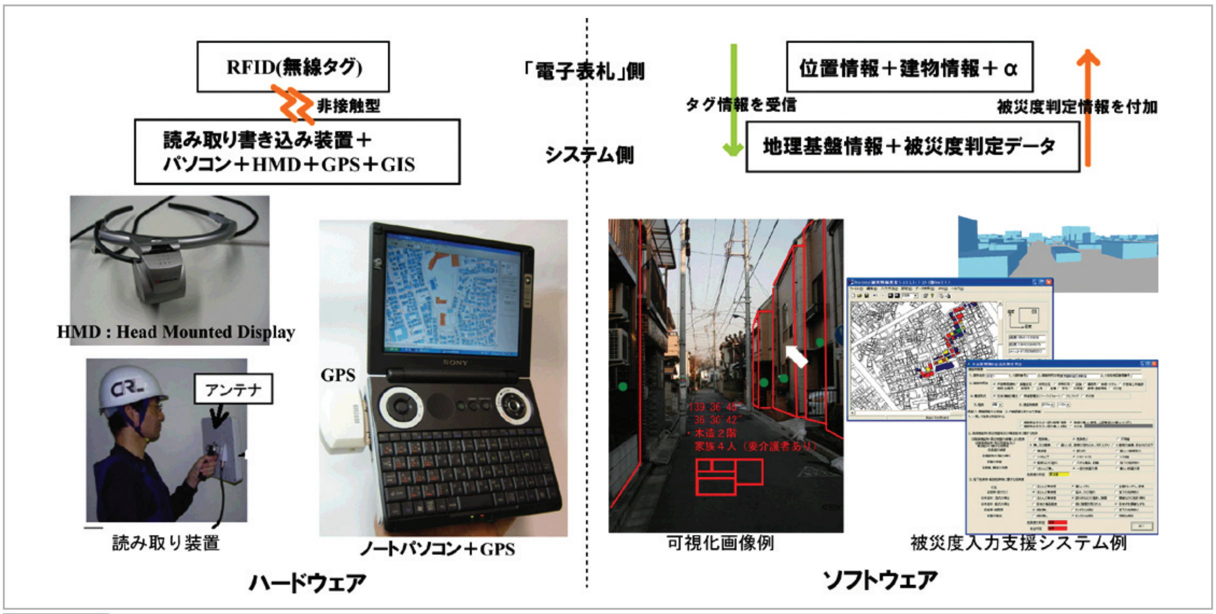

Fig. 18 *Configuration and Software of the Damage Information Collection System*

a target building provides failsafe identification, improving the efficiency of collection of damage information. In addition to positional information, other building details stored in the electronic nameplate will likely prove useful in the gathering of information at the time of a disaster.

(2) Using the RFID as a temporary storage device in the event of a disaster

RFID devices can be used to collect damage information even outside of the information sharing system. Specifically, the system can be applied to a successive flow of damage information tasks. The assessment of building damage is a process that is already in place, and is used after earthquakes. The flow proceeds from initial survey to emergent risk assessment to damage classification to victim's certificate (victim classification), with many items of shared information among the steps. Under these circumstances, providing an RFID device for storage of damage assessment results in the field will allow common information to be written or read, drastically reducing mistakes, eliminating duplication, and ensuring greater accuracy and efficiency in surveys.

(3) Information collection using "electronic nameplates" in normal periods

Above we discussed the uses of electronic nameplates to determine positional information and to collect disaster data at the time of an earthquake. In addition to these applications, electronic nameplates can find numerous applications in normal periods. For example, municipalities are required to conduct urban planning or urban infrastructure development surveys, to update maps, or widen roads, for example, or to perform field surveys for building or rebuilding permits. Furthermore, fire departments must carry out surveys in response to changes in available water resources, in addition to field surveys for disaster prevention. These surveys can be streamlined using the damage information collection system and electronic nameplate information.

3.4 Strategies for widespread use

The information sharing and damage information collection systems discussed above will become functional as the use of electronic nameplates becomes more pervasive. As things stand, however, instant widespread use would be difficult to implement. In this section we will examine methods of RFID use prior to widespread adoption of electronic nameplates, in addition to strategies to encourage such widespread use.

3.4.1 RFID utilization method prior to widespread adoption of electronic nameplate

RFIDs do not necessarily need to be available everywhere in a city in normal periods; empty RFIDs may at these times be kept in locations such as public meeting halls or elsewhere around the city for use as temporary storage devices in the event of a large-scale disaster. These temporary RFIDs could then be activated to facilitate information sharing following a disaster.

3.4.2 Strategy for widespread use

In order for electronic nameplates to become pervasive, they must be highly beneficial both for the ordinary households in which they will be installed and for the entities and public organizations that will use them. Several advantages were cited above; however, despite these advantages, widespread use will not be easy to implement. The road to widespread implementation will thus lie in the specific advantages of a system in which they are employed.

Electronic nameplates can store information such as building position and resident family details, and this information can be entered by residents on their own. In contrast, the ability to input building information (such as the floor plan and construction details) is generally limited to those with architectural expertise. This limitation can be overcome by allowing non-specialists to take advantage of building-related systems to acquire building information, thus eliminating one hurdle in the wide adoption of electronic nameplates. In the case of a newly built house, for example, building information can be obtained through the Government Housing Loan Corporation[11], which provides financing for home construction, or from a seismic performance evaluation system such as the House Performance Indication System[12]. In the case of an existing house, on the other hand, building information can be acquired through details of building permits for additions or remodeling. If these existing systems were to reward the installation of electronic nameplates through tax reductions or otherwise, then installation would become beneficial for both residents and public organizations, thus leading to more widespread implementation.

3.5 Security issues in the information sharing system

While the information sharing system offers the convenience of acquiring and rewriting RFID information in conjunction with a portable terminal, the risk of abuse or information tampering cannot be ignored. Accordingly in this section we will address various RFID security measures.

The first possible measure would involve incorporating a locking feature on the RFID side. The RFID circuitry can be configured to remain silent; i.e., it can be programmed to ignore calls from the interrogator. Therefore, one possible scheme would consist of two coexisting storage areas in the RFID; one that responds to arbitrary calls and the other that does not (unless the lock feature is canceled), thus allowing only publicly disclosed information such as positional information and owner name to be read in normal times. Conversely, all information can be read once the lock feature is canceled in the event of a fire or earthquake. The challenge in this case lies in automating the trigger that will cancel the lock.

In terms of software, encryption of information within the RFID system is essential. Requiring user authentication before reading the RFID will ensure that only those authorized may operate the writer/reader. Alternatively, if the writer/reader is managed with great care, then authentication may be possible on a device-by-device basis, rather than on a user-by-user basis. In this case, the writers/readers would be ranked according to the security level of readable data. For example, writers/readers capable of handling the most sensitive information would be limited to public safety organizations such as fire departments.

One possible countermeasure against unauthorized writing to the RFIDs would consist of locking the active field at the moment the data written to that field is processed and written to the RFID.

It should be noted that in light of concerns over destructive attacks on RFID hardware, possible countermeasures include some very basic ones, such as installation of the RFID in a location that is not easily accessible. Such countermeasures are particularly practical in light of the RFID's noncontact design.

RFID security countermeasures are considered to represent the most important of all challenges facing widespread implementation of electronic nameplates; accordingly, the authors are currently studying the necessary security requirements and countermeasures [3].

3.6 Other applications

In addition to the applications discussed in the present section, RFID may be utilized in a variety of additional ways in the event of a large-scale disaster, as follows:

(1) Individual identification of victims

When used as an ID card for individual identification, RFID can be used, for example, in entry/exit control in shelters, delivery of rescue goods and determination of required amounts, and resident access control in off-limit areas (as part of burglary-prevention efforts). These applications are immediately feasible with the use of a commercial IC card reader, without requiring the installation of the RFID writer/reader developed by the authors.

(2) Information supply from utility poles

RFIDs may be attached to utility poles rather than to buildings, holding information such as shelter location information (location and map data), utility pole control, and positional information. In cases in which utility lines are underground, the RFID may be attached to a tree instead.

At normal times, the installer of utility poles (e.g., the power company) can use the RFID for utility pole regulation. Alternatively, when calling an ambulance or fire engine, location information can be read from the RFID on the nearest utility pole for transmission via email or telephone. Further, RFID technology can be used as a guidepost for the visually disabled. Lighter uses can be imagined: an RFID attached to a tree, for example, could hold information on the tree itself, for use in school field trips or the like.

In times of disaster, evacuees can search for shelters by acquiring information from utility poles. On the other hand, if utility poles fail or collapse, information related thereto can itself be useful for the power company.

In these uses, the information source must be installed outdoors, highlighting the advantage of RFIDs over two-dimensional barcodes, which are liable to become dirty.

4 Conclusions

This paper discussed progress in the development of RFID writers/readers for use in the collection of damage information, as well as the deployment of this technology in information sharing and damage information collection systems. Going forward, we will need to conduct verification testing at a test site, pursue greater convenience in design, and study ways to achieve widespread use of electronic nameplates while pushing ahead with system development. We anticipate the incorporation of the RFID writer/reader into mobile phone terminals in the future. Commercialization of mobile phone terminals with an RFID read capability has already begun, and realization of write capabilities and improvement of the communication distance of the passive devices are among the technical challenges we must face if we are to ensure broad application in the collection of damage information.

On the other hand, in order that information collection is as advanced as possible in disaster-stricken areas (the basic goal of the DDT Project), we are faced with the challenge of coordinating the "Rescue Communicator" (a sensor network server subject to joint development with the DDT Project) with the RFID write/read device. With an interface developed in fiscal year 2003 to control the RFID write/read device via TCP/IP, basic functional coordination along these lines is now feasible.

We intend to incorporate the RFID writer/reader into the Rescue Communicator itself and to mount the equipment on a self-regulating rescue robot that can automatically search for RFIDs in a disaster-stricken area, collect information, and transmit that information to disaster response headquarters (via an ad-hoc network, for example). The Rescue Communicator will be discussed in another paper[13] in this special issue.

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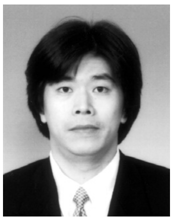

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