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**The ARP virtual reality system in addressing security threats and disaster scenarios**

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## The ARP virtual reality system in addressing security threats and disaster scenarios

### Abstract

Nations, corporations and political organizations around the world today are forced to deal with an increasing number of security threats. As a result, various organizations must find ways to adequately equip and prepare themselves to handle numerous dangerous and life threatening circumstances. Virtual reality is an extremely important technology that can be used across a variety of different fields and for a number of diverse applications, ranging from simulation training to visualization tools, in order to prepare for and manage disaster situations. Head mounted display (HMD) virtual reality systems attempt visually to immerse the user in a virtual environment. However, it is well recognized that latency, the delay in responding to a user's head movement, is a major shortcoming that plagues immersive HMD virtual reality systems. Excessive latency destroys the illusion of reality that such systems attempt to present to the user. A hardware architecture known as the address recalculation pipeline (ARP) and a computer graphics rendering technique called priority rendering, were designed to reduce the end-to-end latency suffered by immersive HMD virtual reality systems. This paper discusses the benefits of using the ARP virtual reality system in addressing security threats and disaster situations.

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# The ARP Virtual Reality System in Addressing Security Threats and Disaster Scenarios

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**Abstract**— Nations, corporations and political organizations around the world today are forced to deal with an increasing number of security threats. As a result, various organizations must find ways to adequately equip and prepare themselves to handle numerous dangerous and life threatening circumstances. Virtual reality is an extremely important technology that can be used across a variety of different fields and for a number of diverse applications, ranging from simulation training to visualization tools, in order to prepare for and manage disaster situations. Head Mounted Display (HMD) virtual reality systems attempt visually to immerse the user in a virtual environment. However, it is well recognized that latency, the delay in responding to a user's head movement, is a major shortcoming that plagues immersive HMD virtual reality systems. Excessive latency destroys the illusion of reality that such systems attempt to present to the user. A hardware architecture known as the Address Recalculation Pipeline (ARP) and a computer graphics rendering technique called priority rendering, were designed to reduce the end-to-end latency suffered by immersive HMD virtual reality systems. This paper discusses the benefits of using the ARP virtual reality system in addressing security threats and disaster situations.

## I. INTRODUCTION

With the escalation in security threats that grip our world in this day and age, labeled the 'age of terror' [1], nations, corporations and political organizations around the world are constantly under the threat of having to deal with acts of terrorism from various local or international terrorist groups. Recent events such as terrorist attacks, bombings, bio-chemical threats, etc., are becoming more and more frequent, and have highlighted the vulnerability and inability of various agencies in effectively dealing with and responding to such terrorist activities. On top of that, natural disasters like tsunamis or earthquakes also threaten the loss of life. To cope with these disaster situations, many government agencies and corporate organizations around the world now strive to adequately equip and prepare themselves against this rise in security risks as well as disasters events.

It is imperative that military personnel and emergency responders, who might include: fire departments, medical personnel, bomb disposal units, and others, be well prepared to handle these dangerous situations. These are people who risk their lives on the front line and will be even more at risk if they are ill-prepared or are poorly trained for the dangers of these life threatening conditions.

Preparations for addressing security threats are not only restricted to training emergency first responders, but are also vital in many other areas, for example, in planning building safety and evacuation procedures in the event of a fire, bomb or bio-chemical threats, etc. Such safety measures and precautions are essential in ensuring minimal casualties and fatalities in disaster situations.

Virtual Reality (VR) is an important technology that can be harnessed in preparing various personnel in different areas for handling security threats and disaster situations. VR can be applied across diverse fields, ranging from military to medical applications, for a number of different purposes such as in training simulations or for modeling and visualization tools.

Immersive Head Mounted Display (HMD) virtual reality is a means of visually placing a user in a believable virtual environment. These systems are designed to present the user with an illusion of reality, and to create a sense of presence in a virtual environment. In HMD virtual reality systems, computer generated images have to be presented to the user in real-time, based on where the user is looking in the virtual environment. Therefore user head orientation tracking is required for this purpose.

It is well recognized that latency is a major shortcoming suffered by current virtual environment and teleoperation technology [2]. Latency is the time delay between a user's actions and when the virtual reality system responds to those actions. This is especially problematic when it comes to HMD virtual reality systems because lengthy latency in head orientation measurements, can lead to inaccurate visual representation of where the user is looking in the virtual environment. This may cause the user to lose his/her orientation in the virtual environment and can also cause various side effects like motion sickness.

The Address Recalculation Pipeline (ARP) is a graphics display architecture that was designed to reduce the end-to-end latency perceived by the user during user head rotations [3]. In conjunction with the ARP, a rendering technique known as priority rendering was developed for the purpose of reducing the overall computer graphics rendering load, and to potentially facilitate the display of complex and more realistic graphics [4].

In this paper, we stress the importance and extensive uses of various aspects of VR technology by presenting several virtual environment applications and discussing their benefits.

We then present the ARP system and priority rendering technique, before discussing the advantages of implementing this system for a variety of applications.

## II. VIRTUAL REALITY APPLICATIONS

There are numerous virtual reality applications being used across a range of different fields in the world today. These virtual reality applications are also used for different purposes, for instance, in entertainment, simulation training, modeling and visualization, etc. These systems include a variety of interfaces, such as display devices, tracking devices, tactile feedback systems, and sound systems. In this section we present some examples of VR applications in a number of different fields and discuss the benefits of these applications.

### A. Entertainment

The entertainment industry has widely used computer graphics technology in attempts to provide consumers with commercially available 3D visual experiences. Gaming is an example of an area in the entertainment industry that has successfully made use of 3D graphics and virtual environments in order to enhance a user's interactive gaming experience.

Even the U.S. military has realized the benefits of virtual environments in gaming, and has attempted to capitalize on these benefits by releasing a game called America's Army [5]. America's Army is a free PC game which provides first person mission experience by presenting players or gamers with a realistic 3D virtual military training environment.

America's Army was developed by the Modeling, Virtual Environments and Simulation (MOVES) Institute in response to a 1997 report by the U.S. National Research Council, entitled '*Modeling and Simulation: Linking Entertainment and Defense*' [6], that specified a joint research agenda for defense and entertainment modeling and simulation. Developed in secret for two years, the MOVES Institute attempted to design an accurate and fully 3D gaming environment with technological efforts far more complex than previous attempts, in order to produce a game that was more advanced than any product currently on the market. Its launch in May 2002 received much praise and awards [7].

The goal of the America's Army game was to demonstrate life in the infantry for the benefit of young civilians. The purpose of the game is also in recruiting and enlisting soldiers into the army, by attracting teens of this digital age to take up careers in the U.S. Army.

### B. Simulation Training

VR is also acknowledged as an extremely important technology for simulation training. In a 2002 report by the Committee on Science and Technology for Counter Terrorism of the U.S. National Research Council [8], modeling and simulation was identified as one of the challenges to be addressed in countering the threat of terrorism, and has recommended the development and deployment of threat-based simulation models in training for disaster events [9], [10].

Macedonia [11] illustrated the importance of training simulations by highlighting the fact that weeks prior to their

actual mission, U.S. military pilots undertook many hours of simulated missions rehearsals over the skies of Afghanistan. These training simulations were accurately modeled and built from satellite images and aerial photos of the terrain, as well as intelligence data of the region. As a result the pilots were well prepared for flying over the rugged mountain terrain.

The military has been, and still is, a heavy investor in the research and development of tools and technologies for advancing various types of simulation training [11], [12]. Many of the current technologies used today have originated from military research and development. An example of this can be found in the development of the SIMNET system.

The SIMNET system was developed for real-time distributed military team training and mission rehearsal operations [13]. SIMNET was the first successful implementation of a large scale networked virtual environment and was developed by the U.S. Department of Defense. The success of this system led to the establishing of the Distributed Interactive Simulation (DIS) standard, a protocol fundamentally aimed at achieving interoperability linking simulations built for different purposes. The concepts originally defined by the DIS standard are widely used in non-military distributed networked virtual environment systems nowadays [13], [14].

Many other simulation training applications are being used by the military for all types of training, for example in flight simulations [11], naval firefighters training [15], naval gunfire support [16], etc.

Simulation training is not only confined to military applications. Over the years, VR has been increasingly recognized as an important tool in enhancing the field of medicine. Zatzchuk and Satava [17] listed four main areas in the medical field that VR helps to enhance, among these are education and training, medical disaster planning and casualty care.

BioSimMER is an example of a distributed multiple user VR simulation training platform used in the medical field. The purpose of the system is to train medical first responders to an act of bio-terrorism. The training scenario presented in BioSimMER is as follows: terrorists have taken over an airport and are holding hostages; they claim to have released bio-warfare agents and upon raids by law enforcement, the terrorists have detonated a bomb causing injuries, casualties and further dispersing unknown biological agents [18]. Trainees must enter into the bio-hazardous environment and give treatment to the virtual patients. This system attempts to train emergency responders in handling and dealing with complex tasks where situations assessment, critical thinking and decision making are required for success.

The Medical Readiness Trainer (MRT) is another fully immersive VR medical education environment. The MRT team argues that normal hospital 'bedside' teaching methods are limited and fail to capture the complexity of medical reality. By combining highly advanced medical simulation technologies with medical databases, the system seeks to expose trainees to the vast range of complex medical situations [19]. The MRT system provides believable environments where the individual

or the team is under realistic pressure of real life, time being a critical factor, and has to perform high intensity operations for patients.

These applications underscore the many benefits and advantages of using VR for simulation training. In the past, staging live training exercises was the way to realistically train military personnel and emergency responders. However, the task of planning, coordinating and executing live training exercises is an extremely expensive, time consuming and labor intensive undertaking. For this reason, live training cannot be held very frequently. Large scale military live training operations have to be conducted on large, remote and secluded locations like an uninhabited island. In this day and age, it is becoming increasingly difficult to find and secure such large training sites [12]. The next challenge would be in transporting all trainers and trainees involved to the training site, incurring a tremendous amount of time and money. With distributed VR, these large scale training operations can happen as frequently as required on large virtual battlefields.

Distributed virtual reality also means that training simulations can involve people who might be geographically separated over very large distances. These people can meet together and collaborate to perform tasks in virtual space, thus encouraging communication and cooperation between organizations. By sharing information and expertise, departments and organizations can be better prepared when encountering security threats. For example, medical personnel from another country might have greater knowledge and more experience on how to better handle patients exposed to a particular bio-chemical agent.

Using virtual reality, it is possible to recreate situations that in real life are too dangerous to stage live training. Unlike live training where accidents or mishaps can occur, virtual training simulations can be conducted at no risk to life. War or disaster scenarios can be realistically represented in VR. In this manner, users can get a practical feel of 'entering' the disaster zone.

Mission rehearsals can be accurately modeled based on latest intelligence data, location information and precise layout. The various personnel involved can practice their missions well in advance before the actual operation. Simulated mission rehearsals can also be observed and analyzed by the commanding officers and tactical errors or incorrect decisions can be rectified. Virtual training sessions can easily be recorded on the computers and debriefing sessions can be held to discuss mistakes a trainee might have made or to recommend improvements in handling particular situations.

### C. Modeling and Visualization

Virtual reality has extensive uses in the field of modeling and visualization. Through the use of VR technology in modeling and scientific visualization tools, it is possible to create and to simulate various events in order to understand the behavior of certain phenomena. For example, good physical simulations of interactive fires in virtual building environments as conducted by Bukowski and Séquin [20] provide building designers with a medium to evaluate the performance of building designs with respect to fire safety. From the simulations, architects and engineers can determine how best to

minimize structural risks in the event of a fire. Such interactive fire simulations also aid in the planning and installing of fire safety systems to existing structures and buildings.

In preparing for disaster situations, it is also crucial to plan building evacuation procedures for large human crowds in the event of fire, bomb or bio-chemical threats, and etc. Li et al. [21] describe their implementation of a real-time interactive VR simulation, that models the movements of a high density human crowd in buildings under the constraints of fire evacuation procedures. VEGAS (Virtual EGress Analysis and Simulation) [22] is another example of a system that models crowd evacuation in VR. These modeling and visualization tools can simulate crowd psychological reactions in panic situations, and are vital for planning efficient and safe evacuation routes through buildings, ships, airplane, etc. to minimize casualties and avoid any loss of life. These systems can be integrated with immersive virtual reality technology so that users can view from a first person's perspective the panic and chaos in the crowd.

Virtual environment modeling and visualization technology can also be used for operations management training. These tools can provide commanding officers with a high level depiction of a disaster scenario so that they can analyze the situation and determine how to effectively deploy personnel under their command. The Firefighter Command Training Virtual Environment was developed in collaboration with the Atlanta Fire Department [23] for the purpose of assisting the training of fire company officers, who are in charge of commanding and managing their team of firefighters. Among the reasons why the system was built was the fact that officers might not have experienced many fire emergencies situations over the course of their job.

## III. IMMERSIVE HEAD-MOUNTED DISPLAY VIRTUAL REALITY

There are many types of virtual reality systems; these include desktop virtual reality, fish-tank virtual reality, CAVE systems [24], Head Mounted Display (HMD) systems, etc. Immersive virtual reality is a genre of virtual reality that provides the user with full visual immersion in a virtual environment. CAVE and HMD systems are examples of fully immersive systems. The main aim of immersive virtual reality is to present the user with an illusion of reality. Nevertheless, latency is an acknowledged and well recognized shortcoming of current virtual environment and teleoperation technologies [2].

### A. The Latency Problem

Latency is defined as the delay between a user's actions and when those actions are reflected by the display. Excessive latency results in virtual reality systems that are hard to use and destroys the illusion of reality that the system attempts to present to the user. There has been much documentation on the effects of latency or lag on the user's sense of presence as well as hindrances to user task performances in virtual environments [25], [26].

The problem of latency is particularly challenging in HMD systems, as delays in head tracking information can lead to

inaccurate visual representation of where the user is looking in the virtual environment. This often forces the user to have to wait for the system to catch up, before performing further actions in the virtual environment.

This is a major concern in HMD virtual reality systems designed for real-time training or visualization, where time is a critical factor in situation assessment. Lengthy latency can have a huge impact on a user's reaction time and performance. For example, latency or lag in a building evacuation simulation might cause a user wearing a HMD to become disoriented and lose his/her sense of direction. Latency in the system might also cause the user to walk into virtual walls or doors while attempting to navigate through building, due to errors in presented visual direction. Prolong use of systems with excessive latency can also result in the user experiencing serious side effects like motion sickness.

### B. The Virtual Reality Address Recalculation Pipeline

The Address Recalculation Pipeline (ARP) is a graphics hardware architecture designed to reduce the end-to-end latency perceived by a user during user head rotations in immersive HMD virtual reality systems [3]. The ARP is fundamentally different from conventional VR systems in that it performs a concept known as delayed viewport mapping, whereby viewport mapping is performed only after the rendering process, instead of the usual way which requires viewport mapping to be done prior to rendering.

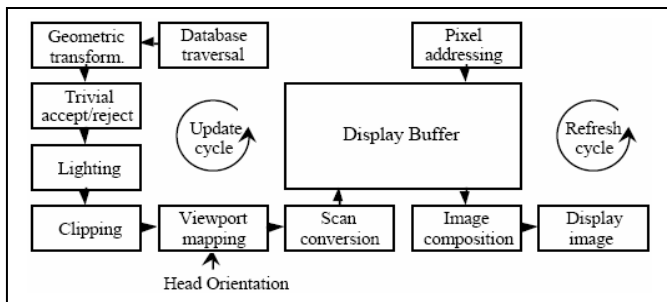


Figure 1. Conventional virtual reality display architecture.

Figure 1 shows the normal sequence of events in conventional VR systems. Conventional systems require head orientation information, i.e. where the user is looking, to be known before the rendering process can commence. This means that even with the powerful rendering engines available today that can render over 100 frames per second, conventional VR systems are still bound by the need to obtain up-to-date head orientation information prior to the rendering process. Therefore if the system cannot keep up with a user's actions or if the processing load is too great, the displaying of frames will be delayed, consequently leading to rather jerky displays and/or increased latency.

The delayed viewport mapping approach used by the ARP system is depicted in figure 2. By implementing delayed viewport mapping, the system effectively detaches user head orientation information from the rendering process. In this respect, user head orientation information only has to be known just before the first pixel of a frame has to be displayed on the HMD device.

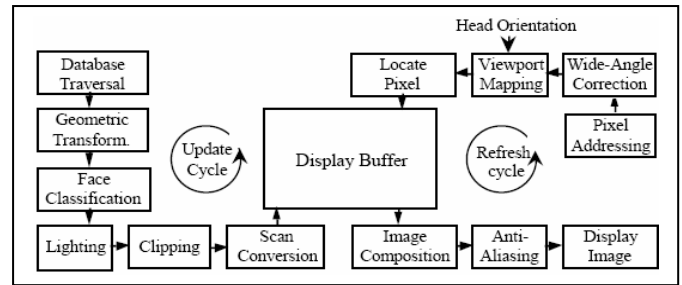


Figure 2. Delayed viewport mapping.

In order to implement delayed viewport mapping, the scene surrounding the user's head has to be pre-rendered onto display memory. Viewport orientation mapping is then only done when the HMD device requests for an update, and is performed by mapping relevant sections of the scene already residing in display memory. This not only guarantees an interactive response but has the effect of reducing the latency perceived by the user during user head rotations. This is extremely important in HMD systems as even the slightest rotation of the user's head will completely invalidate the currently displayed image. A comparison of the latency components between a conventional VR system and the ARP system is shown in figure 3.

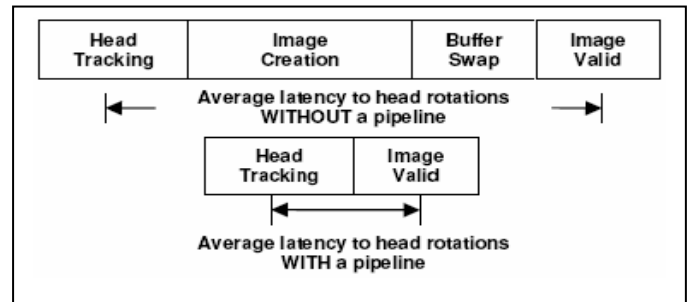


Figure 3. A comparison of rotational latency components with and without an Address Recalculation Pipeline.

### C. Priority Rendering

Priority rendering is a specialized rendering technique developed for use in conjunction with the ARP system, and has been shown to be successful in reducing the overall rendering load [4]. Priority rendering is based on the concept of image composition, whereby multiple display memories and multiple renderers are used, and different sections of the scene are rendered onto different display memories before being combined to form an image of the whole scene.

The idea behind priority rendering is that in a scene that surrounds the user's head, different objects in the virtual world will appear to move or change at different rates, whilst the user is translating through the virtual environment. The display of dynamically animated objects or objects closer to the user will appear to change at higher rates, as compared to objects further away from the user. It is therefore possible to update different objects in the scene on separate display memories at different update rates, this successfully reduces the overall rendering load and allows for the generating of more complex and realistic scenes.

Further reductions to the rendering load have also been found to be possible through the use of large object segmentation and region warping together with the priority rendering technique [27]. Using this approach, large objects in a scene can be segmented into smaller sections and different sections of the same object can be updated at different update rates.

#### D. Related Technologies

Similar concepts of using multiple renderers and/or multiple display memories have also been looked into by other researchers.

NVIDIA Corporation has recently launched their Scalable Link Interface (SLI) technology which combines the rendering power of two Graphics Processing Units (GPUs) on a single system with output to a single monitor [28]. The SLI technology uses software drivers to dynamically share and balance the load between the two GPUs. One of its rendering modes is called split frame rendering. In split frame rendering, the frame is divided into two portions and rendered separately. Each GPU renders one of the two sections, before the sections are digitally composited to form the whole frame.

Microsoft Corporation has also been researching a 3D graphics and multimedia hardware architecture which they code named Talisman [29]. One of the main uses of the Talisman architecture is for use in animation. In smooth animated sequences, most of the display remains the same from frame to frame and it would be wasteful to have to re-render the entire frame. Therefore the Talisman architecture takes advantage of similarities between sequential frames, by allowing individually animated objects to be rendered onto independent image layers before being composited together to form the final display [30]. In this way, only changing image layers have to be modified or re-rendered.

#### IV. BENEFITS OF IMPLEMENTING THE ARP SYSTEM

The ARP virtual reality system presents an approach that significantly reduces the rotational latency suffered by existing conventional HMD virtual reality systems. This is extremely important in real-time training and visualization applications because time is a critical factor in emergency situations. The user will have difficulty in assessing the situation, and this will consequently affect his/her decision making, reaction time as well as task performance in a latency plagued system.

A method used in many graphics systems to reduce the latency and to increase system performance is Level-of-Detail (LOD) management. This technique entails reducing the complexity in a scene by degrading the display details of non-essential objects in a scene, so that less rendering and computational power will be taken up. However it is difficult to find a criterion for LOD switching in high-risk simulations [31], as it is both impractical and unrealistic to pre-determine or to restrict a user's focus of attention in an emergency or dangerous scenario since everything in the scene might potentially have a bearing on the user's decisions and actions.

Using priority rendering in conjunction with the ARP system allows for the rendering of high quality and more

realistic scenes in real-time, without having to compromise on the details of a scene, the performance of the system or the user's immersive experience. This provides for a better and more practical training or visualization experience, as the trainee will be under real life pressure to make critical decisions based on the wealth of information and detail contained in the surrounding scenario.

Application of the ARP system can also be extended to teleoperation technologies [32]. Teleoperation or telerobotic technology provides a way from humans to operate machines from remote locations. This means that the human operators can send a robot into places that might be dangerous or hostile for a human, and control the robot from a safe location.

On typical telerobotic applications, a video camera is mounted onto a robot to capture video images that have to be transmitted back to a console computer. This provides the operator with visual feedback of the robots surrounding environment that can be viewed on a display device like a HMD [33]. In order to look in another direction, the operator has to send commands for the robot to rotate its camera to a new position. Due to the latency in transmitting these commands, the operator might potentially over-compensate or under-compensate for the latency resulting in the camera over-rotating or under-rotating, thus giving an incorrect view and requiring multiple tries to correct the error.

It is possible to remove this latency by using multiple cameras to transmit visual feedback to an ARP system's display memory. In this way, when the operator wishes to look in another direction, the view presented to the operator will be immediately mapped from the scene already residing in the ARP system's display memory.

The implementation of this approach will be advantageous on robots used by bomb disposal units, or robots used to enter into bio-hazard zones. This will avoid any risks to the human operators.

Real-time operations management systems can also greatly benefit from the use of the ARP system. The purpose of such systems is to facilitate "out-of-the-corner-of-the-eye" situation awareness in time critical situations being viewed through VR displays, like HMD devices [34]. Live up-to-date information regarding a disaster situation can be feed into the system so that analysts or commanders can visualize and gain an understanding of the current state of affairs in real-time. Fast assessment of the situation based on accurate information in operations management can assist in the deployment and mobilization of the various personnel involved in order to effectively deal with the situation. It is therefore imperative to minimize the latency in such systems.

#### V. CONCLUSION AND FUTURE WORK

The importance of virtual reality applications in preparing various organizations for addressing security threats or disaster situations cannot be overstated. This paper has shown the benefits of VR applications in areas such as simulation training, modeling and visualization, teleoperation, and others. We have described the ARP architecture as well as the priority

rendering technique, which provide a means of decreasing latency and increasing realism for virtual reality systems.

We are current experimenting with approaches to further improve the overall rendering load reductions achievable in priority rendering, using methods like large object segmentation and region warping [27], [35]. Future possibilities include compositing computer graphics with real-time video capture on the ARP systems multiple display memories, in order to create more realistic virtual/augmented reality experiences.

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