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Visual and Tangible Interactions with Physical and Virtual Objects Using Context-aware RFID

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ABSTRACT

Radio Frequency Identification (RFID) has recently received a lot of attention as an augmentation and interface technology with physical and virtual objects in the ubiquitous computing domain. As RFID tags can be attached to any items, they can be used to provide various ubiquitous and tangible interfaces. Although a new paradigm shift in computing environments offers various opportunities for extending existing RFID capabilities, most of the previous works have utilized only simple RFID IDs and their mappings such that a rich set of RFID capabilities has not been fully utilized. In this paper, we propose a visual, context-aware and tangible interaction technique with physical and virtual objects using RFID. It combines context awareness with RFID for providing context-aware RFID services, which can seamlessly integrate physical worlds with virtual worlds in a user-oriented manner. The proposed approach adopts semantic ontology in order to systematically represent and reason about RFID related contexts. Moreover, the rewritable characteristic of the RFID tag memory is utilized to manage the dynamic RFID context. Further, the paper presents how to support visual and tangible interactions with physical and virtual objects by combining context-aware RFID services with augmented reality. We will show the effectiveness and the novelty of the proposed approach by demonstrating several practical case studies.

Key Words: Augmented Reality (AR), Context Awareness, RFID, Tangible Interface, Visual Interaction, Ubiquitous Computing

1. Introduction

Mark Weiser described a vision of ubiquitous computing where technology is seamlessly integrated into our environment and provides useful services to humans in their everyday lives [1]. By embedding computers into the background, embodied virtuality will make the individual more aware of the others. In particular, RFID has recently received a lot of attention as an interaction and augmentation technology with physical objects in the ubiquitous computing domain. As RFID tags can be attached to everyday items, they can be used to support various ubiquitous services. It is well known that RFID technology has many benefits over other identification technologies because it does not require line-of-sight alignment, multiple tags can be identified almost

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simultaneously, and the tags do not destroy the integrity or aesthetics of the original objects [2]. Towards this end, the potential of RFID to contribute to the realization of seamless bridging physical worlds and virtual ones has been demonstrated by many researchers in various applications such as logistics & asset tracking, mobile application, and healthcare [3,4].

Meanwhile, computing systems become smaller and smaller in the ubiquitous computing era, eventually invisible, which will be pervasive into our daily lives [1]. On the other hand, we, human beings, require more realistic view or tangible interface of our environment. This can be derived from the fact that we require larger LCD or PDP screens, immersive and haptic displays, and high-quality virtual reality objects. Although it seems that invisible devices and larger visual aids are exclusive each other, eventually they can complement each other since we need more visual interactions of invisible computing services. Augmented reality (AR) is considered as an excellent visual and tangible interface for ubiquitous computing services, because it can augment virtual objects into physical worlds seamlessly. Interaction with these objects occurs in real-time providing relevant feedback to the user and giving the impression of natural interaction. Correspondingly, the human-computer interfaces and interaction researches originating from AR research have proven advantageous in a variety of real-world pervasive application scenarios [5,6,7].

There are a few research works which tried to apply RFID for visualization and interaction. Grønbæk *et al*. [8] introduced the notion of physical hypermedia, addressing the problem of organizing material in mixed digital and physical environments. They presented a prototype of a physical hypermedia system which could run on an augmented architect's desk and digital walls utilizing RFID tags as well as visual tags. RFID could allow users to tag physical materials and have these tracked by readers (antennas) that might become pervasive in their work environments. RFID has been considered as a key component in mobile applications. Rashid *et al*. [9] proposed PAC-LAN, a mixed-reality gaming with RFID-enabled mobile phones, which showed a possibility of incorporating RFID readers with mobile phones for mixed-reality entertainment experiences. Africano *et al*. [10] presented the development of a design concept for an interactive play system and learning tool for children using RFID. Kim *et al*. [11] proposed a method for automatically activating a display and offering selective contents using RFID. These works showed the possibility of applying RFID into ubiquitous applications such as gaming and hypermedia editing. However, RFID is just used for simple ID matching between virtual objects and physical objects such that only a limited set of capabilities of RFID could be utilized.

Considering previous research works, we can expect that RFID will play a major role in providing effective, wireless, and tangible interfaces in various applications. To make RFID more user-centric, context awareness should be utilized. We call it *context-aware RFID service*. Context awareness is used to provide user-oriented services and information by utilizing contexts. Contexts mean information on locations, persons, software agents, devices, and their relationships. Usually, context-aware systems can collect context information from sensors, analyze it, and deliver it to application services. Further, they infer higher level context information from low level information, make an abstraction to them, and expect new context information in advance by managing the previous context information [12,13,14]. However, there are few previous research works which support context-aware RFID services. Note that context-aware RFID services can extend the existing capabilities of RFID to provide more valuable features in the ubiquitous computing domain. Eventually, the context-aware RFID-based interaction and visualization will be a key concept to compliment the generic characteristics of the ubiquitous computing.

In this paper, we propose a visual, user-aware and tangible interaction technique with physical and virtual objects using context-aware RFID. The proposed approach adopts semantic ontology in order to systematically represent and reason about RFID related contexts. It acquires, interprets and queries RFID context information for context-aware RFID service. The rewritable characteristic of the RFID tag memory is used to manage the dynamic RFID context. Thus, the temporal and visual information can be changed and stored during at any point of RFID interactions. It also presents how to support visual and tangible interactions of context-aware RFID services using augmented reality, which realizes bi-augmentation between physical and virtual worlds. Further, we show the effectiveness and the novelty of the proposed approach by showing several practical case studies. The remainder of the paper is organized as follows. Section 2 briefly describes the basics of RFID, visual and tangible interactions, and overviews the proposed system. Section 3 presents how to support context-aware RFID services. It also discusses how to support visual and tangible interactions of context-aware RFID services using augmented reality. Section 4 show implementations results. Finally, Section 5 concludes with some remarks.

2. System Overview

The section describes a context-aware RFID framework that supports visual and tangible interactions with physical and virtual objects in augmented reality environments. Firstly, it describes the basics of RFID. Secondly, it explains the importance of visual and tangible interactions in our daily lives. Then, it presents the proposed context-aware RFID framework.

2.1 Basics of RFID

RFID is an automatic identification technology that can be used to provide a unique ID to a physical object. A typical RFID system consists of RFID reader(s), tags, reader(s), RFID middleware, RFID database, and RFID services as shown in Fig. 1. Communication in RFID occurs through radio waves, where information from a tag to a reader or vice versa is sent via an antenna. Unique identification is stored in RFID tags, which can consist of serial numbers, security codes, product codes, and other object specific data [4]. It is well known that RFID technology has many benefits over other identification technologies because it does not require line-of-sight alignment, multiple tags can be identified almost simultaneously, and the tags do not destroy the integrity or aesthetics of the original objects [3]. To achieve interoperability of RFID device and exchangeability of RFID information, various standards of protocols are proposed for different applications. Among them, the Electronics Product Code (EPC) [15] or ECPglobal plays the main role in standardizing and developing hardware physics, communication protocols, the EPC network infrastructure specifications, and so on.

Tags can either be *active* or *passive* or. The active tag has a power source whereas the passive tag does not. Note that the passive RFID powers up and exchanges commands/responses by gathering energy from RF transmitted from the reader antenna [4]. Due to the battery-less characteristics of the passive RFID, it has been considered to be widely used in various applications. In this research, we assume that passive RFID tags are attached to physical objects.

[Fig. 1]

2.2 Visual and Tangible Interactions

Augmented reality (AR) or mixed reality (MR) is considered as an excellent user interface for various applications [5,6,7]. Interactions with these entities occur in real-time providing convincing feedback to the user and giving the impression of natural interaction. However, the AR presentation has limitation in providing tactile and graspable or tangible feelings of physical models although the rendering on the physical ones results in realistic appearance. One way of removing this separation between the physical space and virtual space can be done through Tangible User Interface (TUI) that couples digital information to physical objects and their ambient space [16,17]. For this reason, tangible AR interfaces are suggested where each virtual object is registered to a physical object and the user interacts with the virtual objects by manipulating the corresponding tangible objects. Thus, tangible AR can support the intuitiveness of TUI with the realistic rendering capabilities of AR.

In particular, RFID is considered as an enabling technology for mixed reality experiences where all kinds of physical and virtual objects can be combined to provide interaction between the real and virtual worlds. In addition, the emergence of mobile devices such as cellular phones and PDAs that incorporate RFID readers gives the opportunity for ubiquitous interfaces in which users interact with real physical objects, in real locations, and provides mixed and tangible experiences [9]. Further, by combining AR with context information, it can provide more context-sensitive cues while the user is performing a task or navigating pervasive environments.

In this research we seek to identify what context-aware RFID services can offer in terms of visual and tangible user experience combined with AR. Fig. 2 shows a possible scenario which utilizes context-aware RFID where an RFID tag is attached to a physical object such as furniture and electronic device. When a mobile device with an RFID reader is close to the tag, its corresponding visual information such as virtual 3D object, price, option, and variables such as color, size, and design change can be read or queried on the device or its corresponding virtual object can be visualized in the context AR environment. In addition, considering the selected items and user preferences, the system can suggest several alternatives as well. Further, the user can interact and simulate his/her made cyber home easily.

[Fig. 2]

2.3 The Proposed System

One of the important issues in applying RFID to different applications is how to provide a seamless environment: moving data from the point of transaction to the application systems, which should support the encapsulation of communication details, RFID-related hardware and software interoperability, system integration and system extensibility [3]. In this regard, the proposed system is based on the context-aware RFID framework which provides visual and tangible interactions with physical and virtual objects in AR environments using RFID and its contexts shown in Fig. 3. The framework has been built on the three layers: 1) interface layer, 2) RFID context layer, and 3) RFID service layer. The interface layer supports bi-interactions between RFID-related devices and the service framework. Thus, all the devices and services such as RFID readers and physical tags are registered, searched, and executed. The RFID context layer facilitates reasoning and execution of RFID contexts for providing context-aware RFID services since it acquires and propagates RFID contexts as a RFID middleware. It also plays as a repository which maintains RFID context information from various resources such as RFID related devices. As will be discussed in the next section, Web Ontology Language (OWL) is used for context representation and processing [18]. The RFID service layer provides user-aware RFID services by considering user-oriented contexts such as preferences, device profiles, and security. The service layer converts RFID contexts into corresponding visual and tangible interactions. Based on this framework, we can provide a variety of context-aware RFID services such as customer-oriented cyber home modeling and simulation, personal healthcare service, ubiquitous campus and museum service. A customer-oriented cyber home design and interaction was shown in Fig. 2.

[Fig. 3]

It is still necessary to provide users with higher levels of RFID personalization that infer different elements of user contexts. They comprise user preferences, device profiles, and environment with respect to the RFID service selection and provision. User preferences may vary depending on the device capabilities and other contexts. Therefore, the context awareness should provide for means to express conditions and reason them applicable to adaptable ubiquitous services [12]. The RFID context management and awareness is done by the RFID context layer as shown in Fig. 3. First of all, RFID sensors update or receive the changes of the real environment and its contexts are read by RFID readers. Then, the RFID filters and aggregates these changes. It also makes a high level of abstraction to them. Based on these, the RFID context layer infers implicit contexts based on the gathered and filtered contexts, and it also records and manages them. The inferred contexts are also used to update or archive the context in the RFID tag memory.

3. Context-aware RFID for Tangible and Visual Interactions

This section explains how to support tangible and visual interactions with physical and virtual objects by processing RFID-related contexts.

3.1 Ontology for Context-aware RFID Services

Usually an RFID event occurs when a person or an object with an RFID tag interacts with an RFID reader in a certain location. To make the RFID-related context more readable and unique over the ubiquitous domain, each RFID context is designed to consist of *EPC ID* for a unique RFID tag, *Context Entity* for a actor type, *Instance* for a real actor, and *IdentifiedByDeviceID* for a RFID reader class as shown in Table 1. In particular, four key context entities interact with one another when such an RFID event occurs. The *Location* entity represents the geographical or interesting location of a person, an object, or event. The *Object* entity represents real or virtual objects that are interesting in RFID interactions. For example, a 3D virtual model representing a real physical object can be visualized on the mobile device when the tag in the physical object is read by the RFID reader in the mobile device. The *Activity* entity is a kind of event which shows the intent or action of a person or an object.

[Table. 1]

When an RFID event occurs, a dynamic relation among these entities is created. For this reason, a semantic network among these entities can be modeled as shown in Fig. 4. Note that these static entities and their relation should be further represented as ontology for semantic reasoning and processing. The rectangular shape represents an RFID context entity, and the diamond shape represents a relation between types.

[Fig. 4]

The specified ontology cannot represent all the activities and relations of RFID interactions. Thus, those should be derived from an extended upper ontology. An upper ontology is used to create an ontology which describes very general concepts that are the same across all domains [5]. The aim is to have a large number of ontologies accessible under this upper ontology. The RFID context management and processing is based on the extended ontology called the context-aware RFID ontology. It is derived from upper context ontologies such as CC/PP [19], FOAF [20], and CONON [14] as shown in Fig. 5. CONON provides an upper context ontology that captures general concepts about basic context, and also provides extensibility for adding domain-specific ontology in a hierarchical manner. CC/PP is Composite Capability/Preference Profiles which is the W3C proposal for a profile representation language. The CC/PP specification defines a basic structure for profiles. A profile is basically constructed as a strict two level-hierarchy: each profile having a number of components, and each component having a number of attributes. FOAF (Friend of a Friend) is about our place in the Web, and the place of the Web in our world. FOAF is a technology that makes it easier to share and use information about people and their activities to transfer information between Web sites, and automatically extend, merge and re-use it online.

[Fig. 5]

3.2 Context Management of Dynamically Rewritable RFID Tag Memory

In addition to high reading speed, multiple reading and writing simultaneously without line-of-sight of using RFIDs, the data carried by an RFID tag is dynamically rewritable. Usually, the memory storage ranges from several bytes to few mega bytes. With the RFID tag memory, the ubiquitous and visual information carried by the tag can be changed during at any point of interaction dynamically. Thus, the temporal information without internet connection can be captured at any location and time.

To effectively utilize these characteristics, a simplified RFID tag context is embedded into the RFID tag memory. Fig. 6 shows the context embedded in the RFID tag for a healthcare service of a person (e.g. exercise) which may include location, time, blood pressure, and so on. For example, during the exercise, a person's or patient's vital signs will be able to be monitored through several embedded ubiquitous devices like RFID readers in near future. The analysis of the signs can be used to give a warning for the on-going exercise. For example, Fig. 7(a) shows the status of the dynamically updated RFID tag memory according to RFID interactions. Further, the collected vital signs are analyzed and the analysis result can be updated in the RFID tag memory as shown in Fig. 7(b). With this updated information, the machine or utility can scan the RFID tag and then decide whether it is still safe to allow another exercise when the person is trying to do it. If it is concluded that it is not safe for him/her to continue the exercise, then the machine gives a warning and stops. Or, the speed of the machine or the level of difficulty can be adjusted. Fig. 7(b) shows that the person should not be allowed to do more exercise by updating the body condition of the person into the RFID tag memory. Fig. 8 shows another example of the dynamically rewritable RFID tag memory. It is related to the cyber home modeling or similar activity using virtual objects, and some of the geometric relations and characteristics are kept to provide a customer-oriented design service. For example, several key parameters for modeling the cyber home are written into the RFID tag such that they are used to generate the desired design result or to save an intermediate result temporarily. As shown in Fig. 8, several characteristics of a person are used to suggest customer-oriented selections of furniture, electronic utilities, and floorplan. In conclusion, by dynamically rewriting important context information into the RFID tag during the interesting interaction, the information can be very effectively utilized to provide customer-oriented visual and tangible interactions using RFID.

[Fig. 6]

[Fig. 7]

[Fig. 8]

3.3 Semantic Processing of RFID Contexts

When a user requests a context-aware RFID service, the RFID context layer infers user-oriented RFID contexts based on the context temporarily stored on the RFID tag and the context stored on the ontology repository. The result is given to the RFID service layer for supporting user-oriented visual and tangible interactions. The overall procedure of the RFID context processing is shown in Fig. 9. The RFID manager collects all the RFID-related events, and the collected contexts are propagated to the RFID context processing server.

[Fig. 9]

To derive new contexts based on the existing RFID-related contexts including user preferences, device profile, and location, the framework utilizes Jena [21] for the definition of rules and reasoning which refer to the extended context-aware RFID ontology. Fig. 10 shows an example of a context ontology representing a person's vital condition during the exercise. Some of the collected vital signs are; 1) his age is 38, 2) his body temperature is 38°C, and 3) blood pressure is 200/180 (high/low). According to this condition, the RFID context processing server deduces that he is under the overexertion. The result is derived from the inference rule represented by Jena as shown in Fig. 11, and the analysis result is rewritten into the RFID tag memory. With this updated information, another machine or utility can determine whether it is still safe to allow exercise when the person tries to do it.

[Fig. 10]

[Fig. 11]

Fig. 12 shows another example of service adaptation considering device profiles and service preference. For example, if a person has a PDA with an RFID reader, which cannot support the visualization of the AR-based objects to limited hardware capability, the system can suggest a new service which can support the same functionality but be adaptable to such a situation. In this case, the context processing module suggests post-augmentation service which is adaptable to his/her PDA. Post-augmentation means that the augmentation is done in the server side and only the result is sent to the service requestor [6]. Fig. 12 illustrates a series of rules which can support a post-augmentation service. Fig. 13 shows the result of inferencing the rule defined in Fig. 12. The post AR service implies that the visualization processing is executed on the server side and its result like an image or result model is sent to the mobile device, which makes it possible to visualize and interact with the service on the PDA with limited hardware and software capabilities.

[Fig. 12]

[Fig. 13]

3.4 Interactions with Context-aware RFID

RFID plays a main role for visual and tangible interactions where all kinds of physical and virtual objects can be combined to provide interactions between the real and virtual worlds. By combining AR with RFID context information, it can provide more context-sensitive cues while the user is performing a task or navigating pervasive environments. Usually, an execution of an AR service based on the context-aware RFID is shown in Fig. 14. First of all, we assume that an RFID tag attached to a physical object can be read and linked to a virtual object. Then, the user interacts with a physical object using an RFID reader such that its corresponding service which is invisible or visible can be visualized. Internally, the system queries and infers new contexts for the given interactions, and applies the inferred contexts for generating adaptable visualization services by embedding 3D virtual objects onto the detected physical markers. Further, a set of virtual objects corresponding to the context level of details of an RFID tag can also be inferred. This means that an appropriate virtual or physical object that matches with the context detail of the RFID tag can be given to the user, which can extend the usability and capability of context-aware RFID by utilizing RFID generic ID as well as derived RFID contexts.

[Fig. 14]

The service is executed by the RFID service agent in the service layer as shown in Fig. 2 and Fig. 15. The service agent is a software module performed as a proxy to connect various external sensors and devices to the framework. That is, it delivers information of the sensors to the RFID context processing module. Also, it receives control commands from them, controls devices in the environment, and conducts applications. The interface manger makes accesses to the appropriate service agent out of the currently running service agents using a searching function. Various kinds of service agents can be loaded to the service agent container by the service code loader and they can be used by the several ways (install/modify/remove). These loaded service agents communicate with the RFID context processing module.

[Fig. 15]

A detailed process for executing a context-aware RFID service using the RFID service agent is shown in Fig. 16. One of the main characteristics of the context-aware RFID service lies in using the dynamic tag memory which can store information which can be modified, collected, or updated during various stages of the interaction processes. When the tag is read, the service agent checks the memory of the tag and its contexts, then it communicates with the context-aware RFID processing server for the its related contexts and processed contexts if needed, and finally it executes context-aware services through the RFID manager.

[Fig. 16]

4. System Implementation

This section explains how the proposed framework can support visual and tangible interactions of context-aware RFID services by demonstrating practical and futuristic applications. ALEServer is used as a middleware for context-aware RFID services [22]. ARToolkit is utilized as AR implementation, an open source software library for developing vision-based AR applications [23]. Moreover, to provide context adaptable services in mobile devices, CrEme^{TM} is used as a Java virtual machine [24]. The RFID related devices used in this research include the RFID reader for the desktop computer, the CF type RFID reader attached to PDA, passive RFID tags, a PDA, and a desktop computer as shown in Fig. 17. These devices are registered and linked together through the RFID manager. This makes it possible that they can communicate each other regardless of their locations and their heterogeneous platforms.

[Fig. 17]

Using the context-aware RFID, we implemented the following two applications for the visualization and interaction of context-aware RFID services using AR: 1) customer-oriented cyber home design and simulation and 2) ubiquitous campus guide. Fig. 18 shows a set of snapshots of a cyber home design using RFID interactions. Note that the application can also support mobile RFID interactions with a PDA as shown in Fig.

18(f), which can support the remote authoring of and the interaction with virtual objects. Moreover, based on these RFID-based interactions, it can suggest a different cyber home considering user's contexts as shown in Fig. 19. In this scenario, we assume that a young family prefers a modernized style (Fig. 19(c) and (d)), whereas an old family prefers a traditional style (Fig. 19(a) and (b)). According to the user's contexts, the system searches for appropriate 3D models from the database such that it is possible to simulate the suggested cyber home as shown in Fig. 20. Dynamically moving objects and multimedia such as movie and animation can also be embedded in this physical model such that the user can get more realistic and immersive feeling during visualizing, interacting, and evaluating the cyber home. Fig. 20(a) and Fig. 20(b) show how to embed a virtual object into the AR environment using an RFID interaction. Fig. 20(c) shows a simulation of the modeled cyber home. Fig. 21 shows how the context-aware RFID can also be utilized to visualize the campus information for campus guide. Through these applications, we realized that combining RFID, AR, and context awareness could provide a great deal of opportunities that might be applied in near future.

[Fig. 18]

[Fig. 19]

[Fig. 20]

[Fig. 21]

5. Conclusion

Radio Frequency Identification (RFID) has recently received a lot of attention as an augmentation and interface technology with physical objects in the ubiquitous computing domain. In this paper, we have proposed a visual, dynamic and tangible interaction technique with physical objects using the context-aware RFID service. In addition, AR is utilized to provide the visualization of the context-aware RFID service. To verify the effectiveness and usability of the proposed approach, we demonstrated two application scenarios. To derive new RFID-related contexts, we proposed an extended RFID-related ontology. Thus, an appropriate virtual or physical object that matches with the context detail of the RFID tag is given to the user if the corresponding context can be inferred from the existing RFID contexts. Further, the dynamic nature of RFID tag memory is utilized to archive temporary RFID contexts and temporal activities such that those RFID contexts are combined with existing contexts to provide more user-oriented services. Thus, the ability of RFID can be fully extended by utilizing RFID generic ID as well as derived RFID contexts.

Several areas of research related to context-aware RFID still remain. Hybrid interfaces that integrate AR with other interaction and collaboration techniques need to be further explored. It is also necessary to effectively manage the context stored on the RFID tag memory according to its different types and the size of the tag memory.

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List of Table and Figures

Table 1. RFID initial context information

EPC	Context Entity	Instance	IdentifiedByDeviceID
1.1.101	Person	Andy	Reader2
1.1.102	Location	CNU_SportCenter	Reader1
1.1.103	Object	Running Machine	Reader1
1.1.104	Activity	Excise using Running Machine	Reader1

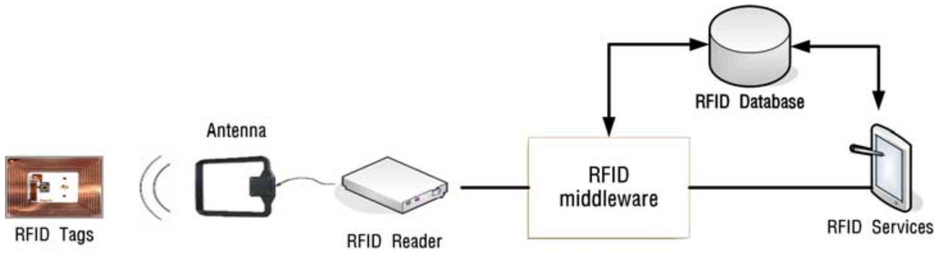


Fig. 1. Typical RFID system

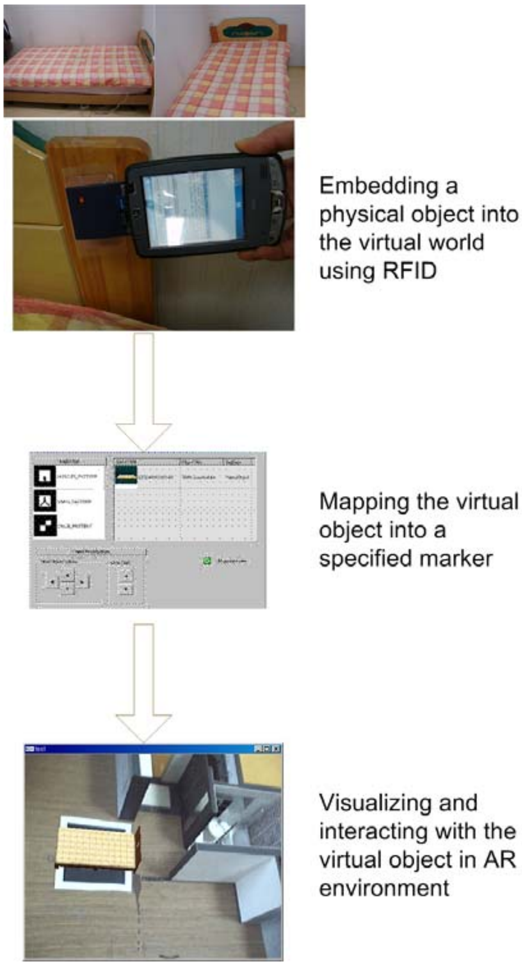


Fig. 2. A scenario: integration of AR with RFID for hyperlinking physical object with virtual ones in the cyber home modeling

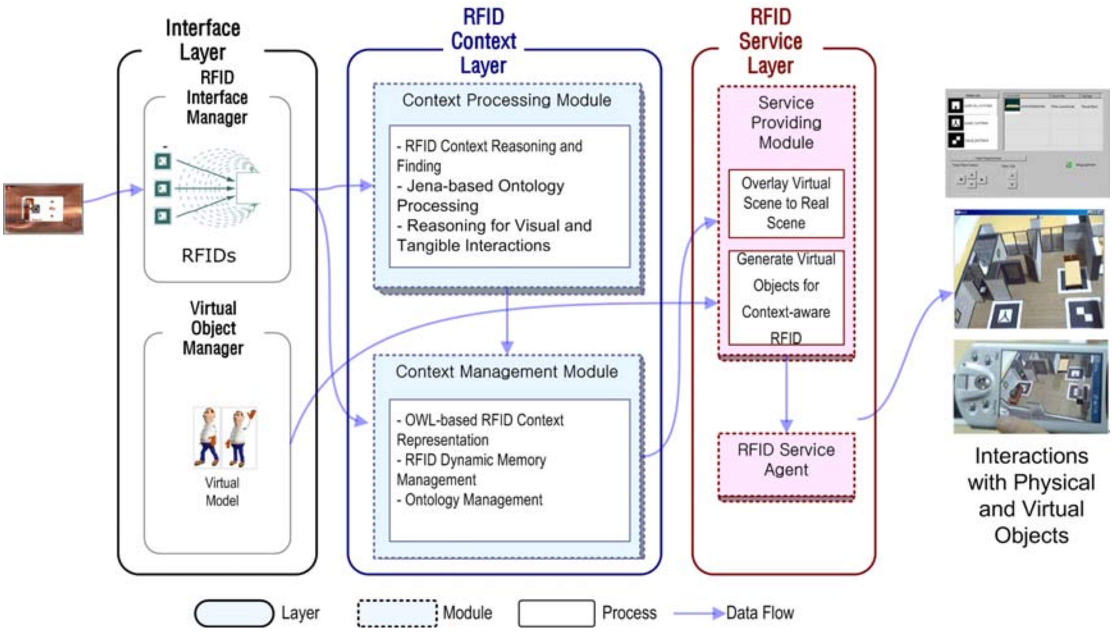


Fig. 3. Framework for context-aware RFID services

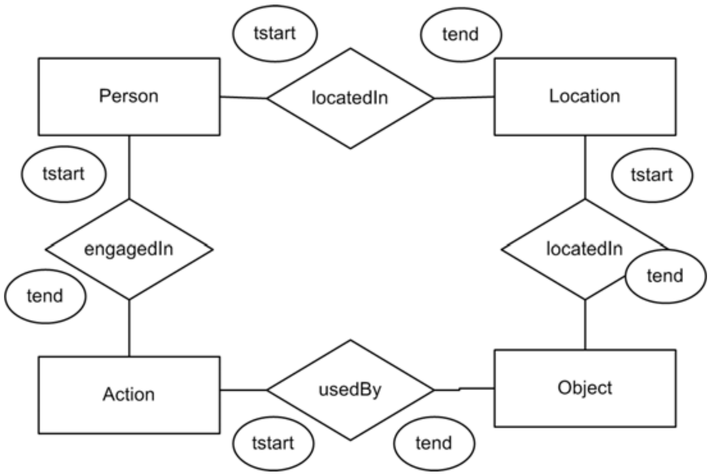


Fig. 4. Semantic relations among RFID context types

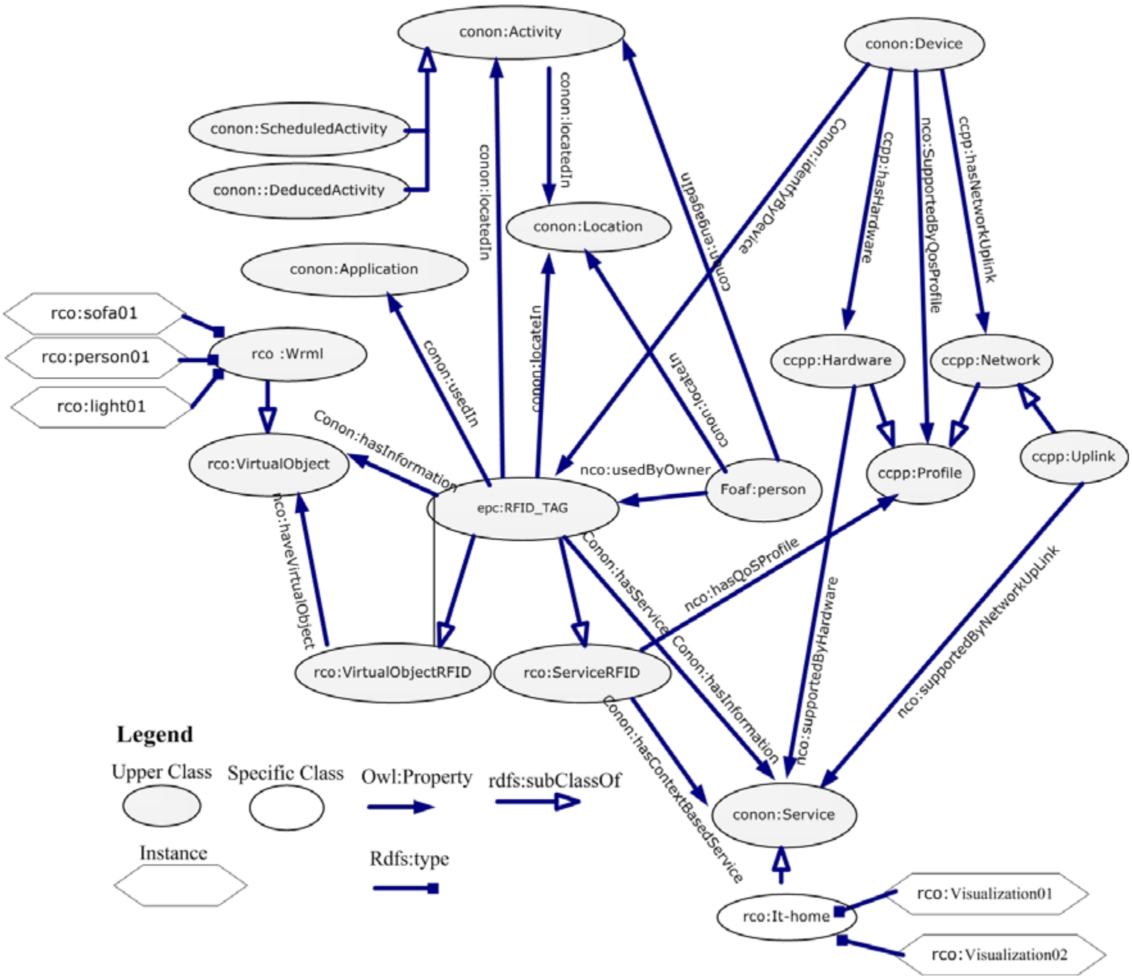


Fig. 5. Integrated and extended context-aware RFID ontology

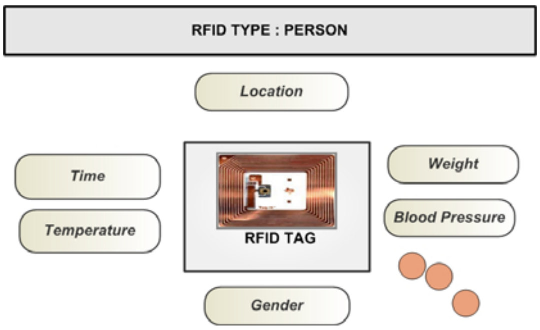
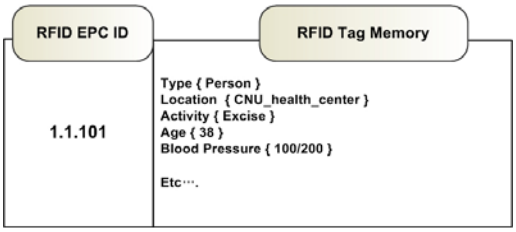
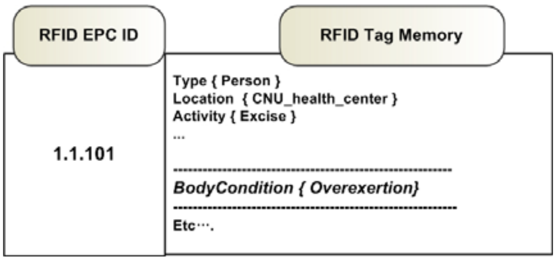


Fig. 6. An example of RFID tag context for the healthcare service of a person



(a)



(b)

Fig. 7. Before and after updating the tag context during exercise: (a) RFID tag context before exercise, (b) updated RFID tag context after exercise

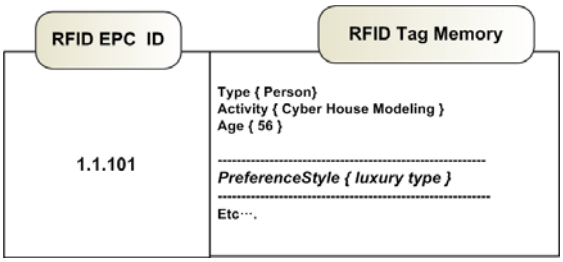


Fig. 8. Another example of the rewritable RFID tag to suggest the preference style for modeling a cyber home design

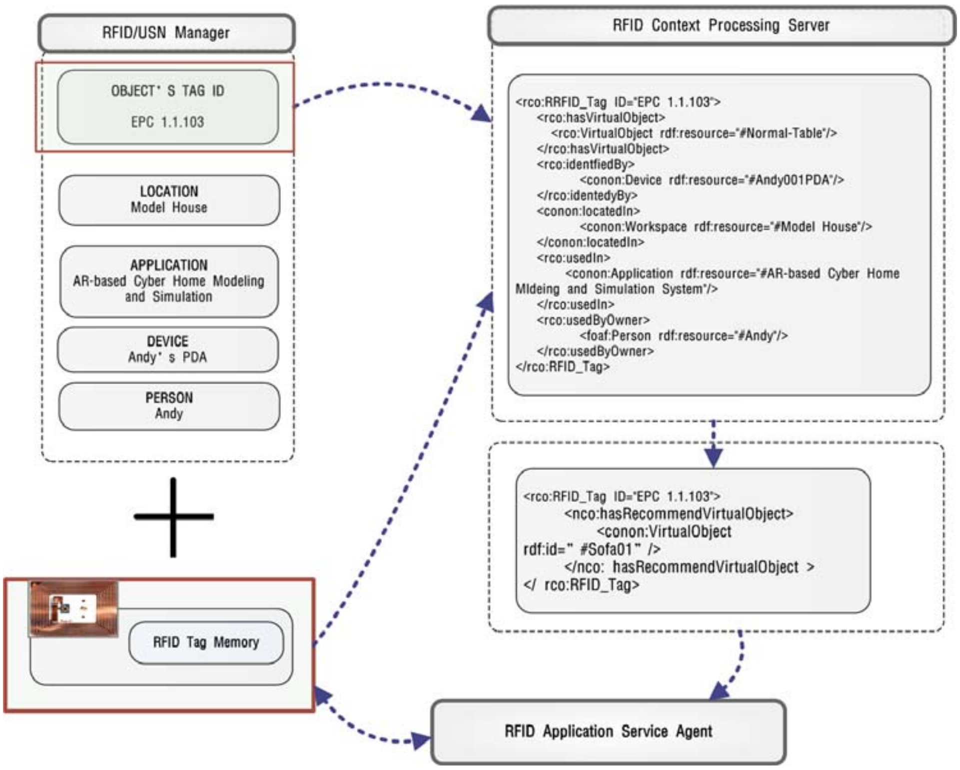


Fig. 9. RFID context processing

```
<rco:RFID_TAG ID="EPC 1.1.101 ">
    <conon:locatedIn>
        <conon:CNU rdf:resource="#CNU_HEALTH_CENTER">
                    <humidity
                       rdf:datatype="http://www.w3.org/2001/
                       XMLSchema#int" >90
                    </ humidity>
         </conon:CNU>
    </conon:locatedIn>
    <rdfs:type>
        <rco:RFIDType rdf:resource="#Person "/>
   </rdfs:type >
    <rco:usedByOwner>
          <foaf:Person rdf:resource="#Andy">
                <bodyTemperature
                       rdf:datatype="http://www.w3.org/2001/
                       XMLSchema#float" >38
                </ bodyTemperature>
                <bodyHighBloodPressure
                       rdf:datatype="http://www.w3.org/2001/
                       XMLSchema#int" >210
                </ bodyHighBloodPressure >
                <bodyLowBloodPressure
                       rdf:datatype="http://www.w3.org/2001/
                       XMLSchema#int" >120
                </ bodyLowBloodPressure >
                <age
                       rdf:datatype="http://www.w3.org/2001/
                       XMLSchema#int" >38
                </ age>
                …
           </foaf:Person>
    </rco:usedByOwner>
</rco:RFID_TAG>
```

Fig. 10. Context ontology about " EPC 1.1.101” tag representing a person’s vital signs during exercise

```
 (?rfid_tag conon:locatedIn rco:CNU_HEALTH_CENTER)
(rco:CNU_HEALTH_CENTER humidity ? humidity)
( greaterThan(?humidity, 60))
(?rfid_tag rdfs:type foaf:Person)
(?rfid_tag rco:usedByOwner ?person)
(?person bodyTemperature ?bodyTemperature)
(?person bodyHighBloodPressure ? bodyHighBloodPressure)
(?person bodyLowBloodPressure ? bodyLowBloodPressure)
(?person age ? age)
( greaterThan(?age,35))
( greaterThan(?bodyTemperature, 37.5))
( greaterThan(?bodyLowBloodPressure,110))
( greaterThan(?bodyHighBloodPressure,200))
…
 -> (?rfid_tag bodyCondition Overexertion)
```

Fig. 11. An inferencing rule for a " bodyCondition " context which results in “overexertion”

```
(?rfid_tag rco: identfiedByDevice ?device)
(?device ccpp:hasHardware ?hardware)
(?hardware ccpp:memory ?memory)
(?hardware ccpp:cpu ?cpu)
(?hardware ccpp:displayHeight ?displayHeight)
(?hardware ccpp:displayWidth ?displayWidth)
(?device ccpp:hasNetworkUplink ?link)
(?link ccpp:bandwidth ?bandwidth)
( lessThan(?memory,100))
( lessThan(?cpu,330))
( lessThan(?displayHeight,240))
( lessThan(?displayWidtht,150))
( lessThan(?bandwidth,40))
->(?person rco:hasQoSProfile ccpp:QoS002)

(?service rco:supportedByHardware ?hardware)
(?hardware ccpp:memory ?memory)
(?hardware ccpp:cpu ?cpu)
(?service rco:supportedByNetworkUpLink ?link)
(?link ccpp:bandwidth ?bandwidth)
( lessThan(?cpu,330))
( lessThan(?memory,100))
(lessThan(?displayHeight,240))
( lessThan(?displayWidtht,150))
( lessThan(?bandwidth,40))
  ->(?service rco:supportedByQoSProfile ccpp:QoS002)

(?person rco:hasQoSProfile ?profile)
(?rfid_tag rco::hasPreferredTourStyle ?tourPreference)
(?service rco: hasPreferredTourStyle? tourPreference)
(?recommended_service_Info rdfs:type ?service)
(?recommended_service_Info nco:supportedByQoSProfile ?profile)
->(?rfid_tag rco:hasRecommendedService ?recommended_service_Info)
```

Fig. 12. A set of inferencing rules considering context adaptation for device capability and service preference

```
<rco:RFID_TAG ID="EPC 1.1.103 ">
  <rco:hasRecommendedService>
        <rco:ServiceObject rdf:resource="# Post AR-based Visualization
Service"/>
  </rco:hasRecommendedService>
</rco:RFID_TAG>
```

Fig. 13. Newly inferred context considering the device capability and service preference

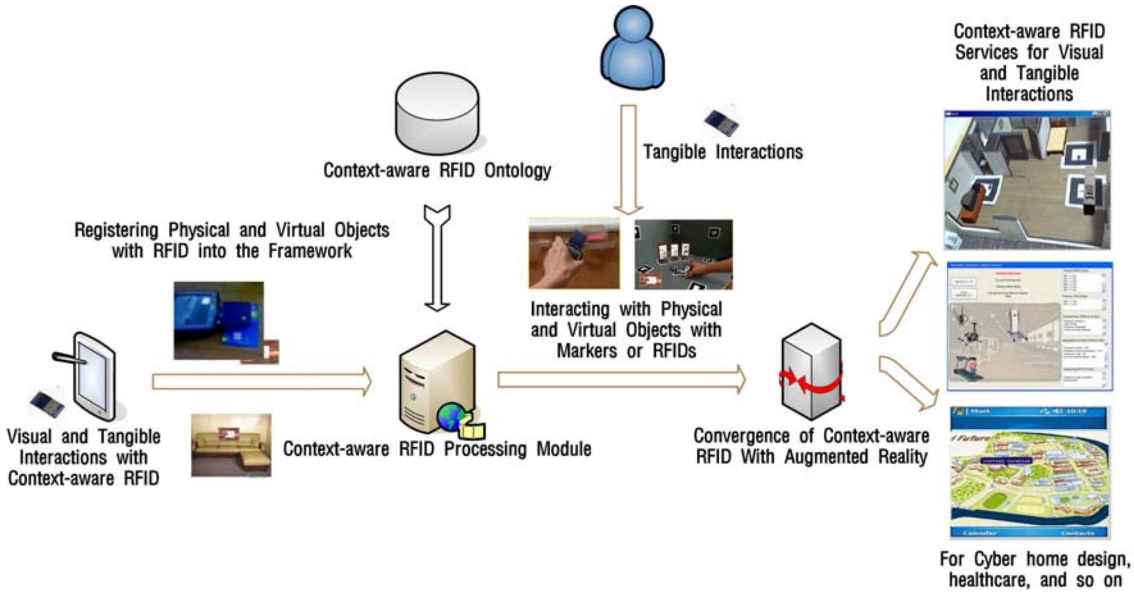


Fig. 14. Execution of visual and tangible interactions of context-aware RFID

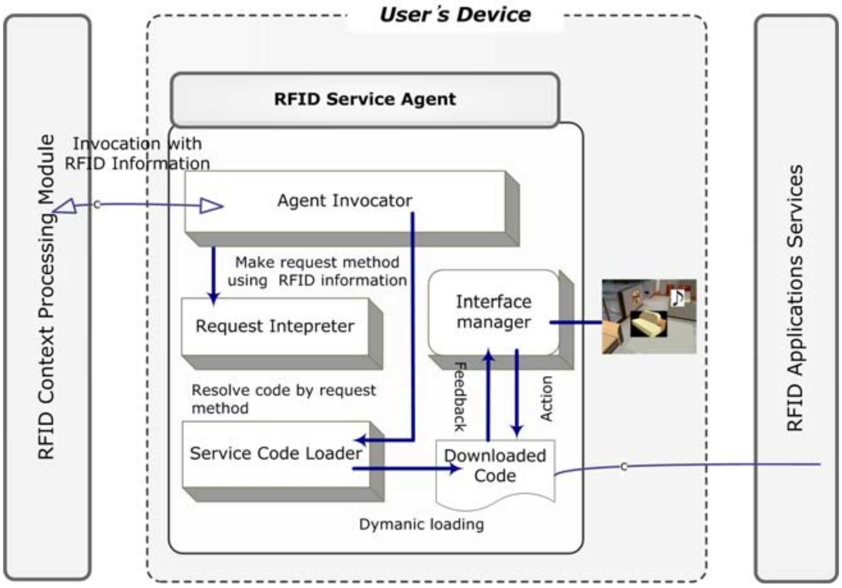


Fig. 15. RFID service agent

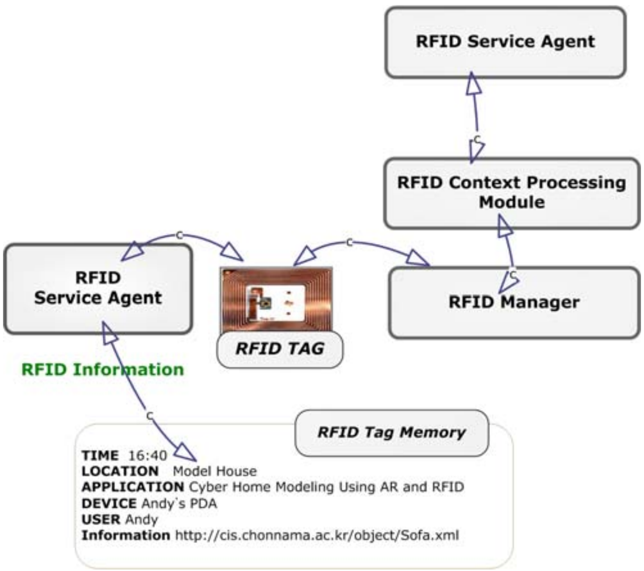


Fig. 16. Execution of a context-aware RFID service via the service agent

Fig. 17. Implemented Context-aware RFID system

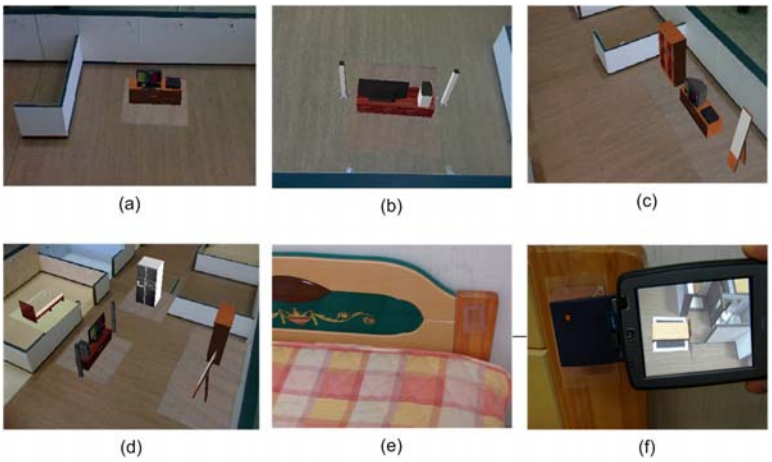


Fig. 18. Interior design and interaction using RFID

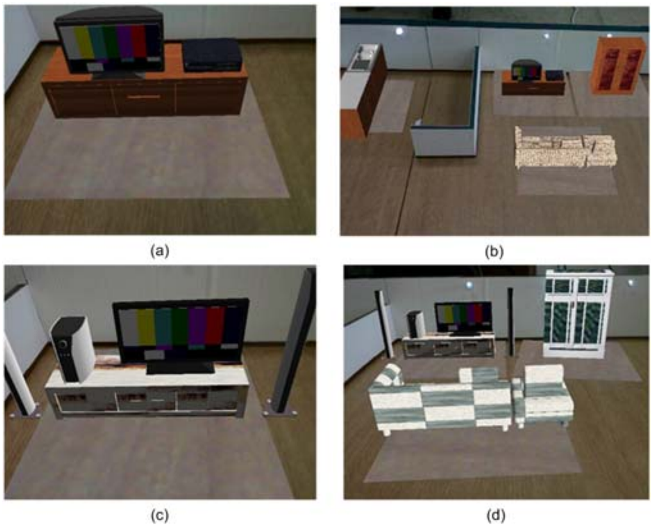


Fig. 19. Context-aware virtual object recommendation

(a) (b) (c)

Fig. 20. Cyber home simulation

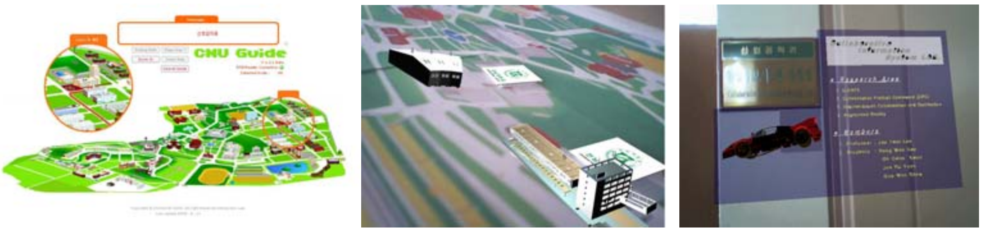


Fig. 21. AR and RFID-based campus guide