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RF Tag with RF and Baseband Communication Interfaces for Product Lifecycle Management

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Abstract

Networked RFID system have been recognized as a powerful industrial tool to enhance the visibility in supply chains by applying RF tags to packages and cases. As the adoption of the technology has been expanded, there has been a strong industrial demand to apply RF tags to product itself for the information management for the entire product life cycle, i.e. the item level tagging. The demand is particularly strong in the consumer electronics arena where manufactures are responsible, at least in part, for the supply chain, the product liability and the product safety. The conventional item level tagging, the data stored in an RF tag memory is only accessed by interrogators. In this paper, we propose the concept of recorder tag, which has both an RF interface to the interrogator and a baseband interface to the microcontroller of a product. This way, we can develop an application for consumers utilizing supply chain related information. We can also develop an application for the product safety and efficient repair by recording essential operational incidents during the product usage into a recorder tag. The key objective of the recorder tag is to bridge the end user and the manufacturers. After introducing the background and the concept of recorder tag, this paper examines the requirements to recorder tag particularly in the consumer electronics industry. A prototype recorder tag using COTS (commercial off-the-shelf) components is manufactured and its fundamental performances are evaluated. This paper also identifies the future issues for the deployment of recorder tag.

1 Introduction

The RFID technology has been gathering a significant industrial interest to enhance the visibility in supply chains [1]. This is particularly true when RFID technology is combined with Internet technology, which is usually referred to as networked RFID. The rapid development of international standards in wireless communication [2], data structure [3] application interface [4],[5], information services [6] and performance evaluation[7], [8] have been boosting development of tags, interrogators and information systems. While the main stream of RFID applications are still the supply chain management in the form of package level tagging, there is a strong industrial interests toward item level tagging. Consumer electronics industry has been supporting and promoting item level tagging for the life cycle information management because of the strong social demands for the product liability and the product safety[9]. The industry requires user specific data in RFID tag, as well as a unique ID, because the network availability is not always guaranteed when they handle the RFID tag data[1]. Those user-specific data stored in an RFID tag, so far, are presumed to be only read and written by interrogators.

This paper proposes the concept of recorder tag, which has a baseband (wired) communication as well as the radio frequency (RF) communication link to interrogators. This way, the essential operational incidents, collected by sensors in applying things, can be written into the tag through the baseband link without an interrogator for later reference in repairs and reuses. Alternatively, the product information and supply chain related information written in an RFID tag by an interrogator can be retrieved by the hosting consumer electronics through the baseband communication link. Those information in an RFID tag, written by an interrogators, can be used in user applications through the baseband link to verify the date of sales, date of repair or an inventory history and a warranty expiration.

Dual interface RFID tag is not necessarily a new idea. A dual interface smart card has been in the market [10] to provide both contact and contactless interfaces to two types of interrogators. MM chip[11] is a multiband RFID chip intended to be used in any frequency band (from 13.56MHz - 2.45GHz). A battery assisted passive tag may house a number of interface [12]. At the best of the authors knowledge, however, there has been no attempt to use a dual interface RFID to be read or written by a device other than an interrogator. The application of a recorder tag as a life cycle information recorder also has a novelty.

In Section II, the background of the concept is explained. In Section III, the concept of recorder tag, requirements, a prototype of recorder tag are introduced. In Section IV, a

performance evaluation and applications using the prototype recorder tag are introduced. Section V summarizes the future issues identified through the prototype development and evaluation.

2 Background

2.1 Issues for product safety of consumer electronics

The user-specific data in an RFID tag can be categorized as the product information and the information collected in the supply chain. Examples of product information are the manufacturing number, manufacturing date and the recycle information. Typical supply chain related information are sales records, sales certificate and repair records. The relatively high

[1] If we have Internet connection every time we read and write data in RFID tags, RFID tags only needs to house a unique ID and all the rest of the data are stored in data base in the network.

price of RFID tag for item level tagging stemming from the user memory and associated enhancement, such as security, could be justified when we use the tag for multiple purposes such as the manufacturing control, supply chain management, repair, reuse, recycle and the product safety.

One of the biggest issues for product safety for the manufacturers is the lack of the end user information, i.e. where and how the product is used. Most of the consumer products are sold in retail stores to which manufactures whole sale their product. The only direct link for the manufactures to grasp the end user information is the voluntary customer registration from the end user. The end user information is crucial for repairing and a product recall and possible product improvement. A research of a Japanese ministry reveals that over 70% of manufactures grasp less than 25% of product end users or no data available [13] (Figure 1).

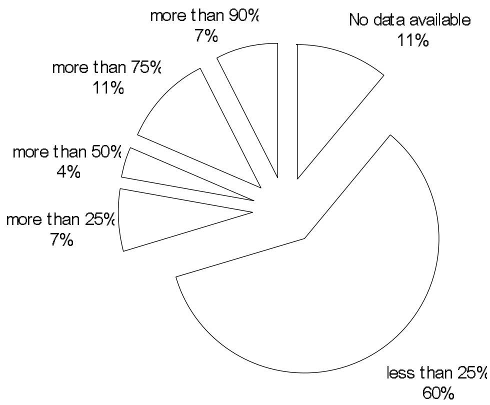

Figure 1How consumer electronics manufactures grasp their end customers. Showing over 70 percent manufactures grasp less than 25 percent of product users

It is, therefore, attractive for the manufacturers if we can establish a link between the individual customer and the individual product at the point of sales. This can be done by an item level tagging where a RFID tag is attached to a product and the product unique ID is read without unpacking. This way, the product ID, the place and time of sales and possibly with the customer information can be collected for the sake of product safety. Japan government has been pursuing research on this operation with major consumer electronics companies and large retailers to collect product location at the point of sales as a preparation for the product recalls [14]

On the other hand, another statistics reveals that almost half of the consumer product accidents are caused by improper or mistaken usage of the end users as shown in Figure 2 [15]. It is, thus, important for the product safety to automatically detect an improper usage and notify users before a fatal accident takes place. It is also worthwhile to record such fatal incidents for the repair and for the valuation of the product in reuse and recycle.

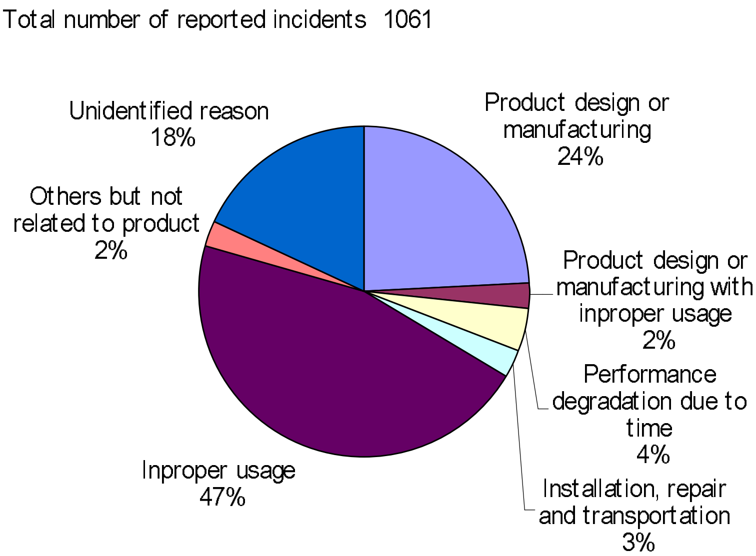

Figure 2Cause of the consumer appliance failure. Almost half of the consumer product accidents are caused by improper use

Those statistics shows the importance of the bilateral flow of information from supply chain to end user and the end user to manufacturers. RFID technology has been regarded as an information sharing technology through whole supply chain peers. When it comes to product safety, however, a mechanism to involve end users in the information sharing should be important.

2.2 Baseband communication to an RFID tag

There are typically three operational modes of RFID tag when it is applied to a consumer electronics. They are the interrogator-off-line mode, the interrogator-on-line mode and the power-on-line mode as shown in Fig.3. The interrogator-off-line mode is when a read/write operation is done by an interrogator without a network connection. Onsite maintenance is the typical example of off-line mode. The interrogator-on-line is the typical operation in the factories, distribution centers and the retailers. The power-on-line mode is the mode where there is usually no read/write operation by an interrogator. Yet, most of the life time of a consumer electronics is spent in this mode and the almost half of the product accidents take place in this period as stated in the previous section. It is, therefore, reasonable to power-on-line establish a communication link between the microcontroller of a consumer electronics and the RFID tag to store essential operational data, such as improper usage and accidental failure, in the tag for future repair and maintenance. Alternatively, an end user can retrieve supply chain related data from the RFID tag for the verification of the product.

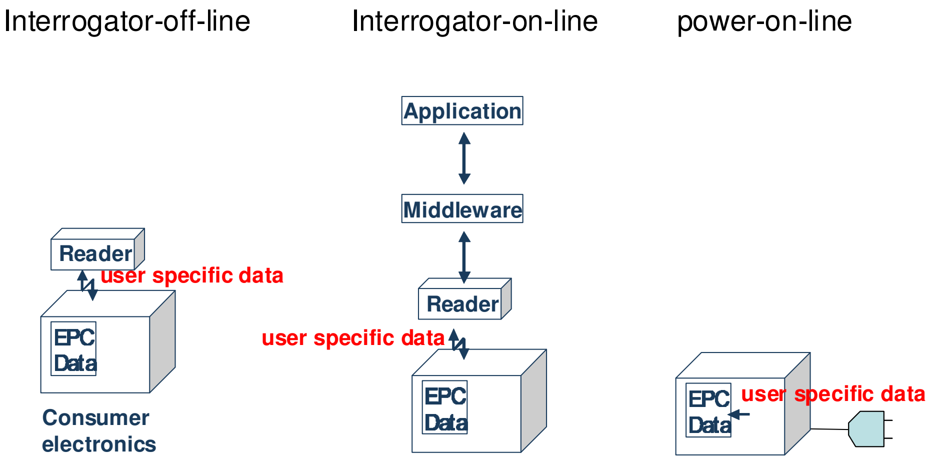

Figure 3 Three operational modes of RFID tag attached to a consumer electronics

3 Requirements to recorder tag

3.1 Recorder tag

It is well known that most of consumer electronics houses a number of microcontrollers. For example, a refrigerator involves microcontrollers for power inverter control, liquid crystal display (LCD) control, serial communication control all connected to a system microcontroller. The recorder tag is a passive RFID tag which has two interfaces. One is the conventional radio frequency (RF) interface to interrogators and the other is a wired baseband interface to the system microcontroller in consumer electronics. In the baseband connection, the electronic power can also be provided to the passive tag chip through the baseband interface by the consumer electronics (Fig.4).

The recorder tag comprises of an embedded antenna, a passive tag chip and a controller. An efficient way to implement the baseband communication is to choose a chip which can accommodate an external baseband communication. The simplest realization of the external baseband communication is to use the same communication protocol in the radio frequency.

This way, the baseband processing unit of a recorder tag does not need to differentiate if the chip is operated through an RF communication or a baseband communication.

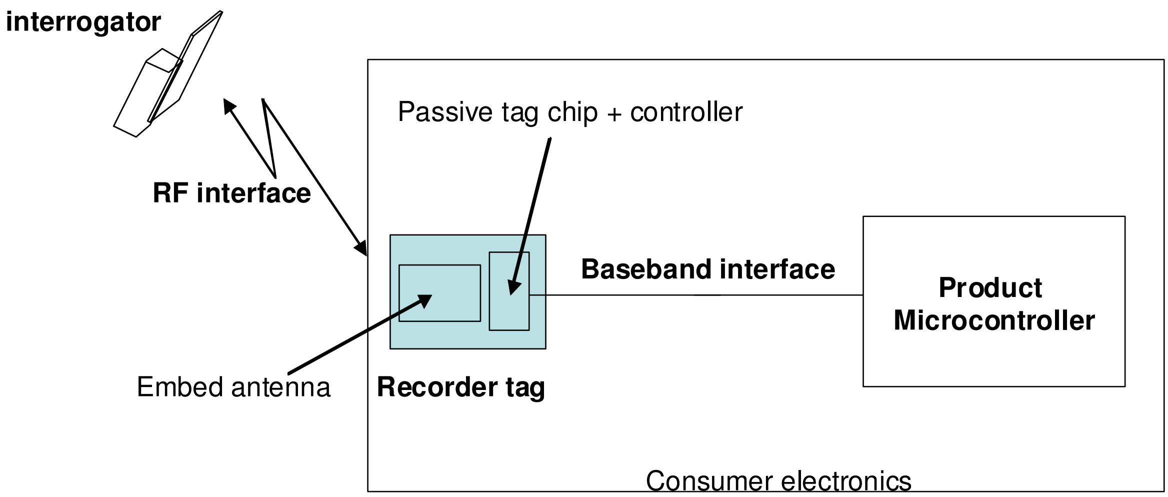

Figure 4 RF and baseband interface of recorder tag

Since most of RFID protocol employs linear modulation[2], the baseband signal can be exactly the same to envelop of RF signal. Since the baseband signal does not travel in the form of a radio wave, we don't have to consider the spurious and out-band-emission so that we do not need a pulse shaping in the baseband communications.

The controller between the passive tag chip and the product microcontroller should be used because RFID protocols usually entail timing requirements and an anti-collision procedure. In case of EPCglobal Gen2 protocol, the reader writer needs to issue an Query and Ack command to identify the EPC in tags in an specific timings. Otherwise, a standard conformal RFID tag may not be responding. The controller takes care of all the timing requirement and protocol issues. Employing a controller, additionally, is advantageous for the selection of RFID protocol depending upon the requirements of consumer electronics usage.

3.2 Requirements on recorder tag

A recorder tag needs to comply with the following requirements.

- Passive operation: Since a recorder tag is applied to consumer electronics during its life cycle, it is impractical if we need a battery or a power source for the operation.
- Non-line-of-sight (NLOS) operation: Since a recorder tag is applied to a consumer electronics itself, which is usually in a cardboard package when it is in supply chain, a

[2] RF signal is a multiplex of the baseband signal and the carrier frequency.

reading and writing operation to the recorder tag needs to be done through the package and thus in NLOS environment.

- Stable reading and writing: Even though the reading and writing distance may change depending on the materials and packages of the applied object, we need to secure stable reading and writing.
- Baseband communications: The reading and writing operation to the recorder tag memory can be done either through the RF interface or the baseband communication.
- Data security: Since a recorder tag stores an essential operational data, tampering of the data needs to be avoided.
- Data compaction and tag data schema: Most of passive tags have a limited memory area, an efficient and standardized tag memory usage needs to be employed.
- Small in size: A small antenna is preferred as a recorder tag.

4 Prototype development

A prototype recorder tag has been developed using COTS (Commercial off-the-shelf) discrete components except an antenna. According to the requirements explained in the previous section, UHF passive RFID and ISO/IEC 18000-6 Type C protocol [16] is chosen for the prototype development. A conformal tag chip Quanray 2230 is used in a SSOP (Shrink small-outline package). UHF protocol is used mainly to secure NLOS reading and writing to the RFID tags. Figure 5 shows the prototype.

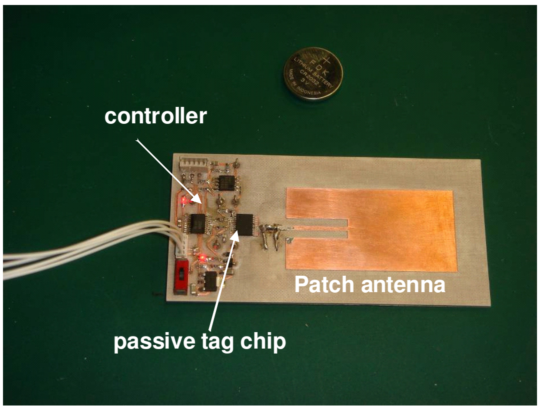

Figure 5 A prototype recorder tag

The realizations in the prototype against the said requirements are summarized in Table 1.

Table 1 Accommodation to the requirements

· Requirements	· Realization
· Passive communication	· ISO/IEC 18000-6 Type C conformal
· NLOS communication	· Relatively high power is available
· Stable reading	· Patch antenna
· Baseband communication	· A controller in recorder tag
· Data Security	· Data lock is available
· Data Compaction	· A data schema is developed
· Small antenna	· High dielectric substrate

A patch antenna using high-dielectric substrate is developed for the reading stability against various materials of target product. The reading distance of the patch antenna with a tag chip is measured by using a 21dBm EIRP reader/writer (carrier power 15dBm and antenna gain 6dBi). We calibrated the result with 10dBm EIRP, with which we can operate without radio station license in Japan. This is shown in Table II. The performance is satisfactory for the item level tagging application. Reasonable reading distances are achieved with relatively low EIRP. The lower power transmission is important because we need to coordinate the reader/writer transmission to avoid harmful interference caused by neighbor reader/writers particularly in a large factory or a large retailer. Also high power (such as 4W EIRP) may be hazardous to human body when the body is under continuous exposure to the radio wave.

Table 2 Reading performance of prototype

· Target object	· 21dBm EIRP	· 10dBm EIRP (calibrated)
· Air	· 90cm	· 25cm
· PC	· 68cm	· 19cm
· Plastic case	· 68cm	· 19cm
· Metallic surface	· 60cm	· 17cm

The target consumer electronics product is a personal computer for the convenience of application development for now (Figure 6).

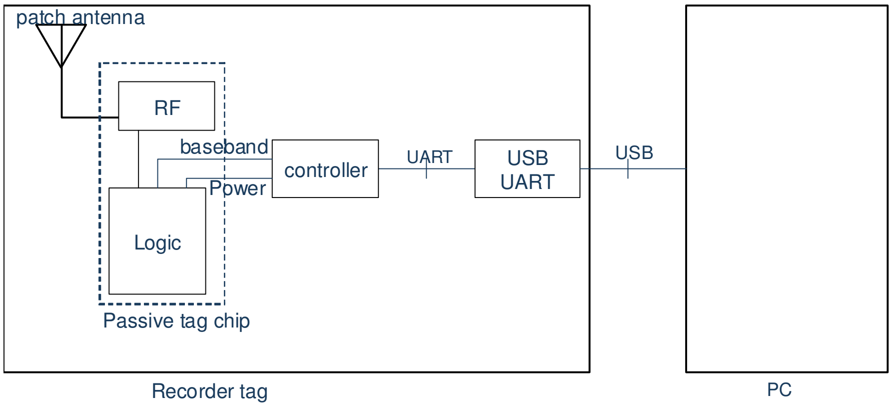

Figure 6 Recorder tag applied to a PC

The baseband communication between the recorder tag and PC is USB leveraging the power transmission. The baseband communication has three tiers, a PC, the controller and the tag chip. In the controller to tag chip link, the baseband protocol of the target protocol[16] is used. In the PC to the controller link, an abridged protocol is developed and used. Figures 7 represents the baseband communication for the unique identifier retrieval and a data write.

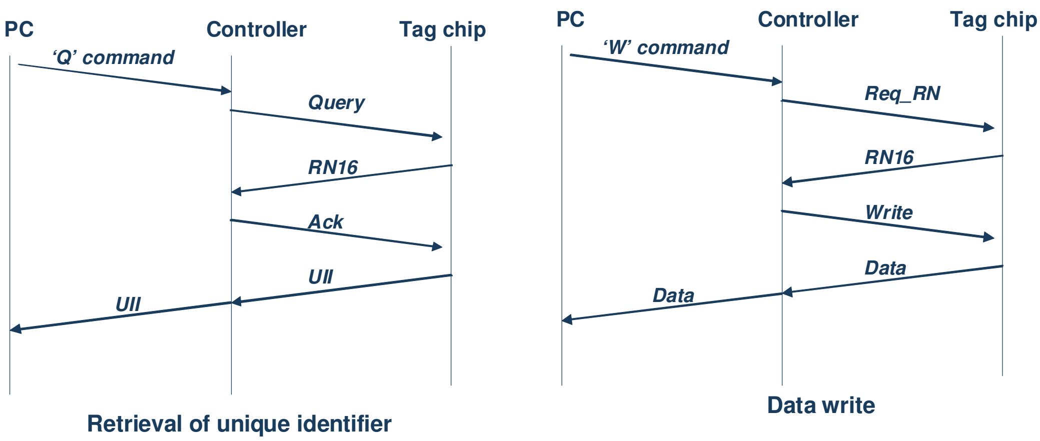

Figure 7 Baseband communication between PC and controller

It was revealed that one of the problems for a recorder tag is the leakage of the voltage from RF communication into the baseband communication circuit in the RF communication mode. If the tag chip is powered, it is not a problem because we can increase the input impedance of the controller by, for example, a FET or voltage follower. We solve the problem by using a diode to prevent the voltage from flowing into the tag chip.

Since the tag chip used in the prototype has just 128 bits user memory, a raw data in a tag memory needs to be a compacted data. ISO/IEC 15962 defines a data encoding rule and logical memory functions using object ID [17]. But for a 128 bits user memory, the index data, such as Object ID, still is a large overhead for the efficient use of the limited user memory. As such, a memory schema, which is not indexed by an object ID, is defined as in Figure 8 and used.

0x00	Number of data		0x0F
0x10	Day of Purchase (origin 1/ 1/ 2000)		0x1F
0x20		Warrant period	0x2F
0x30	Event date		0x3F
0x40	Event Type	Data	0x4F
0x50	Event date		0x5F
0x60	Event Type	Data	0x6F

Figure 8 User memory schema

5 Performance evaluation

5.1 Accessible distance

The recorder tag performance was evaluated by accessing the tag memory both from the RF and baseband interfaces. The recorder tag is applied to a PC as shown in Figure 9.

Figure 9 Recorder tag applied to PC

Recorder tag demonstration model the recorder tag is accessed the RF interface, the PC is stored in a cardboard box modeling the recorder tag access in a supply chain and a retailer.

The memory of the recorder tag is accessed without being taken out from the box. We examined two types of antenna with an interrogator. One is a small 1dBi antenna and the other is a standard 6dBi antenna. Apparently a small antenna is preferable for the industrial and commercial usage. The read and write distance is measured from the outer surface of the cardboard box. There is approximately 6cm gap between the target PC and the inner wall of the cardboard box (Figure 10).

Figure 10 PC with prototype recorder tag in a package card board box

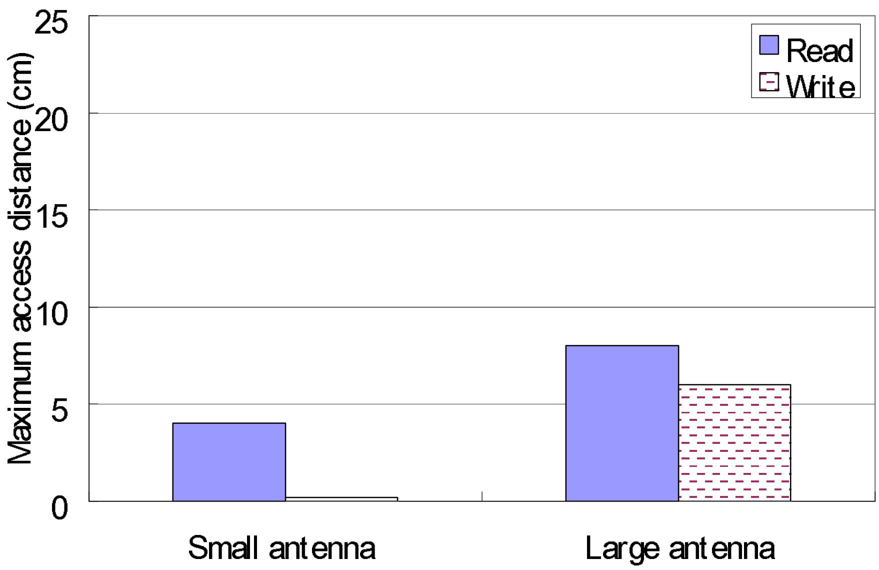

Figure 11 Recorder tag prototype accessible distance with 17dBm

Two interrogator output power, 17dBm and 27dBm are examined (Figure 11 and Figure 12). It is observed that the reading distance is degraded compared with Table II. This degradation may be caused by the metal and cables in the proximity of the recorder tag. It is also observed the writing distance is about the half of reading range. This is understandable because the tag chip employs EEPROM, which requires high voltage when a data is written.

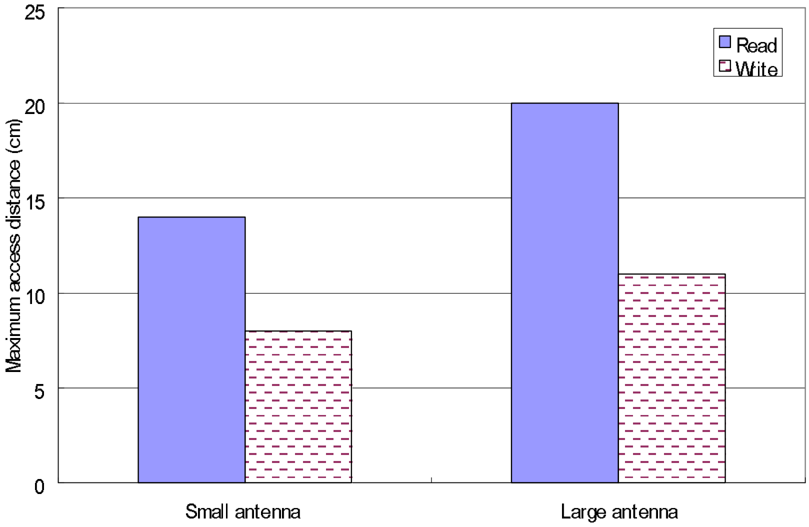

Figure 12 Recorder tag prototype accessible distance with 27dBm

5.2 Demonstration applications

Using the memory schema in Figure 8, baseband communication applications have been developed using C# (Fig.13). In Fig.13, a baseband recorder tag read/write application is shown. The upper text box in the figure displays the raw data interaction between PC and the recorder tag through the baseband interface. The lower textbox displays the translated data based on the prescribed memory schema and the semantics. In the figure, it is shown that the supply chain related data, in this case the date of purchase and the expiration of the warranty are accessed by the end-user. On the other hand, essential operational data, in this case overheat incidents, are collected by PC and stored in the recorder tag. The incident data, which is particularly valuable in case of repair and maintenance, can be retrieved by RFID interrogator without a necessity of turning PC power on. A simplified application has been also developed as shown in Fig.14. This application stays in the task bar and upon clicking it displays data in the associated recorder tag as a balloon help.

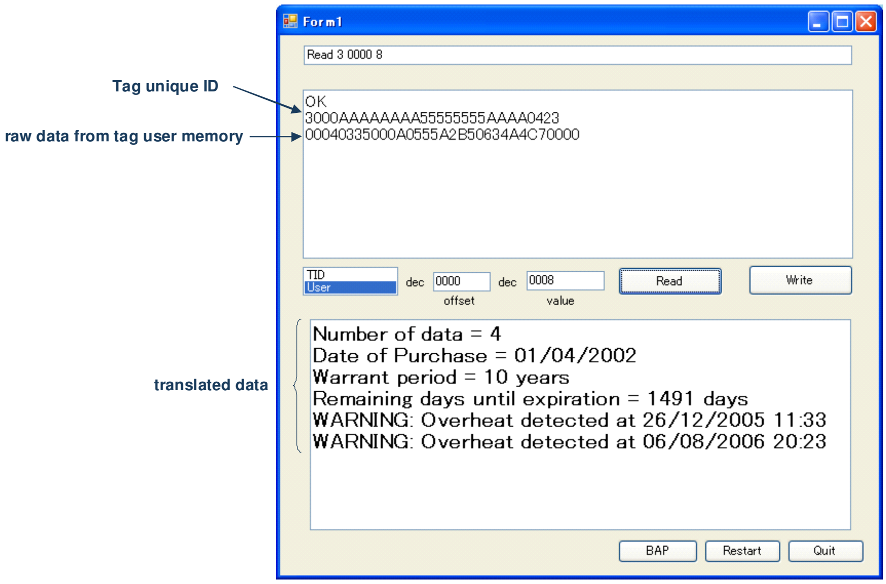

Figure 13 Demonstration application in PC to retrieve data in recorder tag

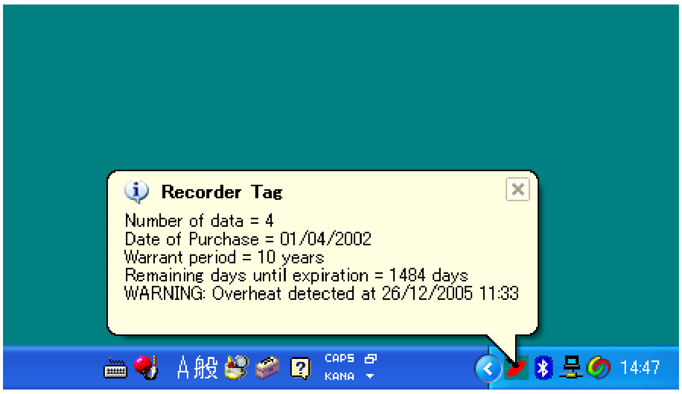

Figure 14 Simplified application user interface

6 Issues for future development

From the development of the prototype recorder tag, it was revealed that the following issues need to be researched for the industrial adoption.

- Even when we have a satisfactory antenna performance in standalone recorder tag, a NLOS operation may degrades the reading and writing performance due to environmental factor, a metal in proximity for example. Further developments on the smaller and stable antenna are important.

- User memory schema and semantics needs to be resolved in an efficient way. Object ID method in [5] may work for a large memory recorder tag. But when we need to handle a tag which has a small memory area, the object ID method is not very memory efficient. The network registry method proposed in [18], alternatively, could be used for the maximum memory efficiency.
- Standardization of the baseband communication interface and the protocol.

7 Conclusion

There have been strong industrial demands from item level tagging, i.e. an RF tag is applied to the product itself rather than a package. Item level tagging fits applications which demand a visibility over the entire product life cycle for the sake of product liability, product safety and recycle. A recorder tag is basically a passive tag, which has two interfaces to the tag memory. One is the conventional RF communication interface and the other is a wired baseband communication interface. The baseband communication interface can be established using a controller to translate the baseband RFID protocol and an abridged application interface. A recorder tag is applied or embedded to a product which has microcontrollers. The key objective of the recorder tag is to bridge end-users and manufacturers. Typical examples are consumer electronics such as PC, TV and a refrigerator. With the wired baseband communication connected to the microcontroller of the product, the product can access the recorder tag memory and retrieve the manufacturing or supply chain related data of the product. With such data, we can develop application for end user such as automatic notification of warranty expiration date. Essential operational incidents during the product use in the consumer premise can be stored in the recorder tag through the baseband communication. This way, the automatically recorded incidents can be used for identification of cause of failure in case of maintenances and repairs. Used product can be properly valuated based on the usage history stored in a recorder tag. For the future deployment, a stable performance small antenna design and an efficient user memory schema in the recorder tag are needed.

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