Overview and Final Results of the MR Project

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Abstract

This paper describes the overview and final results of about four year project on mixed reality systems. This project is unique in that it includes the research themes on display hardware, such as head mounted displays and 3-D displays without eyeglasses, as well as the themes on algorithms, methodologies, and systems for mixed reality. During this project, related research activities have been stimulated by our achievements. In addition to these achievements, the technical demonstrations to be exhibited at this symposium are also introduced.

Keywords: mixed reality, MR project

1 Introduction

The Key Technology Research Project on Mixed Reality Systems (MR Project) is the first research project that seriously worked on the mixed realty technology. As the core organization of the project, the Mixed Reality Systems Laboratory Inc. (MR Lab) was funded by the Japanese government and Canon Inc. and launched on January 31, 1997. This national project is planned to be executed by the end of March 2001 collaborating with three universities, Univ. of Tokyo (Prof. M. Hirose), Univ. of Tsukuba (Prof. Y. Ohta), and Hokkaido Univ. (Prof. T. Ifukube). The MR Project has vitalized this field of research and acted as the mainspring for some similar derivative projects. This is the brief review of this project.

The project of four years, two months and one day is beautifully analogous to a Marathon race of 42.195km. One year of our research corresponds to 10km of the race.

First, we made a video to visualize what is the mixed reality (MR), which was not so popular at that time, in order to make anyone who see the video understand its concept. It was 3 to 4 kilometers from the start point. For the members of our project, the contents of the video showed the goal of the project. We also made simple prototypes of MR systems from what we had at that time to demonstrate the behavior of MR systems.

The start dash of the race was successful. We gathered a lot of advocates in Japan. These advocates became good advisory committees that could suggest us both on technology and application. It was on these days that the Special Interest Group on Mixed Reality was also formed within the Virtual Reality Society of Japan (VRSJ). Thus, the leading group of the race was formed stimulated by our daring start dash.

We exhibited "AR^2 Hockey," an MR air hockey game, in the emerging technology at SIGGRAPH 99. It was at the around the 15 kilometers from the start point. At the exhibition, more than 2,000 visitors experienced the MR system in which two players could share a space of mixed reality and play a game in realtime. The AR^2 Hockey gave many people a vivid image of the MR system.

An international symposium on mixed reality named ISMR'99 was held at Mach 1999, that was at the midpoint of the race [1]. We demonstrated all the results of the first half of our MR project as a special event of the symposium. The special event gathered quite high reputations and helpful suggestions from a lot of experts of this field. The big success in this symposium made the race quite interesting; not only gathered a lot of runners but also supporters who backed us up. The race was broadcasted or published by various mass media far more than before.

At the midpoint, we decided to review the first half of the race in order to make the last half more intelligent. We divided our research themes into two groups; one was to blush up the results of the first half for practical applications and the other to challenge to new targets. We presented our technologies at SIGGRAPH 99 [2], Imagina 2000, and SIGGRAPH 2000. What were presented at these exhibitions were revised version of the multiplayer shooting game which was first appeared at the ISMR'99. The appearance of them was almost the same but the accuracy and precision of the geometric registration and the performance of the see-through HMD were improved each time.

The impact of MR Project is proving to be not insignificant, as it reinvigorates the related R&D activities. The special issue on mixed reality was organized on VRSJ Transactions in December 1999. This issue includes eighteen papers. Within the European Union's Information Society Technologies Program, the mixed reality has been identified as one of the topics for pre-competitive R&D funding.

At the time of writing this article, we have run more than 40 kilometers and the stadium is in front of us. We can hear a joyous yelp from the stadium. A place to present out final results will be prepared at the ISMR 2001. Various MR systems we have developed are

tuned up for the final stage and we have already decided what we can show at the exhibition. One of the objectives of the last half of our race was to make as many people as possible experience and enjoy the results of our MR project. Here is the essence of our activity.

2 Official Target

Official goals of the project at the fellowship application were as follows.

A. Technologies for Merging Real World and Virtual World

(1) To develop technologies for building a mixed environment model from geometric and radiometric structures of the real world, using 3D image measurement and computer vision
(2) To develop technologies that enable the seamless and real-time registration of the physical space and a cyberspace
(3) To evaluate totally a mixed reality system integrated with 3D image display

B. 3D Image Display Technologies

(1) To develop both a compact and lightweight head-mounted display (HMD), with the aim of achieving a mixed reality system that incorporates state-of-the-art optics design theory
(2) To develop a high-luminance and wide-angle 3D display without eyeglasses
(3) To establish methods for quantitative measuring, evaluating, and analyzing the impact of 3D display on people as well as to obtain physiological information for preventing and minimizing hazardous effects

The distinguishing characteristic of our project is that it includes themes of group B to develop devices to realize themes of group A to consider methodologies and algorithms. Therefore, we have not only written papers and applied for patents but also tried to create actual systems in which one can interact with these systems in the realtime.

The results of the first half of our projects are documented in the literature [3]. Although the group A of the official goals are as stated above, we have actually considered the world of MR not by the categories stated above but from the two view points indispensable to think of the MR world; the augmented reality (AR) which augments the real worlds with synthetic electronic data and the augmented virtuality (AV) which enhances or augments virtual environments with data from real worlds.

For the themes of group B, we have researched and developed according to the categories stated above. Using the state-of-the-art optics, we are pioneering two kinds of stereoscopic displays for MR; see-through HMDs (ST-HMD) and a 3D display without eyeglasses. In addition, quantitative measurements and analysis of their impact on the human body are performed to obtain physiological parameters for use in the MR environments. Refer to our collaborator, Prof. T. Ifukube, for the details of the last topic, the impact on the human body [4].

Researches on AV, AR, and development of HMDs have been performed in the last half of our project as described below.

3 Augmented Virtuality for Complex Objects and Outdoor Scenes in Real World

As an approach to AV system, a new paradigm called “image-based rendering (IBR)” is focused on. Our IBR method based on ray space data can reconstruct an arbitrary view directly from captured multiple images. “CyberMirage” is a system that utilizes the method and integrate it with a conventional polygon-based graphic system. The system is designed to target a cyber-shopping in a virtual mall with photo-realistic products[5].

Since necessary technologies to realize this kind of system were already established through the research and development in the first half of the project, the last half was committed to solve problems on actual application. The extended CyberMirage now has shading and shadow casting functions [6]. Compression of ray space data has also been dramatically improved. We have also tried to downsize from the SGI Onyx2 system to a PC-based system in order to reduce total cost of the system and developed a dedicated rendering hardware as an acceleration board for the PC [7] (See Fig.1).

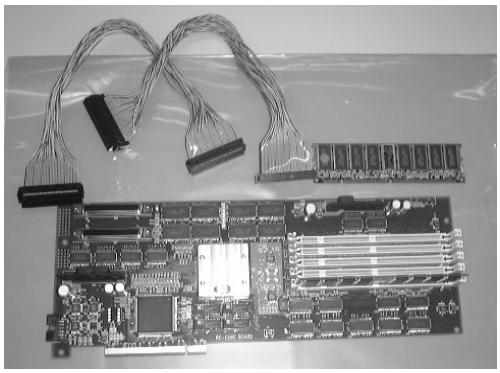


Figure 1 Ray Space rendering engine

Contents of the latest PC-based system are also refurbished. “The Yokohama Character Museum CyberAnnex” is the virtualize version of the actual

character toy museum [8]. A user of this AV system can interact with toys selected from the collection of world famous toy collector, Mr. Teruhisa Kitahara, which are reproduced in a virtual space with our IBR method to have realistic texture that one can feel as if they actually exist.



Figure 2 The Yokohama Character Museum CyberAnnex

Augmented Virtuality methods are not only used to render complex objects, but also applicable to construct a large-scale virtual environment based on the actually existing city. The aim of "Cybercity Walker" system is to enable complete virtualization of an actual city space [9]. Users of this system can walk through and look around a cyber city space with high photo-reality, although the space is modeled without any geometric data. Since we could recognize usefulness of the methods, now we are propelling the second stage in which we have to redesign the data acquisition system to obtain more precise data. Refer to our collaborator, Prof. M. Hirose, for the progression and latest results of this subject [10][11].

4 Progress and Challenge in See-Through Augmentation

As the counterpart of AV, an AR system superimposes computer generated images and data onto the real scene. In order to realize this kind of system, we have to solve the biggest problem of the geometric registration of virtual space onto the real space. Since the hybrid method that adjusts the output of commercially available physical head tracker with vision-based method, which was developed through the first half of the project [12], showed good and reliable performance, we decided to adopt this method and blush up various aspects of it for applications while setting up a new challenging subjects on more advanced AR system.

4.1 Multi-player entertainment in MR space

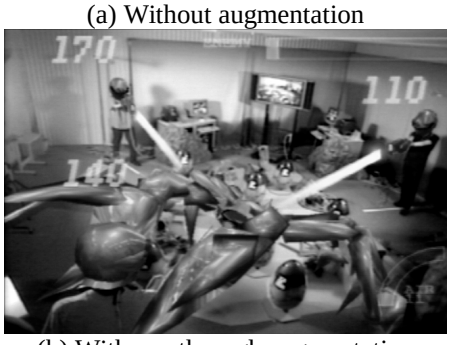
As the target of real-time collaborative AR system, multi-player entertainment was chosen. The first system is called "AR^2 Hockey" where players hit a virtual pack with their physical mallets while seeing each other through ST-HMDs [13]. "RV-Border Guards" is an extension of the technology developed for AR^2 Hockey. More than three players, surrounding a physical game field and wearing HMDs, defend the border between the real and virtual worlds by destroying virtual invaders. This system fully utilizes the physical space in front of the users as a 3D virtual space.

RV-Border Guards was given a special exhibition at the Innovation Village of Imagina 2000 in Monaco. This opportunity was taken to rework the real world objects, and the resulting millennium version was presented at the Centre de Congress Auditorium Monaco from January 31 to February 2, and a large number of participants, including Prince Albert, enjoyed this advanced attraction.

The newest version in this series was presented in "Emerging Technologies: Point of Departure" at SIGGRAPH 2000 in New Orleans. The virtual creatures, the real world objects, and the interface were all renovated. After this RV-Border Guards E.T. Special version, the name was changed to "AquaGauntlet" (Fig. 3).



(a) Without augmentation



(b) With see-through augmentation

Figure 3 AquaGauntlet: A multi-player shooting game in MR space

Now we are downsizing this realtime collaborative AR system. The first AR^2 Hockey system was run on a SGI Onyx 2 computer. Now, it is run on multiple SGI O2 computers. AquaGautlet system also run on multiple SGI O2 computers similar to the newer

AR^2 Hockey. The basic body of AquaGautlet system can be used for other applications and has a modular structure so that the system can accommodate additional users. This platform is now redeveloped so that it can run on PCs. “Contact Water” that will be exhibited at Media Art Gallery of the ISMR 2001 is made on the PC-based system and up to four player can play.

4.2 Embodied conversational agent in MR space

Such image overlay and registration techniques are also applied to a virtual interior design in an actual living room which is half-equipped with real furniture and fixtures. As a guide of this MR application, we embodied an anthropomorphic interface agent [14] who can understand the user's demand, and move and replace the virtual objects (Fig. 4). Most of other conversation-al agents exist in a rectangular window on a computer monitor, but our MR agent named “Welbo” is living in 3D space shared with a user. The agent's behavior and the user's preference are good subjects in HCI research.

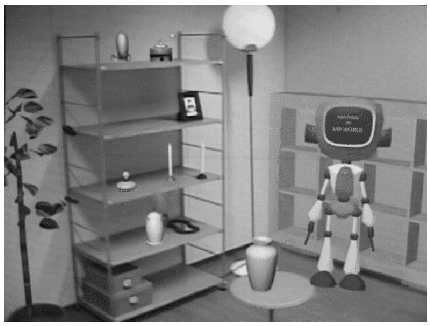


Figure 4 Embodied conversational agent in MR space

4.3 Occlusion of moving objects in mixed reality space

Once the geometry of the real and virtual spaces is correctly registered, the remaining problem to solve is the occlusion between real and virtual objects. To solve this problem, we have to know the geometric model and the position of a real object in MR space. It is easy when the real objects are static, however, the problem becomes drastically difficult when they start moving.

In order to solve this problem, we decided to use a realtime range finder which can sense the real world in the rate and resolution of video frames. We ordered a special devise (Fig.5) that calculate the depth of an object from images acquired by five video cameras using the multi-baseline stereo method. This range finder becomes the key component for the AR system of the highest level which can perform realtime depth keying (Fig.6). This system is planned to be exhibited at ISMR 2001 as the application to VFX (visual effects) for film production named “2001: An MR-Space Odyessy” [15].

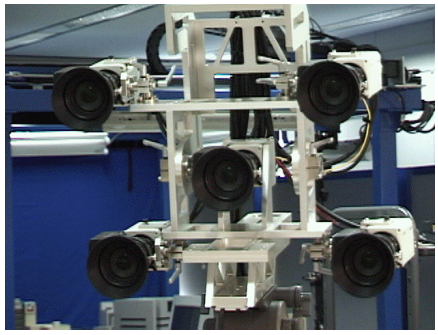
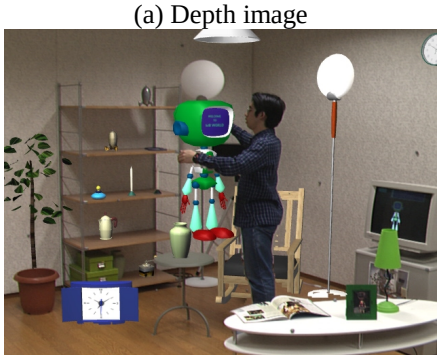


Figure 5 Realtime range finder based on multi-baseline stereo method



(a) Depth image



(b) With depth keying

Figure 6 Realtime depth keying

Note that the depth obtained from the range finder above is the range data from the center of five cameras and not the distance from an observer wearing an HMD. Thus, we have to convert it to the data seen from the observer's view point so that we can determine which is nearer to the observer than others. Our collaborator, Prof. Y. Ohta and members of his group are now studying this subject.

4.4 Wearable AR for outdoor use

All the systems so far developed in the MR Project are capable to be interacted with the user in realtime, but their use is limited to indoors. We have tried to

redesign them for outdoor use in a wearable fashion. For this purpose, some efforts are required to obtain a ST-HMD usable in bright environments and head tracking methods available at outdoors.

We have developed a new optical ST-HMD described later, which can adjust transmittance depending on the brightness of surrounding light. Although this gives a pair of stereoscopic images, a video camera is built at the center of unit so that it can be used for vision-based registration. The magnetic trackers are not suitable for outdoor use, we have combined high precision gyroscope and vision-based registration. In addition to these equipment, a small PC and a battery are packed in a backpack so that the system works in outdoor environment (Fig.7).

This outdoor system is named "TOWNWEAR (Towards Outdoor Wearable Navigator With Enhanced & Augmented Reality)" [17]. We are planning to let visitors experience TOWNWEAR by actually wearing it and go out to the town as one of the technical demonstrations at the ISMR 2001.



Figure 7 TOWNWEAR: A wearable MR system for outdoor use

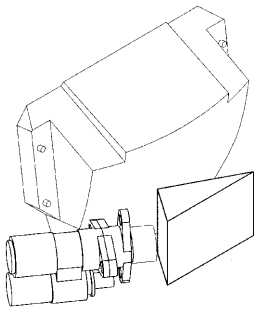
5 Innovation of See-Through HMDs

If our MR Project is reviewed to be successful, it is because we could develop an innovative ST-HMDs and could apply them to the actual system. We have developed six kinds of HMDs. Some of them are optical ST-HMDs and the others are video ST-HMDs. All of our HMDs utilize a free-form-surface prism.

The first AR^2 Hockey used a simple optical ST-HMD of 180K pixels with the view angle of 35 degrees. Development of 929K pixels (VGA resolution) stereoscopic ST-HMD with the view angle of 51 degrees gave us a great turning point. We could try various AR systems and their potential by using this type of HMDs.



Figure 8 A pair of camera attached to an HMD



(a) Optical configuration



(b) Outlook

Figure 9 COASTAR: Parallax-less video ST-HMD

At the earlier stage, the video see-through function of this HMD was built up by placing two video cameras on the HMD (Fig.8). The simple structure of this type captures images as though eyes of an observer are placed at upper front to the actual eye position and prevents an observer from looking 3D objects nearer to him/her correctly. We have developed a new type of video ST-HMD to solve this problem. This stereoscopic video ST-HMD has a pair of built-in video cameras and designed so that the optical axes of camera and display optics are coincide (Fig.9)[18]. Since the AquaGautlet system, this new type of HMDs named COASTAR (Co-

Optical Axis See-Through Augmented Reality) have been used for video see-through AR applications. This COASTAR display is also used in the technical demonstrations called “Magic Paddle”[19], “It's Really Sticking!”[20] and “Whack Them Out!”[21] by three separate universities that will be exhibited at the ISMR 2001. It is also used by “SOUND-EYE,” “Contact Water,” and “Serendipity” to be shown at the Media Art Gallery.

The next challenge was to develop an ST-HMD for the outdoor MR. Video ST-HMDs are far more advantageous than optical ST-HMDs for the photometric registration of virtual and the real world. However, optical ST-HMD can give an observer scenes in front of him/her more realistic than video ST-HMDs. It is also safer. Note that the optical ST-HMD is not suitable to the light place even if it is indoor. Moreover, we have to take the weather into consideration when using it in the outdoor environment. Thus, we have decided to add a function to adjust the amount of light coming into the HMD. Although it is basically an optical ST-HMD, it is convenient if it can capture image also by video that makes it possible to perform vision-based registration. For these reasons we have decided to place a camera at the center of observer's eyes. From the view point of HMD design, we have decided to adopt an optical system that places LCD (Liquid Crystal Display) panel near to the tail of eyes (Fig.10). We also developed a highly bright back light using white LEDs. The result is an optical ST-HMD of 1558K pixels (SVGA resolution) with the view angle of 33 degrees.



Figure 10 Optical ST-HMD for outdoor use

Now, we are struggling with an HMD having both functions of video ST and optical ST as the final development goal. The new HMD should have a pair of built-in video cameras placed so that the optical axes of camera and display optics are coincide as in COASTAR HMD. The optical axis of the third optics, optical see-through optics, should also be coincide with the axes of other two optics in order to realize a parallax-free HMD (Fig.11). The new HMD provides us an advantage of optical ST method while capturing scene without any parallax into stereo video for the vision-based registration. As shown in the Fig. 11, the HMD has a pair of half-mirrors in between the LCD panels and video cameras. In this structure, the cameras capture images of outside mixed with the images shown on the LCDs. Since this is not desired, the cameras and LCDs are so controlled that shutters of cameras are closed when the LCDs are working and opened to capture outside image when the LCDs show nothing.

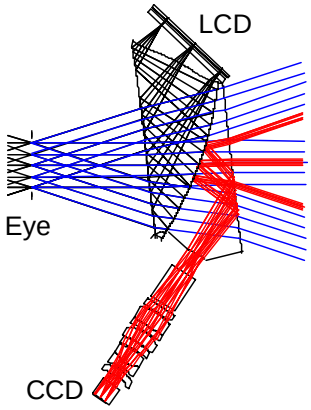


Figure 11 An optical and video ST-HMD

6 Other Topics

6.1 Technical demonstrations to see

At the ISMR 2001, the technical demonstrations from our MR Project will be held at a dedicated booth called “MR Technology Showcase.” The showcase exhibits several other MR technologies not stated above.

(a) Clear and Present Car

“Virtual Car System” developed by ART+COM AG in Germany is one of the most prominent virtual reality systems. The system, developed for the automobile marketing, can render a highly realistic image of a virtual car by controlling LOD (levels of detail) of a precision geometric model.

“Clear and Present Car” [22] is built by incorporating our mixed reality technology into this system. An observer wearing a COASTAR can examine a virtual car while walking around it. He/she can also examine a combination of virtual interior options and see a real scene through the virtual window while sitting on a real genuine seat.

(b) Wisteria World 2001

Four kinds of visual simulations will be presented in that one can see a real landscape mixed with virtual buildings. “Cybercity Walker 2001 [11],” an AV system in witch one can walk around a broad virtual space of a

city virtualize beforehand, also has this mixture function. On the other hand, one can experience scene of real town augmented by computer generated buildings and other objects using TOWNWEAR explained before. In between AV and AR is our Wisteria World system.

This is a system that incorporate functions of mixed reality into a telepresence system in which a user can control acquisition of images of a remote sight at his/her will. Since it is dangerous to put a car or a robot into the real town, our experimental system uses a miniature model of a town with a motion control camera in it. “Wisteria World 2001” will demonstrate the telepresence MR system by connecting our laboratory where the miniature model exists and the conference venue with a broad band network [23]. Visitors can walk around the remote town and make a scene simulation by putting a virtual building in it using a joystick control.

(c) Seeing Through, Inside Out

While developing TOWNWEAR, the outdoor wearable MR system, we have encountered with an interesting offshoot. “Seeing Through, Inside Out” [24] gives users with the same optical ST-HMD as TOWNWEAR an ability to merge virtual objects or characters onto a scene of the real world. This is also a member of four landscape simulation series. Technically, it is not so challenging as the pure outdoor system, since computers and head tracking sensors can be placed inside of a door. The new trial to utilize the outdoor scene of the real world as a background attracts interests of people in the fields of architecture and entertainment.

6.2 MR platform for R&D use

As explained so far, we have been appealing the potential of the MR technology through our MR Project. However, in order to make this technology so popular that everyone encounters it here and there, further research, development and exploitation of application are required. For those people who want to work in these fields, we are going to publish our results as “an MR platform for R&D use.” It serves as the core of various MR applications and includes the revised version of above COASTAR and a variety of programs involved in geometric registration. The specification of this software are now discussed in a working group consists of major groups in this field.

The MR Platform will provide a class library of C++ language so that even a user without expertise such as the geometric registration can rapidly prototype an MR system. This library is planned to accommodate wide range of users by attaching an ability for AR experts to extend their own methods. We are also going to release utility tools including camera calibration tool which is required as a preprocess for the geometric registration.

In our MR Project, SGI graphic workstations (GWS) have been used as the main platform. However, the MR Platform is now developed on the Linux OS (X86) to be convenient for everybody. Performance improvement on PCs and upgraded rendering environment by OpenGL on Linux system make it possible to build up an MR system equivalent to those on the SGI graphic workstations. A part of the library to be published as the MR Platform is also used in the “Wisteria World 2001” demonstration system that runs on the Linux OS.

We have already received not a few inquiries about the MR Platform. However, it will take one year or so until the platform is released since the substantial development of the platform will be started after the termination of the MR Project.

7 Concluding Remarks

The activities in the last half of our MR Project and demonstration systems planned to be exhibited at the ISMR 2001 are as stated above. Although a marathon race is used as a metaphor, the project is relatively short as a national project and the evolution of the project was much like a middle distance race. It is even a sprint race considering a speed and concentration on development activities.

Seamless merging of the real and virtual worlds was the slogan of our project. However, what is accomplished through the project is only a part of it and we still have a lot of problems to be solved. Even so, it is our pleasure to see the term “mixed reality” is becoming popular and the number of research groups of this field increases. We are far more pleased when we here someone wants to apply our research results.

When I was writing this paper, I still was worrying about troubles that make a runner fall down just before the goal. Now at last, however, I have to express our best regards to everyone who contributed to our project especially Ministry of International Trade and Industry (currently Ministry of Economy, Trade and Industry), Japan Key Technology Center and Canon Inc. who gave us this great opportunity of research and development, Prof. Michitaka Hirose, Prof. Yuichi Ohta, Prof. Tohu Ifukube and the members of their laboratory who were pleased to collaborate with us and accomplished favorable results and members of three advisory committees who gave us useful suggestions and various helps. Finally let me say that our project is not so successful without members of our project with passionate devotion and aspiration for the research; members of the Research Dept. 1 including Dr. Hiroyuki Yamamoto and Dr. Akihiro Katayama, members of the Research Dept. 2 including Mr. Susumu Matsumura and Mr. Naosato Taniguchi,

creators who made very charming and impressive contents for our MR systems, and Mr. Juji Kisimoto and others who gave us administration supports.

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