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Toward ubiquitous VR: When VR Meets ubiComp

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Abstract—**We propose a novel concept of Ubiquitous Virtual Reality (U-VR) and promising approaches for realization of U-VR. Currently, Virtual Reality (VR) is still not pervasive in our daily lives despite the development of many computing 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 accomplished to enable applications to adopt to users and environments based on various kinds of contexts obtained from distributed yet invisible computing resources. In this regard, we consider how to revive VR in an infrastructure, i.e. ubiComp environments. Thus, we present a concept of U-VR that is realized through Collaborative Wearable MAR (Mediated Attentive Reality). In addition, we investigate five challenges that are significant factors in establishing U-VR environments. Finally, the proposed approach for each raised issue is illustrated. The usefulness of the presented concept is proved by demonstrating some applications.**

Index Terms—**ubiquitous VR, Ubiquitous Computing, Virtual Reality, Augmentation, Intelligent Contents**

I. Introduction

UNTIL now, VR has striven in order to create a computer-generated Virtual Environment (VE) to enable a user to feel realism through interaction that stimulates five senses. Especially, recent advances in computer graphics (CG), multimedia, parallel/distributed computing and high-speed networking technologies make it possible to construct Collaborative Virtual Environments (CVEs) [1]. The participants in the CVEs can collaborate with each other by exploiting audio, video and 3D graphics even though they are located around the world [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-oriented to user-centered. Consequently, intelligent services can be provided based on personalized information that is created or extracted according to user context. 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 this paper, we present novel approaches to remedy drawbacks 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. Therefore, by supplementing the weaknesses of VR with the help of ubiComp, we look for ways to evolve VR in ubiComp environments. In this paper, we present a concept of U-VR and investigate methods for realizing it. After describing associated key features, we illustrate the potential realization of U-VR with some applications. The usefulness of the proposed ideas is illustrated by presenting various applications.

II. Ubiquitous VR

A. Concept of ubiquitous VR

We define Ubiquitous Virtual Reality (U-VR) by extending the capability of human beings into a Real Environment (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. Consequently, U-VR is defined as '*A concept of creating ubiquitous VR environments which make VR pervasive into our daily lives and ubiquitous by allowing VR to meet a new infrastructure, i.e. ubiquitous computing'*. U-VR is demonstrated as Collaborative Wearable MAR (Mediated Attentive Reality).

B. Key Features of ubiquitous VR

1) Collaborative: We believe 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 perception of a human. The devices are smart objects, which prevail in a RE, and include wireless devices as well as wired devices. In U-VR environments, users can collaborate not only within a VE using conventional VR user interfaces but also within the RE. They can collaborate with each other by sharing realistic contents in RE and VE. Thus, users share their goal with each other through the U-VR environments..

2) Wearable: Users are provided with personalized services with the help of wearable devices, which manage personal

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information, anywhere and at any time in U-VR environments. This personal information is managed 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 is transparent to users so that they can concentrate on their tasks without the necessity of being conscious of the user interface.

3) Attentive: A user 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 a RE based on contextual information of environments and users. It is important that 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.

C. Five Challenges

We examine several challenges for implementation of U-VR. Thus, several challenges, which are significant factors in realizing U-VR environments, are investigated.

1) Resource & Contents Sharing

In future computing environments, many computing resources are pervasive and invisible to users. In addition, they have various performances according to their purposes. Thus, requirements for high performance computing resources to implement VR systems can be satisfied by using various computing resources that are pervasive in U-VR environments. Heterogeneity in future computing environments may cause new troubles, such as access, modification, transmission, maintenance, etc. Furthermore, network conditions should satisfy the 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 to carry out the tasks efficiently.

2) Personal Information management: In general, personal information need to be managed to deal with a user's desires, needs, and preferences. First of all, for collecting and processing user-related information from diverse sources, data unification must be achieved. It is also needed to learn the user's behavior patterns to infer user preferences, so that learning results can be reflected into the dynamic update of user preferences. In addition, 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. This signifies the need for mechanisms that provide members with the flexibility to adjust the granularity of context information disclosed to service providers.

3) Responsive Contents: Ubiquitous Contents need to be responsive so that they may respond intelligently to users [7]. That is, for realistic interaction, the contents should understand context in RE as well as VE. Moreover, the contents should also figure out user propensities and preferences. In conventional VR systems, artificial intelligence and artificial life techniques were employed for creating intelligent characters or natural interaction in spite of its high computational complexity. On the contrary, new frameworks or algorithms need to be supported for intelligence in a distributed environment since centralized servers are discouraged in ubiComp environments. 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 contents have to create responsive and believable behaviors reflecting users' context.

4) 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. 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.

5) 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. In addition, the synchronization is very important since the contents manipulation by one user should be reflected to the other users in real-time.

III. Proposed Approaches

In this chapter, we illustrate the proposed approaches for each challenge based on the provided conceptual figures.

A. Resource & Contents Sharing

In the conventional GRID computing, pervasive computing resources including data, devices, and computation power are employed to process a single task. However, when the task is divided for processing as a conventional grid computing, a real-time processing is difficult since a task-assigned computer transmits divided tasks to each computing resource, receives the results back after computing each divided task.

U-VR GRID computing may be one of the solutions to achieve U-VR. It 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, not only computing resources are ubiquitous, but also their performances are known to the other computing resources. Thus, U-VR GRID computing induces better performance in accomplishing 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 knows the performances of other computing resources, efficient task allocation is possible. The instantaneous interaction is also possible by processing the whole procedure in real-time. In Fig. 1, we can see that multiple users manipulate virtual objects.

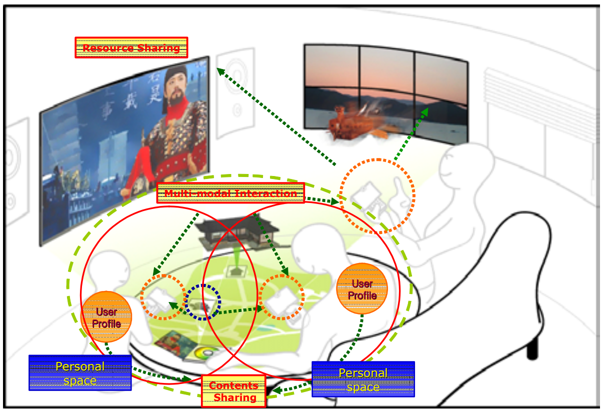

Fig. 1. Challenges for collaboration among users

B. *Personal Information management*

To be aware of context information from user's activities in a daily life, a unified context is needed to create context for triggering services users want by analyzing and integrating information obtained from various kinds of sensors. Thus, user-related information is systematically and extensively described as each field of Context5W1H in the unified context.

We need dynamically to update preferences by learning them. The details such as service properties or contents can be adaptively changed according to learning results. In the proposed approach, it is considered for a user to take care of his personal information protecting his right to privacy. That is, users need to distribute their personal information only when they indeed want to enjoy services. Fig. 2 illustrates an example of the personal information management. We describe the situation with a model scenario of a context-aware service [8]. The service provides the user with proper contents based on 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. 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.

C. *Personalized Responsive Contents*

In U-VR environments, the contexts about users and/or environments plays a key role in interacting with personalized services or 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, it applies the analysis to contents and shows realistic contents suitable for the situation. It offers personalized interactions by showing different responses suitable for a user's situations. Furthermore, it provides life-like impressions on the user through autonomous changes of responsive contents according to context by adaptively interpreting the users' situation and reacting according to its own properties. Various adaptive reactions can be employed by reflecting more environmental context of home environments. For example, vrFlora is aware of a user's situation, and then shows personalized reactions suitable for the user's preference [9]. It perceives user's context and adaptively analyzes it according to characteristics, and then shows different contents according to the analysis.

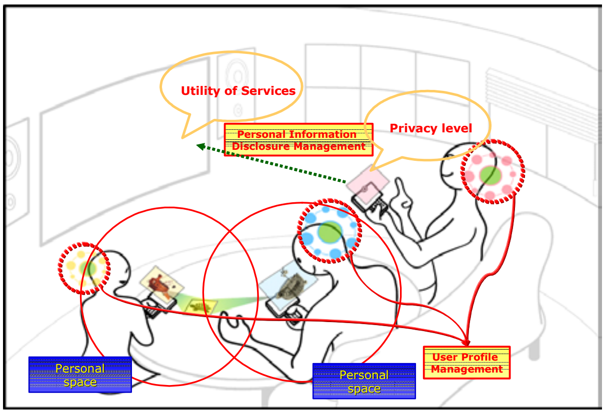

Fig. 2. Challenges for personal information management

D. *Personalized Contents Augmentation*

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. 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. Efficient personalized information retrieval is also required since desired or undesired information is flooded [10].

Note that the augmented contents should be integrated seamlessly with a RE. 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. 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.

E. *Multi-modal Interaction*

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.

In case of the auditory sense, it is rather convenient to transmit audio data over the internet. In case of the visual sense, during the last two decades, rapid improvements in computer graphics have enabled the generation of photorealistic effects, animations, and real-time interactive simulations. There have been interesting researches on transmission of tremendous amounts of photo-realistic data and real-time 3D data [11]. On the other hand, in case of the haptic sense, a haptic interface requires an update rate of about 1 *kHz* to accurately experience force feedback. Some researchers designed and implemented a prototype system with an adaptive intra-media synchronization scheme for haptic interactions for collaboration [12].

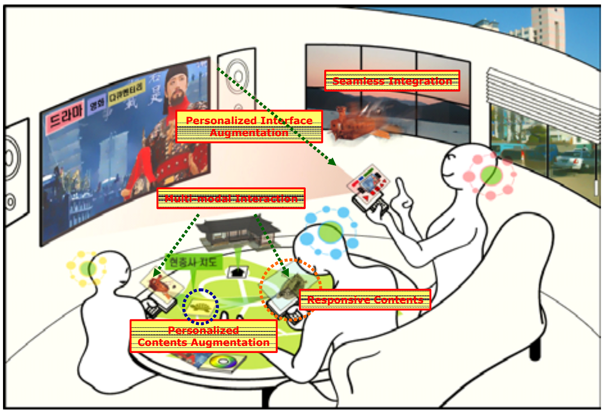

Fig. 3. Challenges for MAR in U-VR environments

IV. Applications

ubiHome is a test-bed for applying U-VR-enabling technologies to home environments as shown in Fig. 4 [13]. Various pervasive sensors and services have been embedded in ubiHome. Those 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.

Wearable computing platform is composed of physiological sensing devices, Wearable Personal Station (WPS), comfortable clothes, application programs [14]. Based on this platform, various technologies for personal information management have been developed, such as emotion extraction and analysis of a user, user profile analysis [15]. In Fig. 4, we can observe two services, namely, *MRWindow* and *ubiTV*, which can provide multimedia services based on user's preferences.

Finally, there have been researches to achieve MAR, such as responsive contents, seamless integration, and personalized multi-modal interaction [16]. 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 [17].

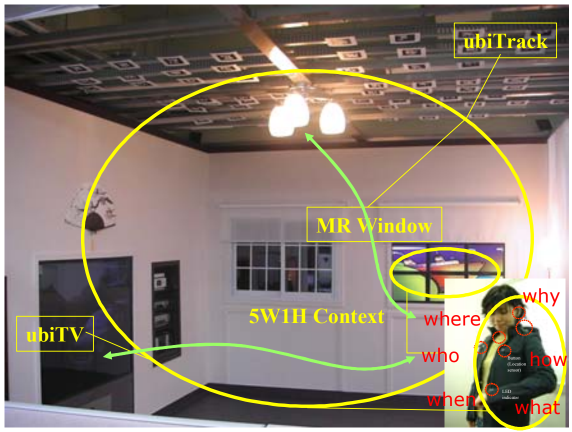

Fig. 4. U-VR environments

V. Conclusions and Future Work

In this paper, a concept of U-VR was proposed and the future directions were investigated. For the future computing environment, we defined Collaborative Wearable MAR and investigated several challenges. We illustrated the usefulness of the presented concept by demonstrating some applications. However, there 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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