The Web as a Distribution Platform for Virtual Reality Systems

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October 14, 2020

I. Abstract

WebVR is an amazing new technology that enables users to view and create virtual reality experiences and share them easily on the web. The WebXR API provides an abstraction layer for VR devices that enables user creations to run consistently across many devices without the need to fragment the logic of their application to account for differences across device hardware and software. This provides a common ground that will allow the VR ecosystem on the web to thrive. This paper explains how the technology works, a brief history of the field, current problems, and both current and potential applications of the quickly maturing technology.

Long regarded as a topic of science fiction, after about 50 years of research and exploration, virtual reality systems are becoming (for lack of a better word) a reality! Technologies involving virtual reality (VR) systems present many new exciting ideas, solutions, and methods for experiencing media. While many virtual reality systems are still rather young, the field opens a nearly infinite spectrum of new ideas and capabilities to explore. It brings new ways to create and explore content, new tools for interaction, news ways to think about how we interact with technology, and many undiscovered technological trends.

Virtual reality works by creating virtual representations of the perceptions of the user. For example, head-mounted displays monopolize the user's vision and use stereoscopic screens to simulate their natural depth perception. The resulting effect is called immersion– a phenomena in which you feel completely inside of the virtual experience. Current hardware also employs input devices used for tracking the hands of the user for performing actions in the virtual world. Three degree-of-freedom (DOF) input devices, such as mobile phones, keep track of rotational positioning while six degree-of-freedom devices track rotational and translation positioning for high-precision inputs. Tracking cameras and gyroscopes detect *gaze*, the precise orientation of the user's head.

WebXR (Mixed Reality) includes WebVR and will be used interchangeably–the distinction is that WebXR also includes augmented reality, a format in which virtual information is overlaid onto the user's view of the physical world (Figure 3). You may imagine ratings displayed upon a restaurant or business in the physical world. Many types of VR hardware currently exist–mobile phones, head-mounted displays, or even entire rooms. Though devices differ, most use spatial tracking in order to simulate a view of virtual content. All of the magic of VR occurs in the mind of the user.

The amazing innovations shared everywhere on the Internet open doors to an infinite array of information. Just as the web has spurred the development of tools for business, education, and entertainment, WebXR opens many worlds of possibilities for sharing, learning, and exploring the complexities of the universe.

II. Background

The earliest technology involved in today's VR was developed in the 1800's–stereoscopic photography. Even today, many head-mounted displays (HMD's) use stereoscopic vision to form their depth perception effects. Ivan Sutherland developed the first stereoscopic HMD in 1968 at MIT. [6] Stereoscopic HMD's are the most common type of VR device today. They use various natural depth cues formulated by the human brain's natural visual signal processing. Visual cues provide the viewer with information about the 3D composition of a scene such as occlusion, relative size, height relative to the horizon, linear perspective, accommodation–a cue taken from the muscular state of the eye, whether relaxed or in tension, vergence–the rotational state of each eye in relation to each other, and binocular disparity–the difference in images that each eye detects. [5] Figure 2 shows an example of how this view is formulated within the stereoscopic HMD using one view per eye. Some displays offer semi-transparency that allows for the overlay of digital information onto the physical world for augmented reality applications.

Development of VR systems in the 1980's was still in infancy, but became more common in the 90's as people

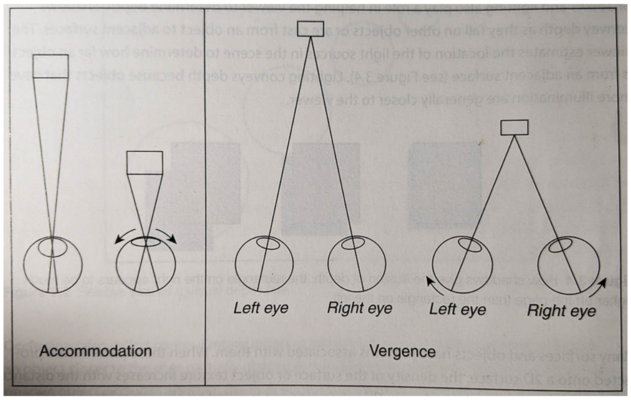

Figure 1: *Diagram showing accommodation vs. vergence visual cues. [5]*

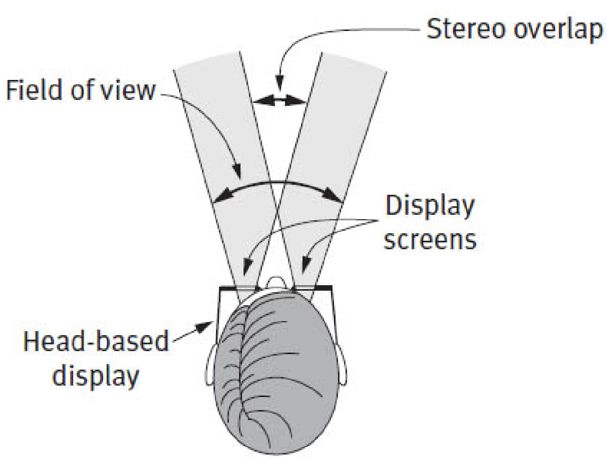

Figure 2: *Stereopsis: A stereoscopic display takes advantage of how the brain interprets binocular disparity to form a view that looks real to the viewer. [6]*

began exploring many different types of ideas and systems aiming to simulate immersion. IEEE VR, one of the earliest VR conferences, was inaugurated in 1993. Today, the Oculus Rift is the most widely successful consumer VR system and was originally released in 2013. Google Glass is a small pair of AR eyeglasses released in 2013 to the development community, but never achieved a consumer release. In 2016, HTC, Microsoft, Oculus, and Sony all released commercial VR HMD's as VR became an overnight success after 50 years of progress.

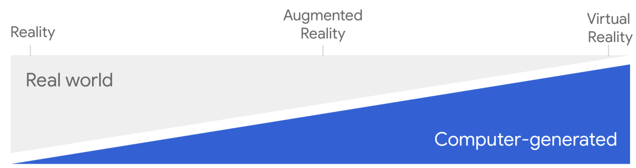

Figure 3: *A diagram referencing the different levels of immersion.*

III. 3D Interactions

The added dimension of 3-dimensional systems brings an entire new set of problems and strategies for solutions in comparison to classical 2D interfaces, but it also brings more advanced uses. 3D interaction is more relevant to real-world problems of the physical space. "Interacting in three dimensions makes intuitive sense for a wide range of applications because of the characteristics of the tasks in these domains and their match with the characteristics of 3D environments. If a user can interact using natural skills, then the application can take advantage of the fact that he already has a great deal of knowledge about the world." [5]

Many classic methods for interaction no longer work in VR without modification. For example, with a head-mounted display, the use of a traditional keyboard doesn't make much sense because the user's entire view is consumed by the HMD. The use of a 2-dimensional mouse input device is not precise for 3-dimensional selections. In this way, entirely new techniques of selection, manipulation, and interaction are forming to work with 3-dimensional content.

However, bringing VR to the web is quickly beginning to accelerate the formation of relevant patterns and standards. The web presents a low cost distribution platform: anyone can create and access VR applications without the approval of an app store. Utilizing the web as a platform encourages devices to integrate browsers for viewing online VR content. This causes standards to form across devices as people begin to build their applications across multiple devices. In turn, this pushes the industry's capabilities forward. The lowering cost of headsets in combination with a new web standard (WebXR API) of interfacing with VR devices lowers the barrier to entry and makes the field more accessible to everyone: ideal conditions for the expansion of the ecosystem. The abstraction layer allows content creators to focus on the content rather than putting in technical work to get their content running on different types of devices. The WebXR API handles the differences among devices itself and provides an interface layer for applications to utilize.

The web represents an entire global community of developers who create and modify content on the web. Content is critical for the development of a web ecosystem. The API will enable many types of VR experiences from simple creations of children to highly advanced professional developments. This creates a large spectrum promoting both creative and technical content and tooling. We are even entering a time when designers can easily participate without a programming prerequisite: "Eventually, experience creation software will progress to the point where non-programmers can begin to create virtual worlds on their own. Modern game engines such as Unity, Unreal Engine, and others have certainly made this a reality." [6]

i. Current consumer-available VR devices

The success of a number of commercially-available consumer devices has now brought the power of VR to the people. The devices will continue to advance with a thriving gaming community contributing to VR and many industries to soon follow. Degrees-of-freedom (DOF) represents the positional and orientation tracking of input devices. A few popular platforms and specifications comparison:

Device	Resolution	Refresh Rate	Motion Tracking
HTC Vive	1,200 by 1,080 (per eye)	90 Hz	6DOF
Oculus Quest	1,600 by 1,440 (per eye)	72 Hz	6DOF
Microsoft HoloLens	2048×1080	120 Hz	6DOF
Sony VR	1,080 by 960 (per eye)	120 Hz	6DOF

This provides a general scale for the current state of accessible VR devices. Though device resolutions are still low, immersion is completely possible and effective. The 6DOF input devices and head tracking provide an exceptional improvement in precision over classic devices such as mobile phones, laptops, and desktop computers.

Examples of Input Devices DOF's:

- 3DOF orientation: mobile phone rotational orientation
- 3DOF position: GPS positonal tracker
- 6DOF: VR hand controller input using positional tracking along with rotational state

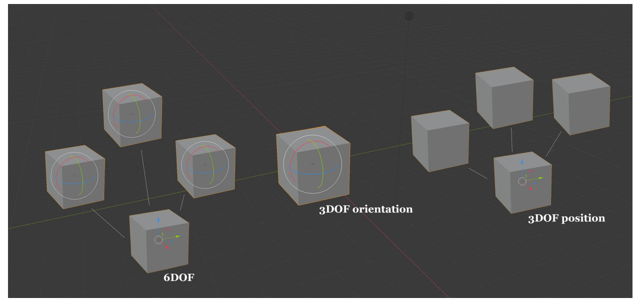

Figure 4: *Diagram visualizing the different variations in DOF input.*

IV. Immersion

The effect of immersion is the most unique aspect of VR systems. First time users are amazed to go inside of a new world with the sensation that they are freely standing and looking around within it. Immersion is typically considered to be the sensation a user experiences as his perceptions are consumed and emulated accurately enough to experience the feeling of being surrounded by the virtual world. The virtual world can be an alternate reality, a different point of view of reality, or some mixture of both.

V. Applications

A clear advantage of virtual reality systems is their ability to simulate attributes and procedures of the physical world. This leads to potential for many educational and analytical tools. You may imagine a surgeon training for highly-technical procedures with systems that allow him to zoom and control detailed anatomical models; or an airplane mechanic observing the construction of a small part deep inside the engine without the need to disassemble a complex and expensive piece of machinery. Research has studied the efficacy on VR training systems, such as training military personal how to operate submarines or training firefighters with in-action procedures without the need to burn real buildings. [2, 3]

i. Viewing and Querying Complex Visual Data

Geographical and topological data can be complex–huge numbers of coordinate points and paths are necessary to capture every 3-dimensional detail over a plot of land. However virtual reality devices have a keen advantage to view and query this data to draw conclusions about the content contained within the data or zoom to specific locations of interest. While 2D desktop screens can also view and query 3D data mappings, they do not exhibit the same level of control precision and viewing capabilities. For example, a technical worker may use a VR headset to view detailed wireframe mappings of city pipelines to assess points of failure for recent or preventative pipeline damage. When combined with the web, a utility worker could easily log in to access computer-aided designs (CAD) on-site remotely over the network. In fact, the nature of CAD translates quite well to VR: CAD drawings are already computerized, 3D, and promote the use of zooming and navigating to observe specific attributes of detailed 3D models and spaces. You could imagine similar cases for architecture, agriculture, building construction, utility administration, airplane & car mechanics, forestry services, and many other interesting uses.

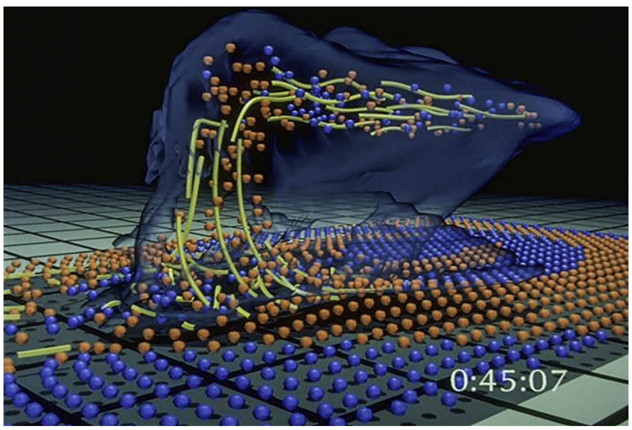

Figure 5: *Data provided by the National Center for Supercomputing Applications shows 3D visualizations of wind flow and direction. [6]*

Virtual reality devices exhibit potential for researchers and scientists to better view and understand complex data. For example, weather scientists could use VR devices to visualize wind flow inside of a tornado. Using quantitative data collected on wind speeds, they could use a VR device to zoom in to the inner areas of the wind storm to observe up-close frame-by-frame changes in wind velocities to better understand weather patterns in areas humans could never travel. Figure 5 shows an example of visualized wind flow data. You could apply the same techniques in many other scientific applications.

Currently, microscopic data is captured and digitized to analyze on a computer screen. Yet with a VR device, you can provide data with high spatial resolutions through 3D capture. Imagine being able to view your microscopic imagery in full 3D immersion, able to precisely move and zoom to any location for observation. If this data is captured over time, you could move forwards or backwards through the frame captures to see how organisms move or behave during that period.

Research is being done in this area related to CAD designs and VR: one example called ShapeGuide is a project which provides interaction parameters for the modification of CAD data. [9] Another example discovers that voice-recognition commands available to VR can make users more productive when building CAD's compared with keyboard and mouse interaction in addition to better accuracy and lower execution time. [10] Providing additional manipulation tools for CAD data has a wide-variety of applications in many industries. You could easily imagine a scenario in which an engine mechanic uses CAD data to view an interactive engine exploded-view-drawing to identify a small replacement part inside of an engine during design, build, or maintenance. With a wide range of engine makes and models, the web could provide an accessible platform for sharing, searching, and viewing of these product-specific CAD imagery.

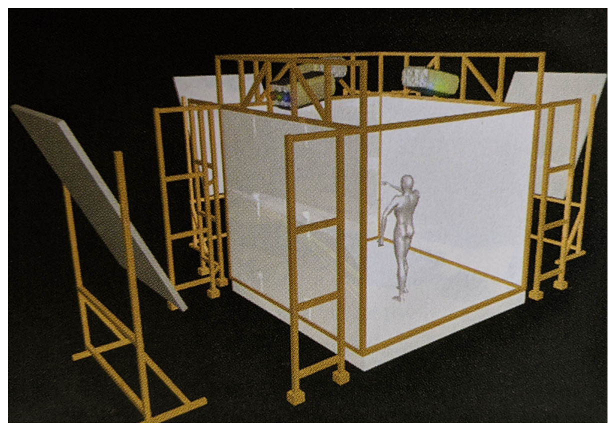

Figure 6: *Surround-screen displays such as the CAVE (Cave Automatic Virtual Environment), developed at the University of Illinois Chicago, use a 3-sided room with projectors to simulate full field of view. [5]*

ii. Remote Procedures

The medical field is ripe for developments unique to VR. One concept many have discussed for years is the ability to perform remote operations. WebVR is a perfect platform for this for a few reasons:

- The remote connectivity over the web supports performing actions remotely.
- The web provides enough bandwidth to transmit high-quality video feeds or other data.
- The VR platform already supports the 3D nature of performing action in the physical world.
- Haptics, an area that is still underdeveloped, presents potential for bridging the sensational gap.

In other words, haptics provides a method for digitizing tactile sensations that surgeons use to make judgements about the state of their actions, procedures, and the patient's body anatomy.

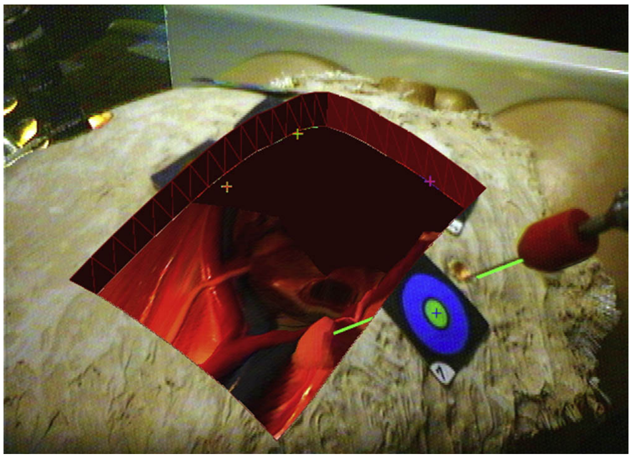

Figure 7: *A VR application that maps ultrasound data onto the real-world view of a patient.*

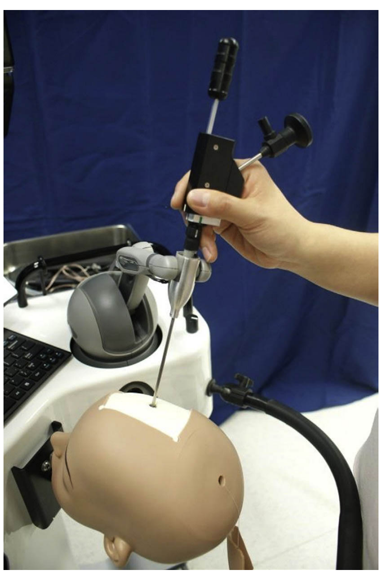

Figure 8: *Haptics provide a mechanism to bridge the tactile gap of the virtual and physical world, important for the sensation-based techniques used by craftsmen or surgeons.*

In addition to performing remote procedures, the virtual space can also simulate procedures for training with doctors that have yet performed them upon real-world patients. Not only do they provide mechanism for improving the skills of novice doctors, training simulations can form a basis that will bridge the gap between the virtual environment and real procedures when remote surgery technology advances further. There are many other uses for WebVR within the medical field that also overlap with other application areas: you could view high-resolution body anatomies or live imagery for training and analysis.

Space travel: VR presents many exciting opportunities for remote procedures in space. Today we have rovers that explore Mars and send back high-resolution photography to help us understand and explore uninhabitable locations. VR would provide an optimized experience for this exploration–you can travel as if your body were in the uninhabitable location with 360 degree video transmitted back to Earth. NASA could provide feeds of this data publicly on the web, allowing average people to explore the vastness of space. One day technology may become advanced and economic enough for consumers to send drones into space for their own personal exploration.

iii. Preview and Simulation

Online shopping is very prominent in today's market. However, one remaining issue is that it becomes difficult to decipher the attributes of goods purchased online, especially when few or low quality photos are provided. For this reason, consumers still travel to brick and mortar physical stores to buy goods since they can look at them directly to better understand their dimensions and features. Of course with WebXR, it becomes an easy task to map 3D models or photography into your living space to preview what the object will look like in your home or if a baby carriage will fold in the correct way to fit in the trunk of your car. This feature would be extremely useful for some consumer products like furniture, eyeglasses, or even merely any object you want to view in higher or dynamic detail.

In a similar way, real estate and architecture have similar needs. A business operator may want to preview a high-profile office before he commits to move his entire company there, or a young couple might want to view the inside of a house before they move across the country. Within real estate, it would not be difficult to provide these features with the 360 degree photo features built into many mobile phones. Companies with specialized equipment can also provide these services to those who need high quality or specialized captures. With WebVR, companies like Zillow or Trulia can provide these features for every house that has the relevant photography data. Just like you can view photos for almost any house on the market, maybe one day this will expand to 3D photography that will enable high-quality virtual tours.

You typical user could also use a similar photo viewing and sharing experience. For example, a mountaineer could capture a 360 photo sphere at the top of a mountain, then share that 360-degree experience with a family member to show them what the world looks like from the mountaintop.

Czerniak et al. have even found VR to be a useful platform for using simulation to treat the of fear of flying. [16]

iv. Collaboration

The collaboration aspect of VR on the web is one of the most interesting applications and has been one of the first to progress by utilizing existing video conferencing technology. The ability to enter virtual spaces with others creates many opportunities for social gatherings, creation of art, learning experiences, networking, or business conferences for discussing ideas and performing work together. The current HMD's are not convenient for video yet since they cover the user's face, but users can participate in varying degrees dependent upon their device–a mobile user can speak or show his face or chat and a desktop user could add a video feed or easily share content from the web.

Meredith Thompson et al. performed studies on collaboration in VR and concluded that "Effective and worthwhile collaboration happens when each [person] is equally involved and are able to fill in whatever information their partner does not possess." [17] This use-case contains high business value since it is in the best interest for a business to share expertise among its employees to enable high-performance across its organization. This especially exhibits potential for cross-disciplinary work, when workers need to collaborate with designers, artists, marketers, or workers of specialized technical areas.

This is a space in which Mozilla is actively investing and exploring with their Mozilla Hubs project. Users can create virtual rooms for conferencing. They can choose any virtual environment in which to meet and add add their own 3D objects. Once inside, users can share videos, documents, or other kinds of media for viewing and discussing. The application creates an avatar for each user to move around in the space and perform discussions with others. Just like the physical world, sound behavior is emulated so that large groups of people can meet and still discuss freely by moving towards or away from conversations. In other words, the sound volume of a sound source will decrease as your avatar moves away from it in virtual space. This gives users the ability to gather and discuss with virtual proximity or break away from the discussion when they need to concentrate or have a sub-discussion with a specific member of the chat. It is easy to add your own video feed so that you have the benefits of traditional video conferencing along with the new features added by the VR collaboration platform.

In March of 2020, IEEE VR held their annual conference virtually and utilized Mozilla Hubs as a platform to gather remotely. Discussion rooms created a space for members of the VR community to gather in a predetermined virtual location and share their expertise with each other. Keynote rooms provided a location to gather and view talks through a video feed. Poster session rooms created a space where conference attendees can walk around a virtual room and view the posters submitted by professors, PhD students, and industry professionals. Since users can move freely, they can walk around and view the posters at their own pace or even discuss content of the ideas with other attendees.

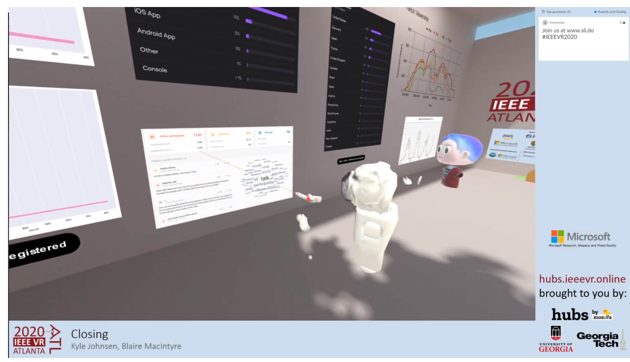

Figure 9: *Screenshot of a live IEEE VR conference meeting in March 2020. You can see two users in the space, with the dog avatar referencing an analytical document during the presentation.*

Spoke is the 3D editor that Mozilla has created to allow users to create their own virtual meeting spaces. Users can meet in fantastical places like on the moon or under the sea or can utilize professionally created high-quality virtual meeting room models in swanky high-rise virtual buildings. This tool also allows for more complex or involved virtual spaces, and provides customization rules for the spaces. For example, IEEE VR created some spaces for their gathering that use special audio properties. In the poster room mentioned above, the room creators added a speaking platform that acts as a megaphone in the room so that users can have their own conversations around the room, but when conference organizers have an announcement to make or presentation, they can step upon the virtual platform to allow everyone in the large room to hear them.

The hyperlinked nature of the web makes it easy for experiences to utilize content from many different locations. For example, users can move from room to room by merely following links to content. In the IEEE VR conference scenario, organizers can add a link to the room for the next talk when a previous talk ends. Then users can merely click on the link to jump to the exact location of the next talk. Or presenters can share links of many resources during the talk that allows attendees to quickly references resources that interest them.

v. Education

The decreasing cost of VR devices presents exciting opportunities for education and VR-facilitated learning experiences in both higher and primary education. The decreasing cost in future years should make VR accessible even to children's education, as headsets are beginning to cost less than desktop and laptop computers or even mobile phones. Headsets can also supplement distance learning, as users can enter the virtual space to watch videos, attend live lectures, ask questions remotely, and collaborate with other students in the virtual space.

Fanini & Cinque discuss how VR can be used to capture session analytics of users' behaviors in order to improve design and efficacy of learning environments, providing greater understanding into the learning process of the user. [12] This gives feedback on learning experiences, how users interpret and navigate the material, and leads to opportunities to improve learning experiences in addition to analyzing their efficacy. Barney Delgado et al. have found that these systems can also be effective with older audiences, contradicting some opinions that digital natives respond more readily to the format. They also observed that the usage of VR environments in the education setting doubled from 2007 to 2008 [14], signs of widespread support of these learning systems.

In the US, it is not uncommon for schools to add computer labs to their campuses for students to utilize. Once the technology becomes accessible enough, it will be easy for schools to provide similar labs for virtual learning: the same can be said for higher education which will occur at an earlier rate, given the larger budgets, collective resources, and specialized research topics of higher education systems. The platform creates a unique affordance for the gamification of learning materials or providing hyper-realistic experiences that allow for augmented learning over traditional reading or video material. For these learning experiences, the web can provide a robust ecosystem for the sharing of learning materials and curricula. This creates an opportunity for experts in education to create high-quality learning materials that can be shared through the web to learning communities all over the world.

The VR platform also provides interesting learning opportunities from virtual learning with experts. Like YouTube or any other current digital learning platforms, VR can facilitate a one-to-many format that allows subject matter experts to share their specialized expertise in a digital format. For example, Tribe XR is a commercial VR title in which users can interface with devices to take real classes in virtual space with remotely located teachers to learn the basics of electronic music creation and live audio mixing. It focuses on simulating the basics of audio mixing equipment in order to familiarize users with techniques they can apply to real equipment. [15]

vi. Entertainment

The entertainment industry has been the industry to invest the most effort into VR technologies. Since video games have been the largest source of 3D content, it is a small and natural jump for computer games and consoles to transition into VR device infrastructures. By merely modifying the main program structure, it can be a small step to enter into a previously created 3D environment and experience it from the perspective of a VR device. In this way, it is not surprising that video games have been the first industry to provide consumer-ready VR-enabled devices.

Much of the benefit of a VR device comes from the ability to experience large worlds from a singular place. For example, a user living in a small New York apartment could still visit expansive worlds or emulate environments that aren't accessible to them from that small location. There are also many new ways to interact with content in VR. Think about an example where you meet up with your family who is spread all over the country to watch a movie together in VR. Since the virtual space is created dynamically, you can emulate the most elaborate and exquisite move theatre on planet Earth (or one that cannot be found here!). With advanced spatial sound, the simulated environment could offer features at higher fidelity than the original experience. This change in format could bring many new ways to experience content: reading books and documents, playing interactive games, or consuming other types of media. Haptic suits can even provide tactile sensations of simulated worlds in film or interactive games.

Google's Data Arts team paired up with the band LCD Soundsystem to create an interactive VR experience for their song *Dance Tonite*. The experience involves a music video type of format that allows viewers to enter the virtual space and dance to the music. The dances of all of the fans are then recorded and compiled to figurines inside the video which show real mappings of previous viewers' dances. [13]

Another interesting example is called A-Painter. A-Painter is a virtual art web application in which users can create 3D art pieces with their natural gestures. Once complete, users can easily share their exact paintings with others by simply sharing the app-provided URL–a direct link to their painting. It is clear how the web enables this application and makes it an even more useful and interesting product.

VI. Performance and Hardware Considerations

i. Latency

Latency is the additional time required for systems to communicate during the transfer of data. In VR devices, delayed vision or input response can have major effects on the perception of the user and performance of the system. Even very low latency has a negative effect on the experience and comfort of the user. [10, 11] The lowest latency required for good VR is 90Hz, which results in the rendering of a frame every 11.1 milliseconds. Visual rendering is not the only operation that requires time: body tracking, world simulation, and data communications must also occur simultaneously. [6]

ii. Resolution

The downside of stereoscopic displays comes in that their GPU's need to work twice as hard to render the images for both eyes. Since 3D graphics is already computationally intensive to begin with, this presents challenges for the technology that aims to move towards a smaller form factor. The act of connecting the display to a computer limits portability and users will want to move around with a lightweight device that doesn't fatigue their heads. Since devices will aim to be relatively small, it will be more difficult to provide such intensive graphical processes, but the technology has progressed quite well already and will continue.

VII. Future

While it is difficult to judge the future of this young and exciting technology, it is certain that the future of VR is bright and now finally becoming reality. The web creates an amazing ecosystem to promote content, techniques, standards, and the overall advancement of the technology. The web makes the technology accessible to many which in turn promotes the sharing of knowledge and new ideas.

Figure 10: *A counterweight display system that avoids fatigue problem created from strapping on a head-mounted display.*

VIII. Current Problems Remaining to be Solved

- **Cybersickness**: Cybersickness is nausea induced by the vestibular system when the body's vision does not match its positional expectation handled by the inner ear. Different users have different sensitivities to this effect. [7] This effect changes considerations when designing interfaces. Movement in 3D virtual space has been explored in great detail by video games using handheld input devices, but these typical practices do not translate well to virtual reality because field of vision movement triggered by the controller without body movement causes cybersickness. As a result, interfaces must find new strategies of interacting in the 3D virtual world. One common solution to this is movement by teleportation–the user specifies where he wants to travel and he is instantaneously transported to that location. Then, he can freely move about within the parameters of his physical room space. This allows customized movement without the effects of cybersickness.
- **Transfer of high-resolution data**: 3D spaces often involve scenery with high complexity of data. For example, all terrain, textures, objects, and lighting must all be rendered every frame to update the

user's current field of view. When all this must be transferred over the web, it creates a bottleneck for the flow of this data. For simple scenes, this is not a problem. For more advanced polygons however, performance will begin to slow. For scenes with many polygons and high-resolution textures, this could cause difficulty if the internet connection is not strong.

- **Social stigmas**: Some VR users and experiences still suffer from awkward social stigmas. In other words, users are not quite yet completely comfortable with all aspects related to VR. For example, IEEE VR 2020 was one of the first conferences to be held completely in VR. The conference presented many social rooms where attendees could enter to have group discussions and share content with each other. Of course, some users are still getting use to this format and must test the waters before they are ready to have a full conversation with an animated virtual avatar.
- **Haptics**: Haptic devices are still complex. Suits are bulky and inconvenient.
- **Device size**: HMD's fatigue users with their weight and long durations of immersion can tire users' eyes. Figure 10 shows an example of an early display aiming to improve this problem.
- **Latency**: Latency causes major problems for display devices that aim to achieve immersion.
- **Device and user mobility**: Some devices need powerful hardware that prevent portable devices and wires restrict the movement of users. This is especially important since the users cannot see the state of the wires while immersed.
- **Establishing resource budgets**: Scene complexity must be managed so that devices are powerful enough to render the scene quickly enough for the display update.

With a growing list of tools available for VR on the web in addition to past tools made popular by video games and other industries, WebVR looks to be an exciting new technology that many can use to explore or share ideas. The future is bright and now is the time to start interfacing with this exciting new industry!

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