Designing a Virtual Reality Game for the CAVE

S. Livatino, V. Agerbech, A. Johansen, B. Johansen

Medialogy Studies, Aalborg University Copenhagen, Denmark

Abstract

Virtual Reality has for many years been a technology which has stagnated in application and software development for games. What was possible and created ten years ago for games in VR environments is still being developed. The applications available for VR environments have increased but they mostly remain related to scientific purposes while computer games in VR only show a part of their actual potential. The game industry has begun to see the possibilities of VR games in a near future with the implementation of some popular games to a CAVE system. However, a full immersion VR solution still remains uncommon and expensive. This paper aims to demonstrate the potential of VR games, and in particular games for the CAVE, now that affordable solutions are close to reach as more powerful hardware is available at low price. The focus is also on the methodology to be pursued while designing a VR game. Results were encouraging and tests performed on a first prototype demonstrates system feasibility.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism

1. Introduction

The birth of virtual reality has its roots deeply planted in the technological achievements of the American research for the US army. For over forty years the development of new interfaces and visualizations has progressed into what we define as Virtual Reality (VR). It was especially in simulation that the new technology began taking form. The simulations gave researchers a unique possibility to test and experiment for example with models for airflow. Today the technology is being used in many different fields from research to software development, e.g. concept visualization, visual data mining and simulation. VR has evolved a lot and many immersive visual displays have been invented as well as application and peripheral devices.

Several systems have been developed for VR with different display and interaction possibilities. Systems with large visualization screens have been proposed for immersive presentations, e.g. Powerwalls, Panorama arenas, usually coupled to a 3D stereo visualization system. On the other side, system for individual use but allowing for high interaction (i.e. where the generated scenes respond to user movements), e.g. the CAVE system, or system with Head Mounted Display (HMD). Figure 1 shows examples of such facilities.

VR systems may provide different input signals to the human sensor modalities in order to enhance a sense of presence in the generated virtual world. Other than vision, audio and touch represent main stimulated human sensors. However, being the vision the dominant human sensor modality, large attention has been payed to the visualization aspect. In particular, different technologies have been developed for generating 3D stereo visualization systems. Among them, passive systems as those using Anaglyph and Polarized filters solutions and active systems typically based on shutter glasses. The above mentioned systems usually require a user to wear special goggles, or a system with separate displays for each eye (e.g. HMD systems). Figure 2 shows some typical solutions.

1.1. Virtual Reality for the Masses

The development of technology for VR continued in the military sector, but in the early 1990's it found its way to the consumer market and the masses. Film became one of the first media to incorporate and advertise for this new medium. Films like: The *Lawnmower Man* (1992), *Johnny Mnemonic* (1995) and *The Matrix* (1999) have all provided us with a fictional glance of the possibilities and the future of VR applications and systems. We could say that the *Lawnmower*

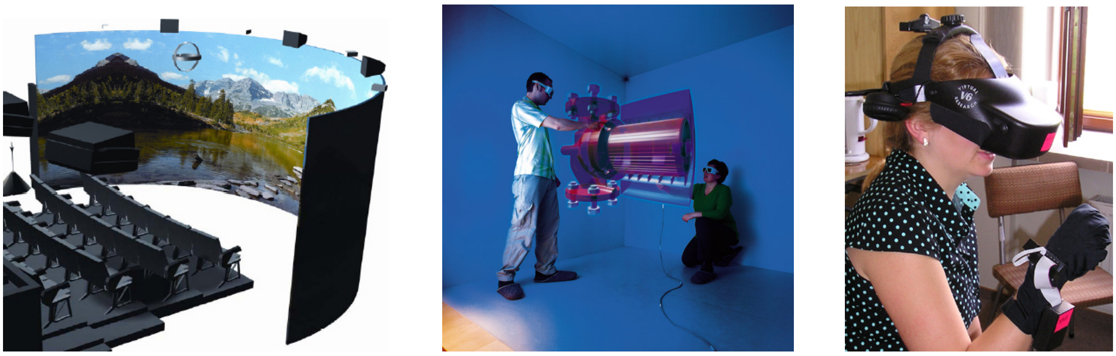

Figure 1: *The Panorama (left) and a representative view of the CAVE system (center), at the Aalborg University VR Media Lab. The HMD system with data glove (right), at the Institute of CS, Tech. University of Lodz.*

Man and the emergence of VR games introduced VR to the masses. Both the movie and the technology created a "boom" within the research of VR. Suddenly the technology became more accessible and developers were able to create new applications. This became especially noticeable within the entertainment area, where game consoles had dominated the market since the early 1980's. As within many new technologies, the interest grew and companies like *Atari* focused on VR games. *Atari* in cooperation with *Virtuality Inc.* manufactured the *VR Pods*, [vwe], and it scheduled to introduce the *Jaguar VR*, [ata95], (console with VR Pack) in 1993 to the consumer market offering a HMD system to a low cost price of only 300$. Many other companies in the early 1990's competed in releasing products for the consumer market, but history shows that they would come out "empty handed". Few succeeded, but they saw the same fate due to a lost of interest, which main reason was not an unaccessible technology, but the increased competition of the console market. Game companies and especially the console developers began introducing 16 and 32 bits game machines (e.g. *PlayStation*, *Sega Saturn & SNES*), which introduced better graphics and better games due to this new technology, but for many companies who were involved with games for VR, it became "make or break" and therefore a lot of the projects and development was abandoned and focus was shifted back to the console market.

The evolutionary steps of the technology for VR environments has not progressed much. New projectors and better graphic cards allow for higher quality and faster rendering, but a VR system still costs a minor fortune. This is the main reason behind VR's lack of success within the consumer market since the downfall of the early 1990's. After this era the development of VR lacked the backup of the industry and VR became more dominant and interesting for universities and research projects. The technology evolved and found new roots in the scientific fields where VR has through the years proved a great success within the professional industry, car manufactures, design companies, to universities and military institutions. VR represents a cheap substitute to evaluate designs and run simulation before setting full scale production in motion. At the universities VR games are still being developed as a means to illustrate the possibilities of VR within various VR environments, but not to promote the technology again. As a conclusion we can identify two main problems which prevent VR to enter the consumer market:

- there are not, currently, new game applications developed specifically for VR;
- the cost of producing a VR facility still is too high for the consumer market.

2. The Resurrection of VR Games and the CAVE

Despite of the stagnation of the development of VR games, the research in industry is slowly changing direction. The reason is due to the advances in CPU and GPU technology. Up until very recent years a lot of VR systems have been based on big *Silicon Graphics* machines, because of the processing power needed to render and visualize the graphics in real-time on multiple displays. This kind of performance can now be delivered by much cheaper PCs or cluster of them. This is a positive direction that hopefully will increase the interest of researchers, but also of game developers and consumers, and will make all them realizing that the technology is not the same existed ten years ago. In fact, the last 15 years the development and improvement of computer technology has come a long way. Today personal computer and workstations are present in many homes and universities around the world. This has not only benefited the computer science community, but especially the game industry which in 2005 has sold for almost 26 billion dollars world wide. It is in times like these, where the VR community and VR games have the opportunity to promote the technology. Researcher Paul Rajlich and Jeffery Jacobson from Visbox have taken the first step by implementing

Figure 2: *The Powerwall arena at the VR Media Lab (left). The projector system with polarized filters for the Powerwall system at the Aalborg University Copenhagen, Medialogy Lab (center). Goggles for 3D stereo visualizatin systems (right): red-cyan Anaglyph on white frame, Polarized filters on black frame, shutter glasses on gray frame.*

the games *Quake* and *Unreal Tournament* in a CAVE-like setting, [vis06]. This shows the game industry the possibilities of VR and how far the graphics for VR environments have come. The implementations of games inside a VR environment has attracted the attention of the gaming industry. Paul Rajlich invited game developers for a preview demonstration of his work. It triggered a positive response which could be a turning point. This may also inspire the gaming industry to start researching in new and cheaper VR systems and especially games specifically designed for VR. Despite it is still too early for the average consumer to have the space for a CAVE system in their living room, it does show the possibilities. A new genre called serious games has slowly crept into the gaming industry, which has the potential to be the genre which breaks the barrier of the current stagnation of VR games. Furthermore, with the improvement of the technology in computers and gaming consoles, new methods and games are appearing on the market.

2.1. Peripherical Development

With the introduction of large arcade simulator games and the *Sony EyeToy* for the *Playstation 2*, new user interfaces are appearing. The new interfaces allow the player to interact with the game on a whole new level. Instead of performing the interaction through keyboard and mouse actions, the human body is now becoming the new interface for controlling the game. This is especially evident within the VR community. In particular, it has existed in VR for quite some time the thought of using our physical actions to experience and control objects in a virtual world. The physical interaction also provides a more immersive feeling in addition to the immersive display.

The CAVE environments provide limited space around the user. Nevertheless, one can move around the limited space inside a CAVE in order to progress further in the virtual world and peripheral devices can be used in connection to use movements. A research project at the University of Tsukuba Japan has devised a solution called *CirculaFloor*. The *CirculaFloor* is a locomotion interface, which uses circulation of moveable tiles. The tiles give the ability to physically walk through the virtual world without going anywhere [Iwa04]. New solutions related to locomotion in a CAVE environment are being studied at the Aalborg University Copenhagen, [Nor05].

3. Creating an Affordable VR System

In order to investigate the main issues which prevent VR to enter the consumer market, as mentioned at the end of section 1, we try to apply the latest advances in hardware and software towards the creating of an innovative VR game. We are not just interested in developing a working prototype, but also to assess its applicability for a future market. Two important parameters which need to be considered are then technology accessibility and affordability. In other words, it is a matter of cost-benefit that our users will have to consider before plugging in a new technology for their creative hub.

VR systems are very expensive having a price tags ranging from 50,000 to over 1 million$. This happens because they feature state of the art technology. E.g. at the Siggraph 2002 *Mechdyne* and *Fakespace* announced multimillion dollars VR systems and support products [Isd02]. There do exist several VR system manufactures who claim to produce affordable systems, e.g. the *Geowall Consortium*, the *SAS Cube*, the *VizBox*, the *VizTek*, [umb01]. However, from our research, the price of a *VizTek* system ranges from 46,000$ for a single wall system (active stereo 6x4 screen, 800x600 at 120 Hz and 1000 Lumens, sound system, VR simulation environment, high-end workstation) to 740,000$ for an ICUBE (an active 6-walls turnkey system 1280x1024).

The above still represents an unaffordable budget for many corporations and research institutions, not to mention home applications. Therefore, to create a low cost VR system one must compromise. The above does not necessarily mean to minimize the available options. In particular, when

choosing to create a low cost VR system it is important to consider the followings:
- *Budget*. Setting a budget limits available options which makes easier to evaluate the cost-benefit;
- *User Requirements*. Carefully selecting among available technologies according to user needs, may turn out to cut the cost down. E.g analyzing characteristics of different systems for 3D stereo visualization (anaglyph, polarized, active), the use of a V-CAVE instead than a full scale one, etc.
- *Quality*. Choosing among different quality equipment concerning projector, screen, workstation, tracking system, etc., also connected to the user requirement aspect.

The above considerations are based on purchasing complete system solutions. If the price tag is still too high, then creating the system in-house is the way to go. Following the above consideration we have decided to crate our "affordable" system in-house. Section 6 will describe the system we have designed together with consideration on performed tests. Next section will instead present criteria for designing a VR game for the CAVE.

4. Designing a VR Game for the CAVE

A main goal of this work has been to develop a game specifically designed for the CAVE. Nevertheless, most of the considerations and findings concerning game design for the CAVE will apply to VR game design in general. As stated before the main motivation behind the presented work was a feeling that the possibilities provided by the CAVE technology had never been fully exploited. We wanted to develop a game application to demonstrate the potential of this technology for game design. Since we were not able to find any significant research result in this field we had to device our own statements to test and explore. To do this we have tried to identify some aspects and features that could be specifically important in creating a CAVE game experience.

4.1. What makes the CAVE unique?

To understand how we can take advantage of the possibilities provided by a CAVE system we first have to identify what characterize it the most. The 3 main features are:

- Omni-Directional Visualization
- Region of Exploration (REX)
- User Interface

When designing a game application the above features lead in turn to design anew the entire game, being that these features are not present in traditional console games.

- **Omni-Directional Visualization.** This aspect concerns with the way he output is displayed. In a conventional game the player has to navigate in his environment by moving the mouse device to obtain new views. In a CAVE system the player has instead an omni-directional view of the scene at all times. This means that we have a new possibility for creating an omni-directional visually immersive game scenario. To benefit from this aspect a CAVE game should be built around an environment designed for omni-directional viewing. Where we had corridors and narrow confined spaces working well for conventional games, panoramic scenarios would now be more suitable for CAVE games. To enhance this further, the vertical depth of the scene can also be included as a part of the scenario. In a CAVE system the floor and ceiling are also displays allowing for a vertical span in the scene. In fact, let us observe that one of the current uses of CAVE technology is in the field of phobia treatment. This includes the fear of heights, since it is one of the properties well portrayed in a CAVE.
- **Region of Exploration (REX).** This aspect concerns with the space available around the user. In fact, other than being suitable for panoramic scenarios, the CAVE provides space in the near proximity of the player which is available for game designers. Virtual graphical elements positioned within the CAVE dimensions give the illusion that objects are right in front of you. In fact, in CAVE environments you often see the user reaching out for objects. The sense of presence in a game can be enhanced by this feature, and objects in a VR application can have the same scale as in the real world, unlike conventional displays. The possibility given by the REX may give the game designer the possibility of creating a virtual world inside the CAVE which can be physical challenging for the user, as well as it gives the game player the possibility of building up objects, interactive menus, interface devices, etc. Furthermore, the REX can be exploited to insert (or bring with you) in the game, environment real objects. This allows for mixed reality scenarios which may increase a sense of presence in the application, as investigated in the EU research projects BENOGO related to Presence in VR, [gra05].
- **User Interface.** This aspect concerns with the way the application is interfaced. The application interface in CAVE systems allows for controlling and interacting with a VR game through body movements. This is mostly due to the presence of tracker systems. Most CAVE systems have two tracking sensors: one tracks the head orientation, while the other is often connected to a peripheral device (e.g. a 3D mouse). This characteristic also provide a big creative input for game designers.

4.2. Navigation, Motion Sickness, and other VR Game Characteristics

In CAVE systems the user has limited REX depending on the physical dimension of the VR system. As mentioned above one or more sensors are often attached to a peripheral device. The device is often used to navigate through a virtual world, when the physical dimensions limit the user in pursuing forward. This form of control works like a computer mouse. Other possibilities for navigation are being developed. In particular, at the Aalborg University Copenhagen the development of a shoe peripheral device has been investigated, where a pressure sensor is placed on each shoe and this gives the ability to walk/ run on the spot or around the CAVE, by adding a translation to the user position in the virtual world, [Nor05]. This form of navigation interface enhances presence, but also adds immersion to the application, because the user body is in direct interaction with the VR game. One can also imagine that having a more physical form of navigating through the world can prevent or decrease the amount of motion sickness.

In relation to the latter, considerations should be made to motion sickness when designing a VR game. This effect is often experienced in CAVE systems, especially by new users. Therefore in the design of game elements, it should be considered not to create too much motion within the scene and especially the floor/ground. However one must also consider that effects such like floor motion, etc., can also be an element within the game to provoke a certain feeling or mood as mentioned above (e.g. the fear of heights).

Another relevant aspect for VR game developers, (not developed for the presented work), is related to sound design. In a CAVE system the generated sound may strongly affect the perception of the VR game and it adds an extra dimension to the virtual world of a CAVE. However stereo could be used, (probably most effective with wireless headphones), an eight point sound system would be most suitable. In particular, a similar sound system has been under development at Aalborg University Copenhagen while developing a VR game for the presented work, The development objective was a CAVE system and early experiments illustrated the potential of such system, [BG05].

Despite certain elements primarily can only be experienced in a CAVE system, this does not exclude other VR systems. The main difference lies within the scale of the display and the sort of 3D stereo visualization technology being used. A lot of different virtual reality technology exist and it often is a matter of evaluating different systems and find the one which fits our demands and usage requirements.

5. VR Game Implementation

This section describes how we have tried to implement in our game the design ideas presented above. The game content (concept art, models, textures, animations) has to be considered from the very start. This was also the result of an authors previous investigation, [AJJ05], which led to the conclusion that making the content is by large a result of the hardware evolution (e.g. machine graphics and available memory). Consequently, the game content has been thought specifically for this work and so for a CAVE system. Being the game content however not a main objective we have chosen to set our game in an existing environment. In particular,

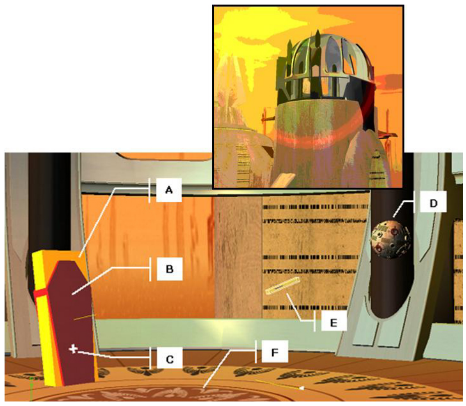

Figure 3: *The VR game main stage elements: target-box "A", target "B", target locator "C", Remote "D", laser-beam "E", floor "F". Top figure shows the main stage seen from outside.*

we have chosen the *Star Wars* universe being this a very suitable game setting, due to its detailed visual documentation and depth of story, as well as being very suitable for a CAVE system application as explained later in this section. In addition, the copyright contracts allow for producing *Star Wars* related content as long as this not commercially motivated.

The proposed game is simple with only 3 active elements: a sword, a beam, and the Remote. The rest of the content is for the most of decorative and visual effect nature. A scene from the *Star Wars IV* is the main stage for our game, where the protagonist of the movie practices his lightsaber skills against a little hovering droid. The droid shoots laser beams at the player, while the player will have to defend himself against a hovering droid. The figure 3 show the game main stage. The player is armed with a lightsaber through which he/she can block a laser beam. The player gets and loses points according to his/her performance. Earning points will increase/decrease the difficulty level. The setup and game play potential of this sequence seemed to be the perfect platform for developing a "CAVE game". In particular:

- the player will need to use his full viewing field to track and effectively fight against the droid;
- the player will be equipped with a real lighsaber-like tool, so that he/she can benefit from the available REX
- the droid will rotate around the player forcing this to turn head and body, so the player may naturally interact with the game environment through tracked body movements.

Having a sword in front of the player is a good way to take advantage of the CAVE possibilities. A sword can and will need to be moved and rotated in all directions. A lightsaber is also a way to use the space close to the player. The player will have the sword right in front of him. This kind of interface simply will only be possible in a CAVE environment. By giving the player a panoramic view increases the feeling of depth and immersion, while the dome architecture will "naturally" limit the space the player can move about, (to not exceed REX dimensions). This contributes to eliminate situations where the player moves in the game but not in reality, so reducing motion sickness. Furthermore, to provide the user with a stronger sense of depth in all directions, we place tall buildings in all direction around the "stage" with a distance between them. This way we want to emphasize the monocular depth cue as well as in general the disparity of the scene. To further increase the feeling of being on the top of a tall building, we have traffic gliding by the window. In the figure 3 we see the different elements in the scene. The geometry named target is the representation of the player. If the laser beam hits inside this zone the player will have taken a hit. The target box is some what larger than the target to insure that the Remote does not have a perfect aim.

The AI controlling the training remote of the game is inspired by observing the behavior and the mythology in the *Star Wars* movie sequel. To achieve a certain degree of realism in combat situations the device features repulsorlift, maneuvering thrusters and blasters. The combination of repulsorlift and maneuvering thrusters makes the training remote a worthy adversary. Depending on the combat drill and the difficulty level set, the remote can move and accelerate with great speed, training reflexes and self awareness. The remotes blaster only stun, but the effect of these increases depending on the combat level of the drill and has been known to "knock" people unconscious. The general AI design scheme behind the design of the AI of the Remote has been authenticity and flexibility. The authenticity of the AI is insured by always attempting to make the Remote behave in accordance to the known facts of the Remote. Flexibility is achieved by having all key values stored in an array which makes it easy to change and adjust values.

Making a game will always require extensive testing and fine tuning, the *Level Array* (containing the values corresponding to each play level) gives easy access to solve the adjustment problems. The increase in difficulty is implemented by making the Remote move faster, shoot faster, shoot more and move closer. These levels can also be referred to as combat levels. We try to narrow down the gap between myth and game as much as possible and we keep the overall design as open ended as possible, giving us easy access to fine tuning the game during testing. The game includes four different behaviors enabled by the distance that the Remote keeps from the player. Three behaviors correspond to different manoeuvres whereas the fourth one involves getting in shooting position. The fourth behavior is the most extensive part of the Remote AI which includes stopping before shooting and a swift rotation around itself to aim one of its blaster to the target. It requires that the Remote knows the positions the different blasters and target.

The Remote AI incorporates different functions (implemented through scripts in Virtools, a powerful software for VR and game applications, [vir05], performing the necessary tasks to satisfy the previously stated design scheme. In particular:
- *Hovering* implements a repulsorlift to hover over the ground by translating the Remote randomly. The translations are small and are meant to mimic small continuous corrections to maintain balance;
- *Remote Fellow* implements the decisions of "when to go where". These decisions are separated to increase design flexibility. The "when" is based on current position and combat level. The "where" is based on different positions with distance dependent intervals.
- *Remote Animator* implements the above mentioned different positions and the aim taking.
- *Target Generator* implements moving a target locator inside a target box between randomly generated positions.
- *Laser Beam* estimates what has been hit and where.
- *Explosion* activates a spherical particle emitter around the explosion locator. It operates in conjunction with hit testing.
- *Player Evaluation* constantly monitors player's hit record.

6. VR System Implementation

As mentioned above we have chosen to design and built-up in-house the VR system for our game. This solution would also allow us gaining know-how on what is actually achievable, and so test feasibility of the proposed concept. Other than low cost, we want the proposed system to address mobility and modularity. The system should also allow for different 3D stereo visualization technologies to be employed, in particular, passive anaglyph and active with shutter glasses.

Modularity. The proposed system is a 4-sided CAVE system. In order to obtain modularity we needed to produce a system which would allow the projection walls to be placed side by side. Consequently, our design features three identical stand-alone walls (other than the ceiling wall), which can be combined in order to obtain different system configurations. In particular, other than a CAVE solution, the proposed system may be configured to be a Panoramic display with different degrees of screen curvature. The system proposes back-projected image visualization to allow for wide interaction possibilities. This setup allows for the creation of different VR systems like CAVE, Panorama, and Powerwalls, as shown in figure 4.

Projection Screen. The basic element of our modular solution is a 1-side CAVE, which we decide to build and to test as first step of the implementation. To obtain modularity we need to produce projection walls which could project through the entire screens area without discontinuities. A Plexiglas material is then proposed to be used in order to place the screen canvas out from the wall frame and allow the incoming projector light to fill the entire wall surface. The choice of Plexiglas to distance the screen canvas from the frame is in order to create seamless edges. In particular, the transparency of Plexiglas enables light to penetrate out to

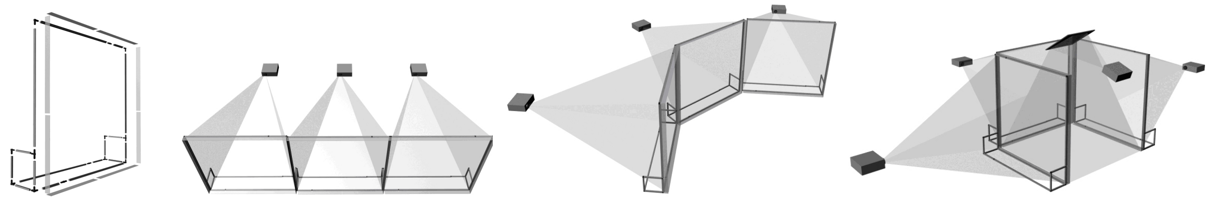

Figure 4: *The proposed affordable system: basic structure (left), powerwall and panorama (center), CAVE (right).*

the screen canvas edge. The distance between the wall frame and the screen canvas is a result of the projectors throw ratio distance.

Material Choice. The final design blueprint was created after thorough investigation of available materials. In particular, we found most stationary CAVE systems are built from wood. Wood is used, because it does not interfere with the magnetic tracker systems and it is robust, so giving stability to the all system. Plastic pipes are an alternative which is very light but for our system this material is too flexible when stretching a screen canvas on a plastic pipe frame. Our selection of frame material landed on aluminum because it has both the strength of wood and the lightness of plastic. The aluminum pipes we use (produced by TERMOTEX), are complemented by convenient joint tools which set the construction time to a minimum. The wall structure is illustrated in figure 4 left-hand side.

Interaction. Before testing the application we have to arrange our setup. To make the game interactive and allow the player to look around and use his lightsaber we use motion tracking. This is done with a Polhemus ISOTRACK II with two sensors, that have 6 degrees of freedom, enabling easy interaction with the game. The first sensor placed on the head of the player and the second sensor attached to a makeshift of a lightsaber hilt. Combining motion tracking with 3D stereo visualization, should give the feeling of holding an actual lightsaber in your hands.

6.1. Hardware and Software selection

It is in the selection of hardware, where the cost of a VR system can be reduced significantly. Our solution uses a PC render platform instead of an SGI. There are two major benefits; firstly the cost, secondly that we only need one (or two) PC due to the dual graphic card setup. The PC render platform includes: D 830 3.0GHz Pentium processor (dual-core processor), 2048 MB DDR-II 533 PC4300 RAM, 200GB Samsung harddisk, 2 MSI NX7800GT 256MB DDR3 SLI. The dual graphic card setup with an SLI bridge provides us with four synchronized video outputs. In order to have the ability to interact with the VR application in our low cost VR system a Polhemus ISOTRAK II magnetic tracker is used. This tracker has a low cost but it has a limited range of 150cm around the magnetic transmitter. Projectors for active stereo are typically very expensive, but new less expensive product are now on the market. In particular, we found the Infocus DepthQ projector at a price tag of 4000$ which is much lower than its competitors. Other miscellaneous devices include active stereo glasses from E-Dimensional (99$) and also different kinds of passive glasses.

The software for developing VR applications is Virtools, although OpenSG can be used. Virtools is designed for PC clusters and supports many of the industries VR peripherals. It also supports most displays (e.g. CAVE, SAS Cube, panoramic rooms, immersive desks and HMD's). Developing applications in Virtools provides users with an off-the-shelf solution to manage content and create applications, but also fast prototyping and low application development costs for VR systems.

6.2. Evaluation Test

A first preliminary evaluation test is below described. We have used passive stereo in combination with a motion tracking system. Though we knew that the test would lack the fully immersive experience of a 6-sided CAVE, we still had positive expectations for our test with the current setup. In particular, we expected that the implemented monocular depth cues will enhance the experience for the player and that the large screen size would give a greater feeling of immersion and presence We also expected to gain insight about how the large screen together with the appositely designed game scenarios would affect the feeling of being present in the game. In other words, we wanted to evaluate whether a VR game designed specifically for a CAVE would play a role in the future of gaming.

At Aalborg University we already have an expensive 6-sided CAVE system, as well as a 160 degrees Panorama Arena and a front-projected large Powerwall. The figures 1 and 2 describe the Aalborg University VR facilities. The CAVE and the Panorama system use active stereo visualization, while the Powerwall uses passive stereo with Polarized filters. We believed the above would provide us a splendid possibility for testing the system that we propose. Furthermore, knowing well the sense of presence achievable with the available 6-sided CAVE we felt confident that we could

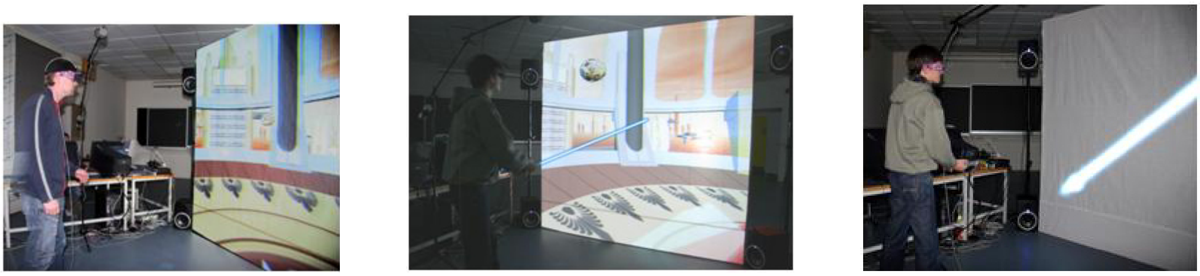

Figure 5: *Some moments of the testing phases: walking (left), lightsaber (center), and mockup (right) tests.*

well judge the obtained results. For what concerning depth perception, the application was tested both in case of passive and active stereo. However, for practical reason the active stereo solution was only tested for a screen size smaller than the large CAVE wall. It became evident that the depth cues we had implemented worked impeccably, using both the passive and active goggles. The cues of distance and occlusion were particularly good. In addition it can be said that if one can abstract from the color difference and ghosting effect the passive glasses give us good a depth perception as good as with the active glasses.

Concerning the general sense of immersion, the big back-projected wall with passive stereo definitely provided a feeling of presence. We tested moving around in the VR game and the lightsaber, both worked well. The figure 5 shows some moment of the testing phase and they way the game is perceived when playing it. For future test we would like to use multiple tracking to see if the immersion and presence is enhanced. Moreover as the game is developed for a CAVE facility we would like to try it on our 6-sided CAVE.

7. Conclusion

If we look back at VR applications in general and VR games in particular, we realize that the building blocks are close to reach. The technology has evolved and provided us with tools that make the rebirth of VR games feasible in a near future. Despite VR games has had an "invisible" existence for the last 10-15 years, we begin to see the first signs of a comeback with the works of Paul Rajlich and Jeffery Jacobson. With the increase of computer games development and the emergence of new genres, the need for VR games and VR in general is steadily growing. For many years VR environments have been used in the industry, military and universities. Therefore we can also predict that VR games can raise again if the right business model is defined between the developers and the consumers. However, one must also accept that the expectations which the VR game community are also very demanding. To provide a strong sense of immersion has been one of the main goals in the design of our VR game. As we stated earlier one of the strongest features of a CAVE is, among others, its capability to give a sense of depth in all direction. A future work could then also be in the direction of increasing depth perception by enhancing monocular and binocular depth cues, as well as to further experiment with different 3D stereo visualization technology solutions.

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