How to Realize Ubiquitous VR?*

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Abstract. In this paper, we propose a novel concept of Ubiquitous Virtual Reality (U-VR) and promising approaches for realization of U-VR. Currently, Virtual Reality (VR) is not popular in our daily lives despite the development of many devices, and people have few chances to use VR systems since there is no indispensable application area. On the other hand, extensive researches on Ubiquitous Computing (ubiComp) have been carried out to allow applications to adopt to users and environments based on various kinds of contexts obtained from distributed yet invisible computing resources. Thus, we consider how to revive VR in ubiComp environments. We present a concept of U-VR that is realized through Collaborative Wearable MAR (Mediated Attentive Reality). Moreover, we investigate several challenges that are significant factors in establishing U-VR environments. Finally, for raised issues the proposed approaches are illustrated. We prove the usefulness of the presented concept by illustrating some applications.

1 Introduction

Until now, VR has strived to build a computer-generated Virtual Environment (VE) to enable a user to feel realism through interaction that stimulates five senses of a human. Especially, recent advances in computer graphics, multimedia, parallel/distributed computing and high-speed networking technologies enable to construct Collaborative Virtual Environments (CVEs) [1]. The participants in the CVEs can collaborate with each other by using audio, video and 3D graphics even though they are located around the world. The CVEs may be distinguished by the following five features: a shared sense of space, a shared sense of presence, a shared sense of time, a way to communicate, and a way to share [2]. Nevertheless, VR is still far from users in a RE, and has no killer applications in our daily lives.

On the other hand, the ubiComp paradigm is popular in our daily lives by allowing to access computing resources and services anywhere and at any time [3]. Furthermore, context-aware services can be supplied to users based on the information obtained from distributed but invisible computing resources [4]. It is also worthwhile to note that ubiComp enables to shift a paradigm from technology-

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oriented to user-centered. Consequently, intelligent services can be provided based on personalized information that is created or extracted according to user context, such as identification, time, location, attention, gesture/behavior/activity, intention and emotion. That is, context-aware applications offer personalized services to users by utilizing contextual information of environments and users.[5][6]. These features of ubiComp can be employed to realize VR in our daily lives.

In this paper, we present novel ways, which remedy problems faced by VR, in ubiComp environments. VR focuses on the activities of a user in a VE that is completely separated from a RE. On the other hand, ubiComp focuses on the activities of a user in a RE. Although VR and ubiComp reside in different realms, they have the same purpose, i.e. to maximize the human ability: selective sharing, collaboration and personalization. Therefore, by supplementing weaknesses of VR with the help of ubiComp, we look for ways to evolve VR in ubiComp environments. In this paper, we present the concept of U-VR and investigate methods for realizing it. After describing associated key features, we illustrate the potential of U-VR with some applications. We verify the usefulness of the proposed ideas by presenting various applications.

2 U-VR: When VR Meets ubiComp

2.1 What is U-VR?

We define Ubiquitous Virtual Reality as U-VR, and fuse Virtual Environment (VE) and Real Environment (RE) by extending the capability of human beings into a RE, not confining it within a simulated space. In other words, we combine VE and RE seamlessly instead of only focusing on the generation of an ideal VE. Furthermore, contents are interactable within RE as well as VE so that they can be systemically associated with services in a RE.

U-VR is demonstrated as Collaborative Wearable MAR (Mediated Attentive Reality), and each term is described as follows. The first term 'Collaborative' means that U-VR enables collaborators to share necessary resources (devices) and contents to carry out tasks in RE as well as VE. The contents mean realistic contents stimulating five senses and cognition of a human. The devices mean smart objects, which are pervasive in a RE, and include wireless devices as well as wired devices. In U-VR environments, users do not need to collaborate only within a VE using conventional VR user interfaces. Instead, they can collaborate with each other by sharing realistic contents even within the RE. Thus, users share their goal through collaborative environments. To share their goal, they also need to share time and space. By extending this concept, collaborators can generate a special environment where they share even their feelings. Thus, we need to deal with resource and contents sharing, and multi-modal interaction for collaboration.

The second term 'Wearable' means that users are provided with personalized services with the help of wearable devices, which manage personal information, anywhere and at any time in U-VR environments. That is, a user can be provided with personalized services without the constraints of time, place and device, based on the personal information, which is low-level information such as activities, behaviors, preference and high-level information such as attention, intention and emotion. For the personalized services to be supplied, the wearable devices sense a user's personal information by utilizing several physical and physiological devices. This personal information is managed effectively through wearable devices that users have in wear to reflect the user's desires, needs, and preferences over services. Furthermore, the intimacy of a user interface must be maintained so that users can utilize wearable devices conveniently. Ideally, the user interface should be transparent to users so that they can concentrate on their tasks without the necessity of being conscious of the user interface.

The term 'MAR (Mediated Attentive Reality)' means that a user accesses and interacts with smart objects, or intelligent and realistic contents, which the user pays attention to, through a transparent user interface. For this purpose, context-aware augmentation techniques make it possible to augment intelligent and realistic contents into RE based on contextual information of environments and users. It is also important that the intelligent and realistic contents should be integrated seamlessly into a RE to provide seamless presence, which preserves five senses, to users. Furthermore, augmented realistic contents are required to be responsive to react intelligently to a user.

2.2 Challenges

We examined the meaning of Collaborative Wearable MAR for realization of U-VR. However, we face several challenges for implementation. Thus, several challenges, which are significant factors in realizing U-VR environments, are investigated.

Resource & Contents Sharing: Resources in U-VR environments are so heterogeneous that we can confront unexpected troubles for data management, such as access, modification, transmission, maintenance, etc. The main problems are how to access resources or contents through a user interface, how to manage computational power that is ubiquitous in environments, and how to share data which are pervasive in environments. Furthermore, network conditions should satisfy requirements for real-time, concurrency, persistency, consistency, security, etc. to manage distributed diverse information, devices and computational power. In addition, sharing of data, devices and computational power is essential in U-VR environments in order to carry out the tasks effectively.

Multi-modal Interaction: In general, realistic contents, which stimulate five senses of a human, are multi-modal. Collaborators manipulate contents through an individually optimized interface, and augmented contents are reflected to other collaborators though the network. Thus, the interfaces need to convey the senses of contents to users. The interaction devices are used for multi-modal interaction with the augmented contents. Thus, in U-VR environments, the synchronization is very important since the contents manipulation by one user should be reflected to the other users in real-time.

Personal Information Disclosure Management (PIDM): In general, personal information need to be managed effectively to deal with a user's desires, needs, and preferences over services. However, disclosure of personal information is inevitable to personalize services and applications in context-aware computing environments. Context-aware application developers need to provide users with flexible ways to control when, to whom and at what level of detail he/she can disclosure his/her personal information. However, while members in U-VR environments may be frank to share the personal information with each other, they may desire to keep certain elements of the personal information obscure from context-aware services. This signifies the need for mechanisms that provide the members with the flexibility to adjust the granularity of context information disclosed to service providers.

Personalized Contents Augmentation: Personalized contents are augmented and provided to a user in U-VR environments. It is worthwhile to note that only personalized information is provided to the user even though many users are interested in the same object. In order to present personalized contents to each user, it is essential to be aware of the contexts for each user as well as the environment. That is, the user can enjoy the optimized contents supplied according to the user profile and the user's current state information. However, the augmented contents should be integrated seamlessly with the RE. A user may retrieve necessary information through wearable devices anywhere and at any time. Thus, these contents should be seamlessly integrated so as not to deteriorate the user's immersive feeling.

Responsive Contents Reaction: Augmented contents need to be responsive so that they may respond intelligently to users [7]. That is, for realistic interaction, contents should refer to contexts in RE as well as VE. Moreover, the contents should also figure out user propensities and preferences. In conventional VR systems, artificial intelligence (AI) and artificial life (ALife) techniques were employed for designing intelligent characters despite the high complexity. However, since centralized servers are discouraged in ubiComp environments, new frameworks or algorithms need to be supported for intelligence in a distributed environment. Another challenge is that it is hard to figure out situations in a RE even though it is comparably easy to know a VE. Furthermore, the system has to create responsive and believable contents reflecting users or environments.

3 Proposed Approaches

In this chapter, we illustrate the proposed approaches for each challenge based on the provided conceptual figures. In the next chapter, we will show a real application, *ubiHome*, in U-VR Lab. at GIST.

3.1 Resource and Contents Sharing

In U-VR environments, a lot of computing resources are pervasive and invisible to users, and have various performances. Thus, requirements for high performance computing resources to implement VR systems can be satisfied by effectively using various computing resources that are distributed in U-VR environments.

U-VR GRID computing may be one of the solutions. In U-VR GRID computing environments, surrounding computing resources including data, computation power are employed to process a single task. However, when the task is divided for processing as a conventional grid computing, real-time processing is difficult since a task-assigned computer transmits divided tasks to each computing resource, receives the results back after other computing resources compute each divided task.

U-VR GRID computing processes tasks with efficient performance by dividing a task into several objects and distributing them according to the performance of computing resources in ubiComp environments. In ubiComp environments, computing resources are not only ubiquitous, but their performance is also known to other computing resources. Thus, U-VR GRID computing induces better performance in carrying out a given task. A task-assigned computer divides a given task, transmits the divided tasks to each computing resource, and receives the results back after processing. Because the task-assigned computer already knows the performance of other computing resources, efficient task allocation is possible. Instantaneous interaction is possible by processing the whole procedure in real-time. Fig. 1 shows an example for smart home environments where resources and contents are shared among several users.

3.2 Multi-modal Interaction

To encourage realism, we take five senses of a human into consideration since humans perceive their environments in which they live through their senses. Because visual, auditory and haptic senses are main factors of human senses, many researchers have focused on these three modalities.

In these days, owing to the wide spread of networks and speed advances of computers, there is increasing interest in collaboration. Participants can collaborate with each other by using audio, video and 3D graphics even though they are located at different sites. This collaboration enables users to be able to enhance remarkably the effectiveness of most virtual reality (VR) applications: remote surgery, multi-hand manipulation, sports training, multi-player game, and so on [8].

In case of the auditory sense, it is rather convenient to transmit small amount of audio data over the internet. In case of the visual sense, during the last two decades, rapid improvements in computer graphics (CG) have enabled the generation of photorealistic effects, animations, and real-time interactive simulations. Nowadays, there have been interesting researches on transmission of tremendous amounts of 3D photo-realistic data and real-time 3D data [9]. On the other hand, in case of the haptic sense, a haptic interface requires an update rate of about 1 *kHz* for the user to accurately experience force feedback. Therefore, for efficient interaction through haptic interfaces, we require a stringent consideration about minimum bandwidth guarantee, bounded latency, bounded jitter, and bounded loss. Some researchers designed and implemented a prototype system with an adaptive intra-media synchronization scheme for haptic interactions for collaboration [10]. In Fig. 1, we can observe that multiple users are manipulating virtual objects stimulating some senses of users.

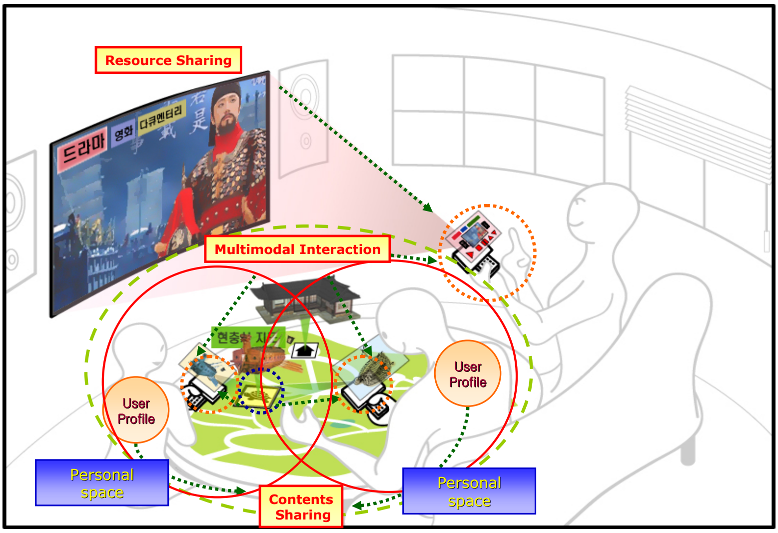

Fig. 1. Challenges for collaboration among users, who has his/her own personal space, in sharing resources as well as contents in U-VR environments.

3.3 Personal Information Disclosure Management (PIDM)

Fig. 2 illustrates an example of the personal information disclosure management in U-VR environments. We describe this phenomenon with the model scenario of a context-aware service [11]. The service provides the user with appropriate contents based upon the detail level of context information he/she discloses to the service. The user can choose and assign priorities to his/her preferences for the contents in "what" element of 5W1H via a GUI.

The 'who' element of 5W1H can accommodate user's age and the 'how' element can keep track of his/her physiological condition. There is a tradeoff between user's privacy and utility of service. The more a user discloses personal information, the more customizable and beneficial the service becomes. The more specific the user is in revealing his/her personal context information to context-aware services, the more relevant services he/she is likely to receive from the service, with respect to his/her preferences ('what'), age ('who'), and physiological condition ('how'). If the user has chosen to disclose his/her physiological condition, the service takes into account if the user is in tension or not. In this way, we provide the user with the option to manage disclosure of his/her personal information and avail the service in relation to the disclosed information.

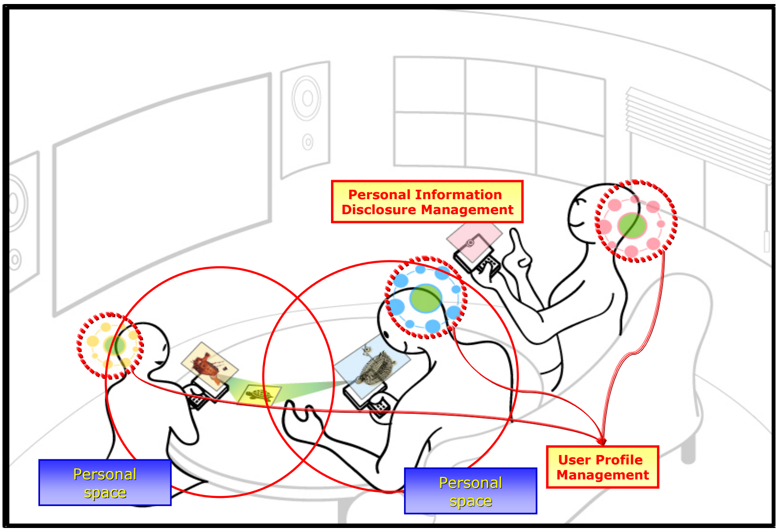

Fig. 2. Challenges for wearable computing such as user profile management and personal information disclosure management in U-VR environments

3.4 Personalized Contents Augmentation

In U-VR environments, pervasive resources are employed to acquire information for environments as well as users. Thus, users can be provided with intelligent services based on the information obtained from distributed yet invisible computing resources. Especially, context-aware applications offer appropriate services to users by utilizing contextual information of environments including users. This information is obtained from various sensors or computing resources distributed in our daily lives.

In U-VR environments, only interesting virtual intelligent contents are augmented and provided to a user based on a realistic scene of a RE as illustrated in Fig. 2 and Fig. 3. That is, U-VR enables to exploit ways that augment and/or replace, in regard of five senses, only information about the objects in which a user is interested. Thus, we only have to provide important virtual objects that a user is interested in by using realistic contents. Even though two users are looking at the same object, each user retrieves his/her own interests based on his/her context. Efficient personalized information retrieval is also required since desired or undesired information is flooded [12]. Accordingly, all the retrieved information is exposed to a user regardless of his/her situations or conditions. In this regard, a personalized information retrieval framework enables users to retrieve the personalized information from objects by exploiting a user's context as a fundamental element in retrieving the personalized information. We may find one application that illustrates how the same object can be utilized for several users [13].

Note that the augmented contents should be integrated seamlessly with a RE. A user may retrieve necessary information through the wearable devices anywhere and at any time. Thus, these contents should be seamlessly integrated so as not to deteriorate the user's immersive feelings. However, seamless integration of augmented contents into a RE is required in regard of five senses. That is, users can have a satisfactory immersive feeling if the augmented realistic virtual objects stimulate five senses of a human and the RE itself is used as the surrounding environment. This also decreases performance requirements for computing resources in implementing a realistic scene. With respect to the visual stimulus, Computer Graphics (CG) or photo-realistic images, light source estimation, realistic rendering are needed in order for the augmented contents to look realistic. As to haptic stimulus, tactile or force feedback technologies have been developed and combined with visual and audio. Auditory stimulus also need 3D sound technologies, not confined to 2D sound, so that the users may hear sound harmonized with the exterior environment. Moreover, olfactory stimulus can be realized by introducing artificial fragrances.

3.5 Responsive Contents Reaction

In general, it is hard for contents to be completely 'rational' or optimal in ubiComp environments. Nevertheless, contents need to respond 'appropriately' or select 'enough good' actions. Conventional AI or ALife approaches show limitations because they model contents based on stimuli-response mechanism that ignores higher-level behaviors such as creativity, humor, entertainment and psychological growth [14]. To solve the problems, many researchers employed behaviorism that has mechanical and formal characteristics [15][16]. Nowadays, there have been researches on synthetic characters that have their own motivations and desires and can interact with human beings in real-time [17].

In U-VR environments, contexts about users and environments play a key role in interacting with personalized contents. Thus, we need to consider reactions of applications that differently analyze the context according to its characteristics, and reflect the analysis to offering functions. That is, we need to analyze a user's context, e.g., the user's profile, location, manipulation, etc. Then, we apply the analysis to contents and show realistic contents suitable for the situation. Personalized interactions are offered by showing different responses suitable for a user's situations. For example, vrFlora is aware of a user's situation, and then shows personalized reactions suitable for the user's preference [18]. It is based on vr-UCAM2.0 (Unified Context-aware Application Model for Virtual Environments) [19]. It perceives a user's context, by exploiting preliminary contexts generated form ubiTrack and ubiFlowerpot. It adaptively analyzes the context according to its own characteristics, and then shows different contents according to the analysis.

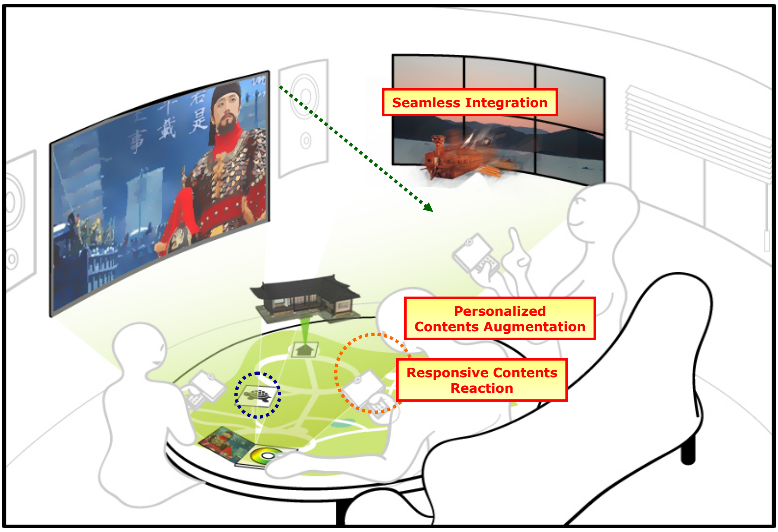

Fig. 3. Challenges for MAR in U-VR environments

4 Applications

ubiHome is a test-bed for applying U-VR-enabling technologies to home environments as shown in Fig. 4 [20]. Various kinds of pervasive sensors and services have been embedded in the ubiHome. Those embedded sensors and services form the foundation of the integrated smart home for multiple residents. For instance, ubiTV is a context-based TV application for multiple users. It provides personalized services to multiple users by utilizing ubi-UCAM 2.0. Additionally, it controls display devices by adapting a user's attention based on the user's direction [11].

Wearable computing platform is composed of physiological sensing devices, Wearable Personal Station (WPS), comfortable clothes, application programs [21]. Based on this platform, various technologies for personal information management have been developed, such as emotion extraction and analysis of a user, personal information retrieval, filtering, and saving, user profile analysis and update [22][23]. In Fig. 4, we can observe two services, namely, *MRWindow* and *ubiTV*, which can provide multimedia services based on user's preferences. A user disseminates his/her preferences to use services in ubiHome. However, the user can control the dissemination of his/her contextual information, i.e., whether to send services or not. Based on his/her preferences, a corresponding service is triggered.

Finally, there have been researches to achieve MAR, such as responsive contents, seamless integration, and personalized multi-modal interaction [24]. We are developing display devices, tangible interfaces and intelligent contents. In particular, the Responsive Multimedia System (RMS) for personalized virtual storytelling was established to provide users with a cultural, creative personalized experience by adapting overall concepts of U-VR [25][26][27].

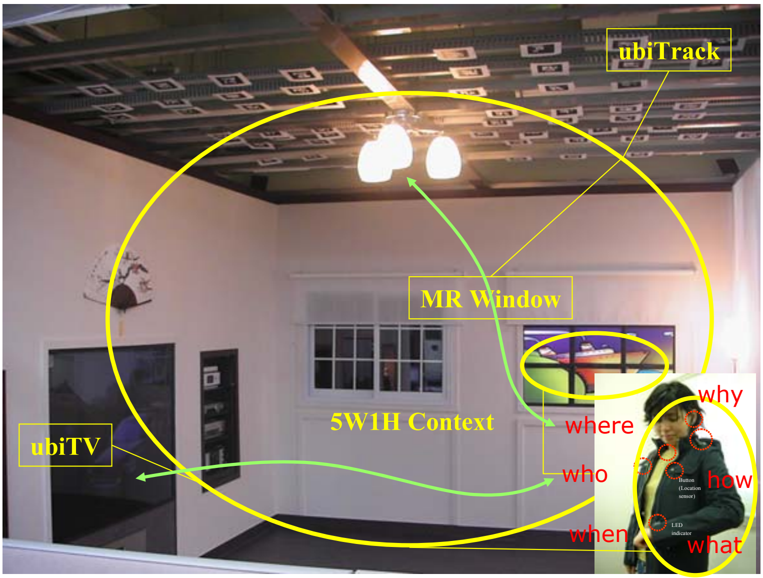

Fig. 4. ubiHome test-bed

5 Conclusions and Future Work

In this paper, a concept of Ubiquitous Virtual Reality (U-VR) was proposed and the future directions for U-VR were investigated. For this future computing environment, we defined Collaborative Wearable MAR and investigated several substantial challenges. We illustrated the usefulness of the presented concept by demonstrating some applications. However, there still remain many challenges that need to be addressed. We are to implement each component and integrate them to prove the challenges towards U-VR. We also need to do usability tests to evaluate whether Collaborative Wearable MAR is proper for residents with difference preferences.

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