THE VDEN: AN AFFORDABLE IPT DESIGNED FOR CONFERENCES

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THE VDEN: AN AFFORDABLE IPT DESIGNED FOR CONFERENCES by Alexander Jaeger, December 2019

ABSTRACT

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

CHAPTER 1

INTRODUCTION

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CHAPTER 2

GENERALIZED DESIGN OF A CAVE SYSTEM

2.1 Display Technology

Monitors

Projectors

2.2 Computing

A CAVE system requires rendering one image per eye on the screen. Robert Belleman et Al specifies a variety of computing configurations to support a CAVE [1].

One Hosts with Two Graphics Adapters

!!! - Warning! Not sure about this

Image of One Host with Two Graphics Adapters

With one set of CPUs controlling a handful of graphics systems, we can support multi-display rendering. In the 20th century, SGI machines were modeled with this architecture and the 21st century saw consumer PCs becoming equipped to handle multiple graphics cards.

The overarching problem is that consumer PCs typically support at most 2 graphics cards. CAVEs require at minimum of 4 displays, thus two cards that can handle two displays each would be suitable. Robert Belleman et Al notes that in 2001 these PCs could not be built due to the limitations in the number of AGP slots [1].

Two Hosts with Two Graphics Adapters

Image of Two Hosts with Two Graphics Adapters

By splitting the responsibility of rendering across two computers, the rendering can be done in parallel achieving better performance.

However special precaution needs to be in place due to possible synchronization issues. These two computers are connected over a network and in theory they just have to render the scene for the given MVP matrix. However in practice, one of these computers is used to compute both eye matrices and will introduce a load imbalance. By running the matrix calculation on a third computer, we can solve the synchronization issues however the overall network traffic is doubled because we need to send both eye MVP matrices over the wire [1].

One Host with Multi-headed Graphics Adapters

Image of One Hosts with Multi-headed Graphics Adapters

In 2001, there some support for multiple displays using a single graphics card and little support for hardware accelerated OpenGL [1]. By 2017, the latest Nvidia cards can support 4 displays in sync with accelerated OpenGL. This performance improvement provides consumer PCs the power to run games and simulations on multiple displays.

2.3 Projection

Image of Rear Projection vs Front Projection

2.4 Stereoscopy

Passive Stereo

Active Stereo

2.5 Tracking Techniques

CHAPTER 3
REQUIREMENTS

Introduction

To help guide our development, we created a few key requirements. These not only guide but also help differentiate our solution from the previous implementations.

3.1 Hardware

Cost

Topics To Write About
How HMDs have changed the landscape What a Typical CAVE system cost in the past What our system will cost How we plan to achieve it

The advent of head-mounted displays has brought forth an expectation of low-cost virtual reality. In 2019, PC Magazine wrote an article on the Best VR Headsets of 2019, the listed price range goes from $100 – $600. [2] In 2010, Carolina Cruz-Neira notes that a typical CAVE system of 3 vertical screens and a floor can easily cost over $750,000. [3].

In a world where you can get a VR headset for $200 and build immersive content, it is easy to see why CAVEs have fallen out of favor. We want to help reinstate the CAVE and provide a solution for less than $40,000.

Footprint and Room Location

Topics To Write About
HMDs space requirements Outlook of the HMD Previous CAVEs How we plan to fix this issue

Not only should a CAVE be used in conference and laboratories, but also in the standard office space. We want to showcase immersive content everywhere, so we will target a maximum footprint of 8' x 8' and a height of 10' for the entire system. Lastly, the room should not be required to be on the first floor with large doors to carry parts through. Each part should be lightweight enough to carry and small enough to fit through a standard door. If the room is on a higher floor, then the the loading on the elevator should not be hampered by the size of the parts.

Resolution

Topics To Write About
Advent of 4K and FullHD in Homes
HMD Examples
Projector space
What are we targeting

The current demand for display technologies is 4k resolution, making 1920x1080 ubiquitous.

Floor Projection

Topics To Write About
Purpose of the Floor
Advantages
Disadvantages
What are we targeting

While the front projection is the most important as it draws the most visual area, the floor projection is a debatable runner-up. Not does it help to fill your vision vertically, but also the corner formed provides a large amount of immersion.

Development

Topics To Write About
How has game programming changed
Ease of Programming HMDs
Difficulties in programming CAVES
What are we targeting

Designing new media in a intuitive way is the highlight of research and development for a wide range of fields. Game Engines, such as Unity3D and Unreal, have largely taken over the face of the computer graphics industry. These tools make it easier than ever before to build immersive media. We want an SDK that is compatible with a game engine to render into a CAVE.

Setup and Shipping

Topics To Write About
Deploying HMDs Difficulties in deploying CAVES What are we targeting

The Emerging Analytics Center goes to several conferences per year all across the world. Bringing the VDEN to these events would be great for PR. Therefore, the final design of the system must be able to be setup within one day and has to fit within the back of a van or shipping container.

Computing

Topics To Write About
advancement in graphics cards HMDs computer reqs Generalized past CAVEs computing What are we targeting

Although distributed computing is still required for high performance CAVE graphics, the capabilities of a graphics card has risen dramatically. Modern cards can handle a system with 4 displays, hinting at the possibility of running a CAVE.

Tracking

Topics To Write About
Deploying HMDs
Difficulties in deploying CAVES
What are we targeting

3.2 Software

SDK

Topics To Write About
Deploying HMDs
Difficulties in deploying CAVES
What are we targeting

Calibrator

Topics To Write About
Deploying HMDs
Difficulties in deploying CAVES
What are we targeting

Management

Topics To Write About
Deploying HMDs
Difficulties in deploying CAVES
What are we targeting

CHAPTER 4

PREVIOUS LOW COST CAVES

4.1 *The MiniCAVE: A Voice Controlled IPT Environment* By Edward Wegman Et Al 1999

This paper marks the earliest attempt found to create a more affordable CAVE system. The researchers found that the 200Mhz Pentium Pro Processor ($3000) was competitive to the SGI Onyx RE2 ($120,000) when running matrix-oriented mathematics software. With the advancements in computing and projection, they hypothesized that using a PC system could run a CAVE for less than $100,000. [4]

4.2 *Immersive Virtual Reality on Commodity Hardware* By Robert Belleman Et Al 2001

Robert Belleman Et Al describes the work by researchers at SARA and UvA to build a CAVE system based on commercially hard- and software. By utilizing CAVELib and OpenGL—Performer, they were to minimize porting efforts for preexisting applications. This minimization naturally makes life easier for programmers used to these platforms. Finally, they tested the performance by rendering 204,480 triangles in 39,134 triangle strips without texture mapping in active stereo. The SGI CAVE system rendered at 5.5Hz whereas the PC solution rendered at 6.3Hz.

4.3 ***Implementation of a Low-Cost CAVE System Based on a Networked PC*** **By Po-wei Lin Et Al** **2002**

In 1999, the researchers installed the first CAVE system in China based on an SGI machine, almost immediately after they began implementing an alternative using a cluster of PCs. Po-wei Lin Et Al wrote a custom architecture to render on their CAVE using MPI and OpenGL. In the end, their system rendered 60,000 triangles at 18Hz. They further tested the performance of an SGI Onyx2 versus a single PC with a 3DLabs Wildcat 5110-G Graphics card. A test of rendering 1.2 million triangles, the SGI rendered at 2-3Hz whereas the PC at 8-9Hz.

4.4 ***Low-Cost, Portable, Multi-Wall Virtual Reality***
By Samuel Miller Et Al **2005**

This CAVE system developed by researchers in NASA's Applied Sciences DEVELOP Program is focused on affordability and portability. They presented a solution for <$30,000 as opposed to the goal for a CAVE system at <$100,000 in 1999 with the MiniCAVE. Stereoscopy is derived through the use of two LCD projectors and a mechanical shutter. The researchers found a number of issues with 3D glasses and the shutter. The 3D glasses used polarizing lens and were destructive to the polarized light from LCD projectors. The shutter failed to adapt to DLP technologies due to the internal color wheel. DLP projectors spin a color wheel and use a chip of mirrors to compose an image. Active shutter glasses cycle at a specific speed, this should be such that a fully composed image is displayed for the appropriate speed causing issues with calibration. Lastly, the system still relied on mirrors even though a floor projection is intentionally missing.

4.5 ***Practical Design and Implementation of a CAVE System***
By Achille Peternier Et Al **2007**

Peternier et Al's CAVE is composed of 3 walls with a floor, a cluster of PCs, and 8 LCD projectors (1 per eye). They adapted a preexisting internal graphics engine. Like Miller's CAVE, they use single screen for the entire system and wire to attach [5]. They use an optical tracking approach, but they also tested a custom tracking solution using ARToolkit and fiducials. The final system managed a framerate of 25 while rendering 15,000 triangles in stereo and with one light source casting soft shadows.

4.6 *A Virtual Reality Installation*
By Francois Sorbier Et Al **2008**

Although monoscopic, this CAVE system tested new strategies for screen materials and tracking while maintaining the goal of affordability and transportability. They handmade the projection screens using tracing paper and remark their lastingness. This paper allowed the projectors to be rear projecting. To cut costs, the researchers created their own tracking system. A tracking system has to determine two things: orientation and position. Orientation is solved by placing an electromagnetic compass on the user's head. Position is through a

4.7 *The LAIR: Lightweight Affordable Immersion Room*
By Barry Denby Et Al **2009**

4.8 *Implementing a low-cost CAVE system using CryEngine2*
By Alex Juarez Et Al **2010**

4.9 *An Affordable Surround-Screen Virtual Reality Display*
By Carolina Cruz-Neira Et Al **2010**

4.10 *Designing a Low Cost Immersive Environment System Twenty Years After the First CAVE*
By Richard Fowler Et Al **2012**

4.11 Discussion

CHAPTER 5

PREVIOUS CAVE SOFTWARE

5.1 *CAVELib*
Owned by VRCO (Now Mechdyne) 1992

5.2 *PFCAVELib*
By David Pape 1997

5.3 *VRJuggler: An Open Source Platform for Virtual Reality Applications*
By Allen Bierbaum et Al 2001

5.4 *VjControl: An Advanced Configuration Management Tool For VR Juggler Applications*
By Christopher Just et Al 2001

5.5 *The CaveUT System: Immersive Entertainment Based on a Game Engine*
By Jeffrey Jacobson 2005

5.6 *MiddleVR: A Generic VR Toolkit*
By Sebastien Kuntz 2011

5.7 *A Survey of Frameworks and Game Engines for Serious Game Development*
By Brent Cowan et Al 2014

5.8 *Overview and Assessment of Unity Toolkits for Cave Automatic Virtual Environments and Wand Interaction*
By Kenneth Ritter et Al 2015

CHAPTER 6

HARDWARE

6.1 Introduction

A typical CAVE installation has four major sources of hardware: projectors, screens, a tracking system, and a structure to mount everything. High resolution CAVEs can contain multiple displays per screen and become difficult to setup.

— FIX ME —

6.2 Projectors

Purpose: What was the process of choosing this projector and what properties did we like?

Topics To Write About
Monitor vs Projector
DLP VS LED
1 Projector Per Wall
Monitor vs Projector
How Did We Choose
Use of a Different Projector for Floor

The display of computer generated content is dominated by projectors and monitors. Projectors use a lamp and lens to project light onto a surface. Monitors utilize a two dimensional array of light cells to present an image to the user.

You can think of these technologies on a loose spectrum, similar to figure 1. On the left end, a large or far image is required, this is ideal for projectors because the resultant image size is a factor of throw distance. As you move closer to the monitors, a close or small image is preferred. This spectrum is loose because you can apply monitor technology that is ideal for a projector (and vice versa), there is an increase in cost and innovation to make it happen.

The ideal CAVE system would be powered by monitors. They are superior in terms of pixel density and resolution, fast response times, physical size, and ease of calibration. A disadvantage is their bezel will cause some issues with rendering and make content like text hard to read. When we increase the pixel density and resolution, there is a increase in power and computing requirements. A cluster of PCs will be required to render and this will drive costs up. Due to this, affordable CAVE systems prefer projector setups.

Although projection based CAVEs suffer from pixel resolution and brightness, we see a savings in computing and cost. It is not necessary for a CAVE to have multiple projectors per wall, although high-end CAVEs may include it to help bridge the gap in performance between the two techniques.

In this project, we decided with using a single projector per wall in order to minimize the complexity and cost of the system. We created a few requirements to filter when we performed a search.

1	1920x1080 Resolution
2	Capable of 3D stereoscopy
3	Ultra Short Throw
4	Less than $2000 MSRP

An EBU Technical Report from 2012 states that 1080p is technically mature and almost all new flat panel displays use FullHD. By 2012, some 4K displays have entered the high-end sector of the market. [6] In 2019, 4K flat panels are becoming commonplace and FullHD displays are ubiquitous. Therefore, we make FullHD a requirement for the resolution of the projector.

Reading the history of affordable IPTs, multiple projectors per wall is a comon theme to enable stereoscopic imagery. Each projector would represent an eye and some technique of shuttering is used to block light. Stereoscopic alignment and portability are special concerns for this technique. Multiple projectors are necessary because

6.3 Screens

Screen Material

Purpose: What was the process of choosing this screen and what properties did we like?

Topics To Write About
Fabric vs Panel White vs Projector Folding the Screen How we found our screen Wrapping screen around frame edge Attaching screen to the frame

Frame

Purpose: How did we choose this frame to hold the screens and what factors became important (e.g. accordion, intuitive, velcro)

Topics To Write About
Why Independent Frames
Corner Shape and Rigidy (Wire for corners)
Conference Pop Up Frames
How we modified the frame

6.4 Structure

Purpose: Describe the thought behind the structure design and explain some key design (e.g. transportability, motorized, and material)

Topics To Write About
Rear Projected vs Front Projected Structures
General description of our structure
Motorized
Cable Management
Packing

At a minimum, a traditional CAVE system requires a structure to hold the floor projector. High-End CAE systems that utilize multiple displays per wall will typically integrate them into the wall, increasing the complexity of the structure. Some rear projected CAVES will have the projectors on individual pedestals due to the throw distance required.

Structures are also used to hold auxillary peripherals such as the tracking system and speakers.

Since our CAVE is front-projected, all of the projectors are within the bounds of the system. We opted for a single beam design that goes across the screens to support the projectors and peripherals.

Image of a frame with peripherals

The structure is designed not only to support but also reduce the complexity of mounting the hardware during setup.

System	Input	Quantity
Projectors		
	Display	1 Per
	Power	1 Per
	Network	1 Per
Tracking		
	Sync	1
	Power	2

Table 6.1. The required inputs into the system

A difficulty in the structure design was cable management. Table 6.1 showcases the required cables for the system. We alleviated this design by multiplexing the network and power cables, by mounting a box a power strip and network switch can be stored.

6.5 Computer

Purpose: Explain why we needed the GTX 1080ti and what other parts were needed (e.g. secondary graphics card). Provide information on specifications of card

Topics To Write About
Explanation of Processing Required
Discussion about Distributed Cluster vs Single PC
How did the 1080TI change our opinion
Overall reasons for single pc

CAVEs demand a large amount of computing resources in near real-time. Ideally, each eye should be rendered at 60Hz minimum for each screen. If a screen has more than one display, then each of these will of course need to be rendered at the same requirements. Originally, this lead to the use of high-end dedicated hardware (e.g. SGI machines) and once PCs were widely available, distributed clusters.

Although dedicated hardware has fallen out of popularity, high end CAVE system require a cluster of computers in order to drive the displays. Consumer graphics cards continue getting more powerful (largely in part due to the new applications in research and video games) with better general-purpose performance and the ability to support multiple displays.

The current generation of Nvidia Graphics Cards are capable of running 4 displays in sync. This ability is what allowed the development of the VDen with 1 projector per wall.

This technique is what we researched when building the VDen. There was no room for a cluster, although it would provide greater performance there is an increase in setup and development difficulty. Not to mention that one PC with a single high-end graphics card is cheaper than multiple PCs with multiple lower-end cards.

6.6 Tracking

Purpose: Explain the reasoning behind the use of SteamVR lighthouse and how we integrated it into the VDen

Topics To Write About
Explanation of Leading Tracking Technologies (Optitrack and Lighthouse) Why is the lighthouse system popular Why did we choose the lighthouse

A tracking system is central to any VR application. It is a core concept to render a perspective correct image and providing interaction into the virtual world.

IR Camera tracking techniques are the most popular at this time. In general, these systems work by emitting light and either watching the reflections or having sensors on the tracked object to directly record the light.

For scientific tracking, systems were designed to produce the highest quality without regards to cost. By using an array of cameras, any angle can be accurately tracked. However, in recent years the computer gaming industry has dominated the market and their desire is for an affordable experience.

In 2016, Valve released the SteamVR lighthouse system which uses an IR emitter and cameras physically located on the tracked object. Although, the size of the tracked area was small, it offered easy setup and a tracking quality that was good enough for the market at a reasonable prices.

This lighthouse system is very popular for consumer VR experiences. They recently released a smaller tracked object that can be placed on things as well as the ability to build your own object. Now researchers can build their own hardware for VR peripherals.

We utilize the light house tracking system because with only two boxes; it can easily coverthe VDen at an affordable price. For head tracking, we attached a small tracker to a hat that the user can wear, making it easy for a user to use the system.

CHAPTER 7

SOFTWARE

7.1 Introduction

Providing just a hardware solution is unacceptable for adoption, a software package that is easy to use and extensible is a necessary feature. Long are the days of the average VR graphics programmer using OpenGL to create simple prototypes. Game engines dominate the interactive media industry and VR SDKs were quick to target them.

The Choice of the Unity3D Game Engine

Purpose: Explain why we chose the Unity Game Engine

Topics To Write About
Usage of Game Engines 2nd wave VR in game engines Unity vs Unreal easy development in programming explain the role of display cameras goal for programming the vden

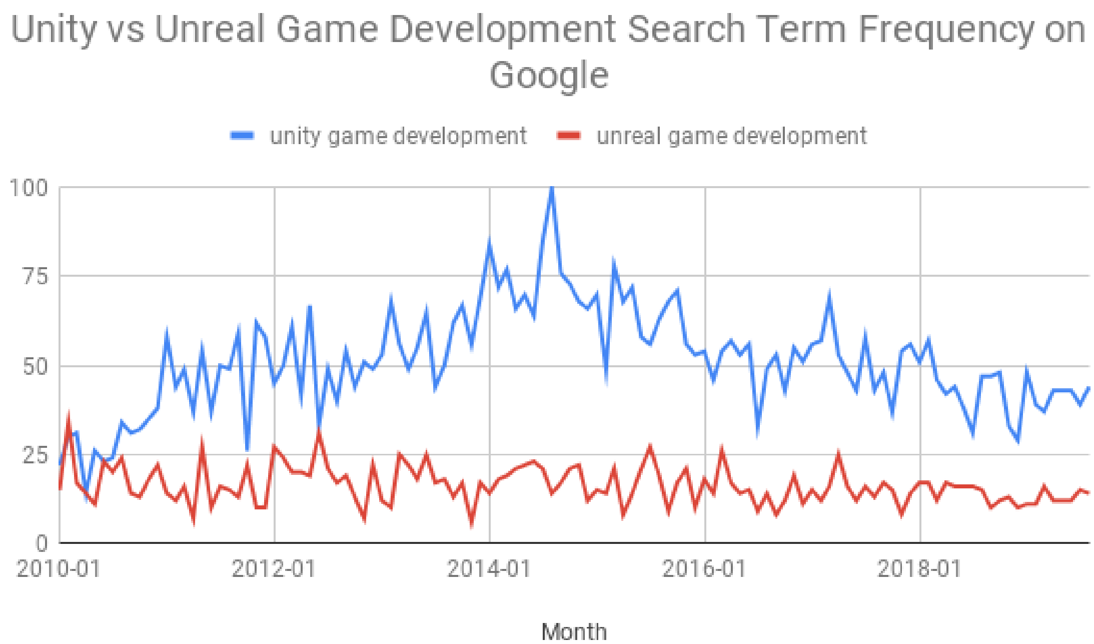

Figure 7.1. A graph from Google Trends showing the search term frequency of ”unity game development” versus ”unreal game engine development” from 2010 (Marking the release of version 3 of Unity). The vertical axis represents the percentage of popularity.

Unity3D is a game engine for creating interactive media. Launched in 2005, the goal was to create an affordable system for amateur game developers. [7] By focusing on a simple asset pipeline and workflow, Unity3D thrived and by 2010 had over 200,000 registered users. Quickly, Unity became the #1 platform for game development. [8]

The major competition to Unity3D is the Unreal Engine. Initially developed by Tim Sweeney, this engine was designed to push the limits of graphics and realism. Not only has it received a 2014 Guinness World Record for "Most Successful Game Engine", but also a long list from game developers and film productions alike. [9] However as shown in Figure 7.1, Unity3D is more searched on Google for game development topics supporting the notion that it is the preferred tool for most games.

A Bachelor's thesis written by Simo Ahola describes the steps necessary to build a Virtual Reality application in the Unity3D game engine supporting two different headsets: the HTC Vive and Oculus GO. By just downloading the individual SDKs then dragging and dropping the associated prefabricated component, Simo had easily developed a VR application. [10]

It is of my personal desire to make CAVE development as simple and accessible as a headset. Unity's history of simplicity has positioned it in the forefront of VR development, making it the preferred platform for the vDen.

7.2 Unity SDK

Purpose: Explain the design of the SDK

Topics To Write About
structure of vive sdk describe how easy the vive is emulate the structure of vive explain the role of eye cameras explain the role of display cameras how did we implement head tracking SDK configuration

The simple act of downloading an SDK and dragging the necessary components into your scene sounds so fundamental, however it was not until WYSIWYG game engines became popular for this to happen. The architecture of the vDen SDK revolves around this concept.

To guide development, we defined three goals for our system: rendering immediately upon importing, allowing full extension and of peripherals, and lastly simulating the vDen rendering in Unity itself.

The core rendering system govern the functionality of the eye and display cameras.

Eye Cameras

Purpose: Explain the how the eye cameras work

Topics To Write About
Purpose Frustum Calculation

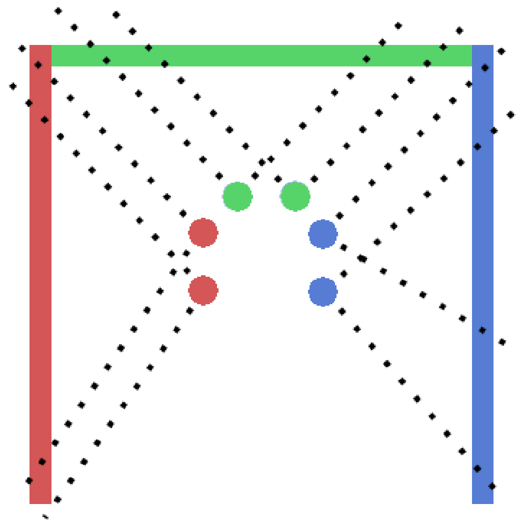

Figure 7.2. The Eye Cameras are paired together and are related to a specific screen. Each camera pair has space in-between related to the inter-pupillary distance of the user's head. The floor cameras are missing in the graphic, but are in the SDK, bringing the total to 8 eye cameras.

Eye cameras capture an image that represents the view from a user's physical eye. As shown in Figure 7.2, there are two cameras per screen, totaling 8 in the SDK. A pair of cameras are spaced apart along the shared axis with the distance equivalent to the user's interpupillary distance. Futhermore, each pair needs to remain orthogonal to the others. Lastly, because the screens represent a window to the world, we need to calculate a custom frustum for each camera.

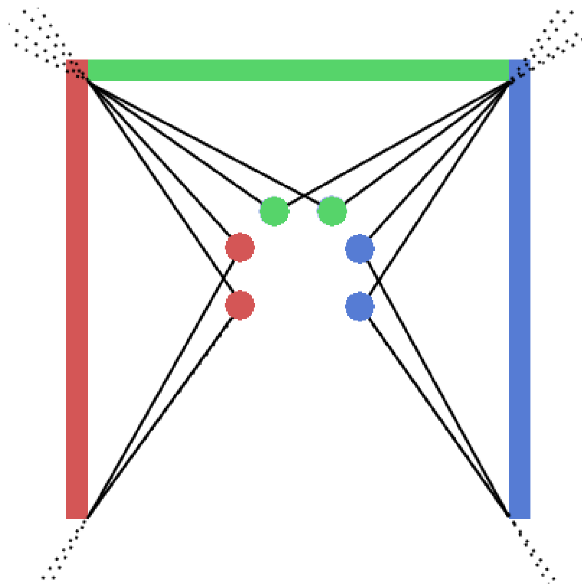

Figure 7.3. Shows the new frustum of each camera after calculation. This provides the correct view as our physical screens represent windows into the world

Looking at the differences between Figure 7.2 and Figure 7.3, we can immediately see the frustum is bounded to the the screen. This bounding guarantees that nothing is rendered outside of the screens.

— FIXME — The calcuation of a new frustum is easy. We need to determine the

Display Cameras

Purpose: Explain the display cameras

Topics To Write About
Purpose
Merging images together

Display Cameras will output the final image for the projectors. With one camera per projector, the vDen has four total. The camera is associated with a pair of eye cameras and is responsible for merging their output together, left-right or top-bottom, for sterescopy, then rendering on the calibration mesh.

Head Tracking

Purpose: Explain the head tracking system

Topics To Write About
Purpose
Utilizing the SteamVR trackable object
Sync virtual and physical positions

A core feature of Virtual Reality is the generation of perspective correct imagery. This is done by understanding the head position and how the eyes view the scene. In order to track the head, the user dons a trackable baseball cap the tracking system syncs its position with the collection of eye cameras.

7.3 Calibrator

Purpose: Explain the design of the Calibrator

Topics To Write About
Dragging each corner to fill the surface
Checking corner image alignment
Checking uniform scaling
User Interaction
Per Project JSON File

7.4 Dashboard

Purpose: Explain the design of the dashboard

Topics To Write About
Purpose
Development
Project Management
Config Management
Projector Control

CHAPTER 8
SOURCES OF ERROR AND DISTORTION

8.1 Introduction

Providing just a hardware solution is unacceptable for adoption, a software package that is easy to use and extensible is a necessary feature. Long are the days of the average VR graphics programmer using OpenGL to create simple prototypes. Game engines dominate the interactive media industry and VR SDKs were quick to target them.

8.2 Software

Projection Overfill

Perspective Distortion

Perspective Distortion occurs when the projector is off axis from the screen causing warping.

This is solved by a technique called Homography which states there is an affine transformation between two planes. Simply put, there is a system of equations to transform each point in one coordinate system A to another B by distorting A to match B. In this case, we have a real mesh R and we want to become a uniform grid G. We can apply homography onto R to get G and thus the screen's coordinate system because ideal for rendering. This technique only needs to happen on startup and requires the calibration data.

Uniform Image Stretching

Corner Image Alignment

Image Screen Fill

Color Correction

8.3 Hardware

Warping

Screen Movement

Corner Gap

8.4 Tracking

Physical Alignment

Coverage

CHAPTER 9

DISCUSSION

In 2011, led by Thomas DeFanti, a team of 25 researchers set out to enumerate the requirements of an ideal CAVE and showcase the systems that have been developed to try and achieve these goals [11]. They list the requirements as

Hardware Requirements	Software Requirements
- Compact footprint	High resolution
- Scalability	Highbrightness and contras
- Usability	Input and full recognition of the viewer's or viewers' bein
- Low noise signature	Audio (sonification) at or exceeding human aural acuity,
- Low thermal signature	Touch (tactile) input and output
- Holds several users	No user encumbrances (special glasses, headphones, nose
- Network connected	Olfactory (smell) output delivered to each user,
- Extended service intervals	Taste output and input recognition
- easy access for maintenance	Linking such devices together with near-zero latency
- Power-efficient	
- Articulated, easily shippable screens	
- rapid installation/de-installation	
- low-cost	

Table 9.1. Enumerates all of the requirements DeFanti's team listed

The systems presented by the DeFanti et Al try to maximize compliance with the software requirements and a looser authority on the hardware requirements.

This thesis presented showcases a true CAVE system that fully conforms to the hardware specifications of DeFanti [11] but also provides additional requirements to emphasize the importance of a floor projector.

The purpose of this system was to fill in the latest gap of research in Low Cost IPT systems from 2010 with Dr. Carolina Cruz-Neira to today. The landscape of modern virtual reality has changed, the advent of game engines to ease development and the wave of affordable headsets brings new requirements for a CAVE.

This CAVE system attempted to fully minimize the cost of production by utilizing off the shelf components and freely available software.

CHAPTER 10

CONCLUSION

Image of VDen at Modex, LA, SF, and Denver

The team at the Emerging Analytics Center has been very successful at demonstrating the effectiveness and usability of the VDen.

Most recently, we showcased the system to thousands at the 2019 AWE Conference in Santa Clara, California. Marketed as "The Most Essential AR/VR Conference and Expo" by Forbes [12], the expo hosts startups and research projects to showcase their work. We had very good feedback from the users concerning the performance of the system. Several people showed initial interest in purchasing one for their companies and research laboratories.

The developers at the Emerging Analytics Center were responsible for producing the demo applications shown at these events. These students are accustomed to programming with the HTC Vive headset, so retraining them to work with the VDen was shown to be easy. The primary difference between platforms is the lack of the headset, the input systems are intentionally the same.

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