

A brief chronology of Virtual Reality

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Abstract

In this article, we are going to review a brief history of the field of Virtual Reality (VR)¹, VR systems, and applications and discuss how they evolved. After that, we will familiarize ourselves with the essential components of VR experiences and common VR terminology. Finally, we discuss the evolution of ubiquitous VR as a subfield of VR and its current trends.

Keywords: Virtual Reality, History, Timeline

“Equipped with his five senses, man explores the universe around him and calls the adventure Science.”

— Edwin Powell Hubble, The Nature of Science, 1954

1. Introduction

Computer graphics are an essential aspect of modern computation platforms. At the turn of the last century, it was required that engineers, architects and designers have the common know-how to operate a graphics workstation in their respective workplaces. With the rapid progress of microprocessor technology, it became possible to produce three-dimensional computer graphics that can be manipulated in quasi real-time. This technology, which enabled interactions with three-dimensional virtual objects, immediately made its way into several different mainstream industry including design, visualization and gaming. This article chronicles the crucial moments in the field of VR and its evolution. We will go

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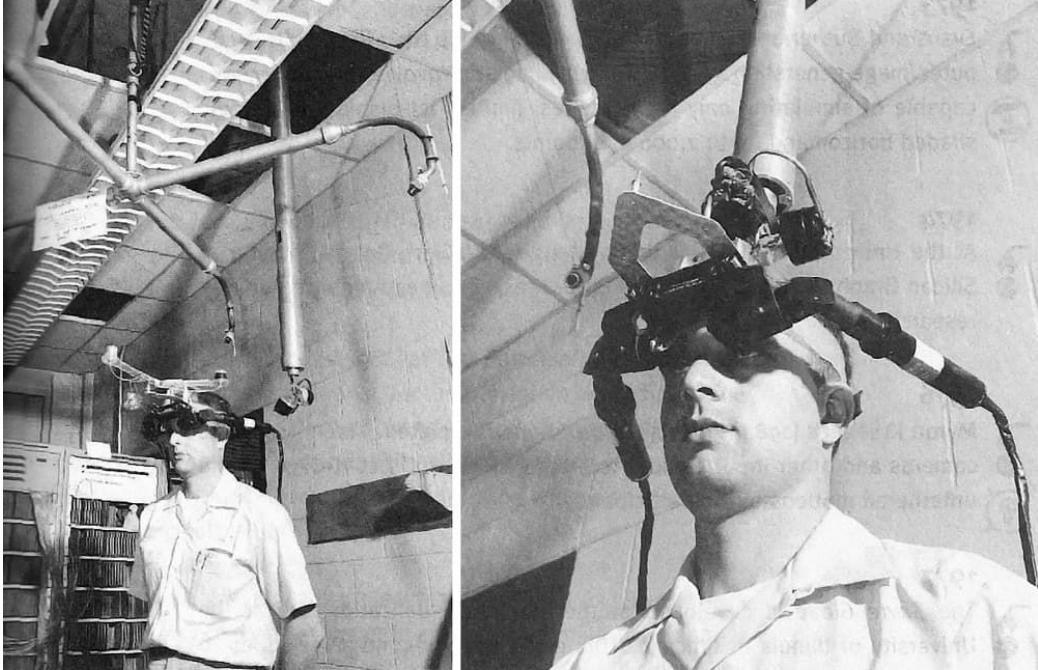


Figure 1: Ivan Sutherland's head-mounted 3D display (c. 1968). The display had a suspending counterbalance mechanical arm and used ultrasonic transducers to track the head movement. (Left) The system in use. (Right) The various parts of the three-dimensional display system. Images reproduced from Sutherland (1968), with permission from Dr. Ivan Sutherland.

through the timeline of major VR technological shifts and events to understand and appreciate the progress of the field of VR.

In 1963, Ivan Sutherland introduced Sketchpad [14], a computer program that used an x-y vector display and tracked light pen for computer-aided drawing. This was arguably the first interactive graphical user interface connected to a computer. Two years later, Sutherland described the ‘ultimate display’ as the “a room within which the computer can control the existence of matter” [15]. He added, “a chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal.” Eventually, Sutherland and his student Bob Sproull created the first HMD system for interactive computer graphics. This system generated binocular imagery that was rendered appropriately for the position and orientation of the moving head. As shown in Figure [1], the display was suspended from a counterbalanced robotic arm and ultrasonic transducers were used to track the

natural movement of the head. This was the first time in the history of computer graphics that people could see into a computer generated virtual world. Sutherland said “make that (virtual) world in the window look real, sound real, feel real, and respond realistically to the viewer’s actions” [15]. This laid the foundation for modern VR applications specifically for immersive VR. Modern VR systems have widespread application domains ranging from simulation and training, industrial design, exposure therapy, surgical planning and assistance, education, and video games. To understand the current trends in the field of VR, it is important to study the history of technologies from which the field of VR has evolved. By exploring the important milestones that have led to the advent of VR technology, the source of many current endeavors becomes evident. We shall see that all the basic elements of VR had existed since 1980, but it took high-performance computers, with their powerful image rendering capabilities, to make it work. This trend continued into the late 2000s until the emergence of smartphones. By 2011 the possibility of having completely untethered immersive VR experience was rising. The section that follows represents a timeline (from 1916-2015) in the development of VR as a field.

The timeline of VR technology and applications showcases important milestones in the field of VR. It includes personal achievements of scholars in the field as well as industrial accomplishments. But there is more to this timeline, for example the gap (approximately 17 years) between Sutherland creating the first HMD in 1965 and the first actual application of an HMD in the form of VCASS in 1982 shows us that computer graphics technology was not ready in 1965. Another interesting trend occurs around in the late 2000s when the mass market was ripe with touch-based smartphone technology. There emerges the need to use the smartphone technology as an inexpensive VR display. The advantage lies in the fact that the smartphones have inbuilt sensors like gyroscope, inertial measurement unit (IMU), and magnetometer to enable sensor fusion, which offers seamless head rotation tracking. Through advances in technology and democratization on an industrial scale, modern day VR systems have become portable and more ubiquitous. The concept of portable, light-weight, easily accessible VR systems is not a very new concept. In 1991, Randolph Pausch proposed his ‘5 dollar a day’ VR system [8] for everyday use. He built this system using the then available video-gaming apparatus. The Pausch approach sparked a democratizing movement in VR technology.

In 2011, before we see a trend of leveraging smartphone technology as primary VR display by commercial entities, the VR research community paved the way. Basu et.al built a system that allowed untethered portability and instant deploy-

Table 1: VR timeline

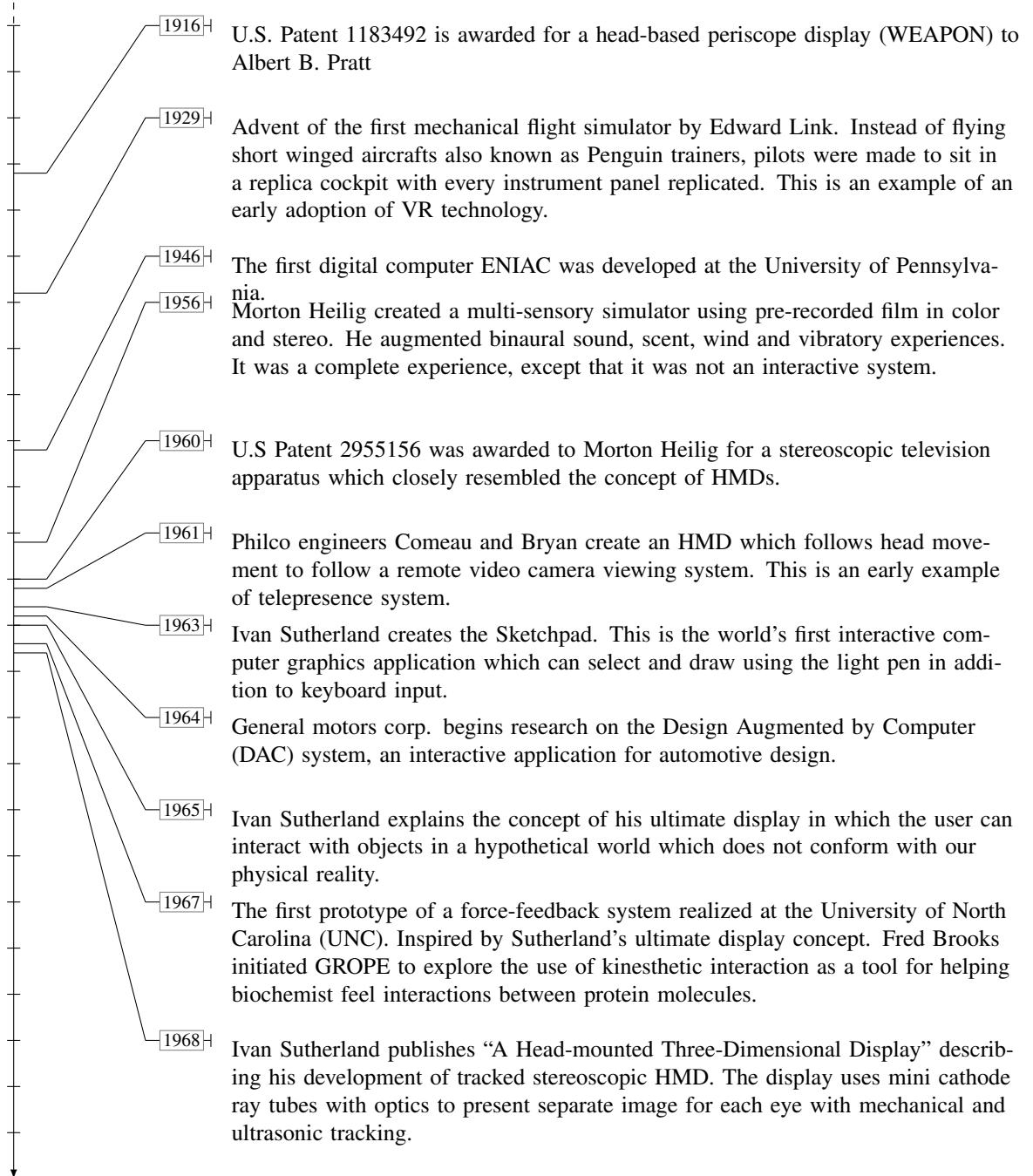


Table 1.1: VR timeline (cont.)

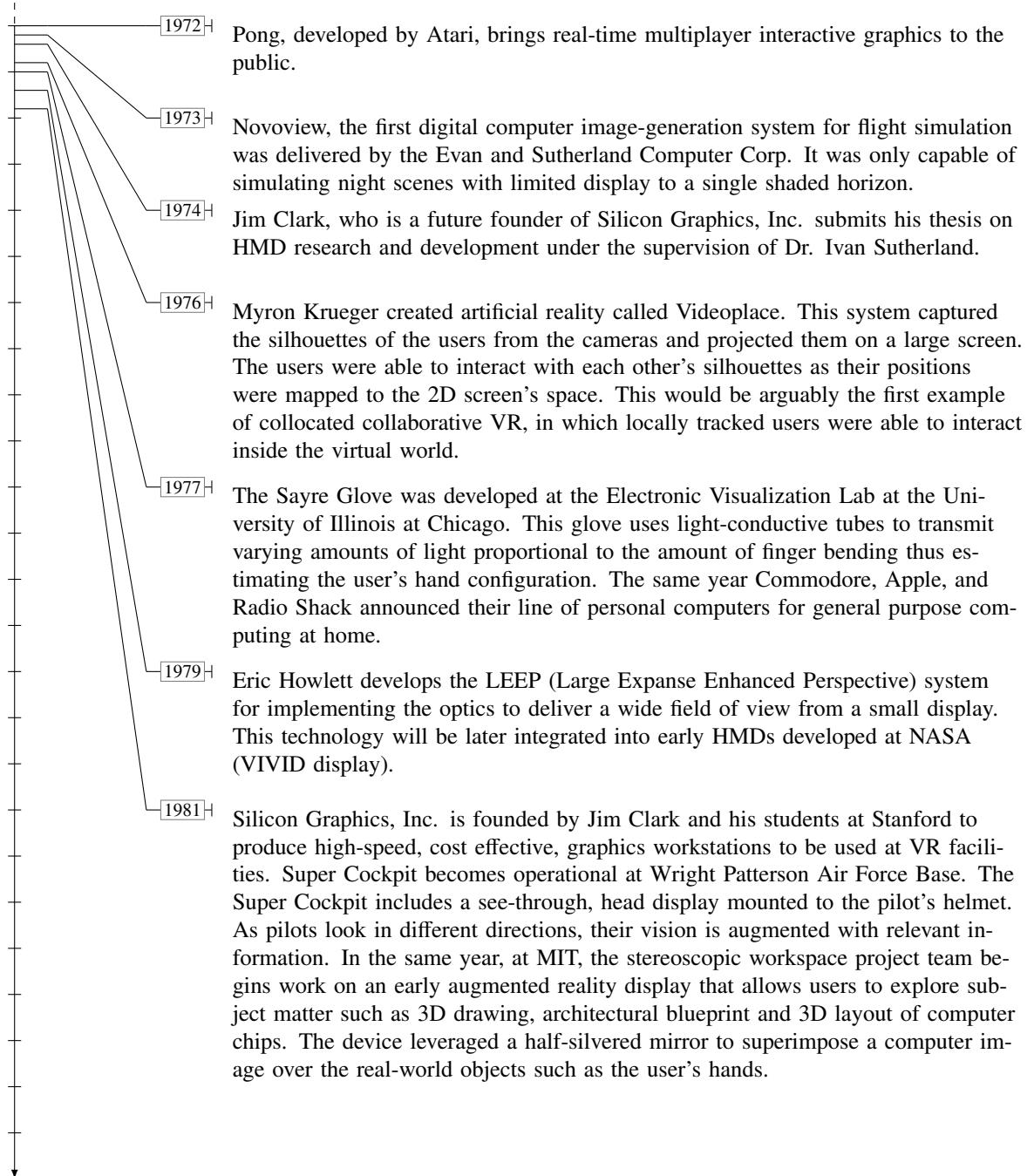


Table 1.1: VR timeline (cont.)

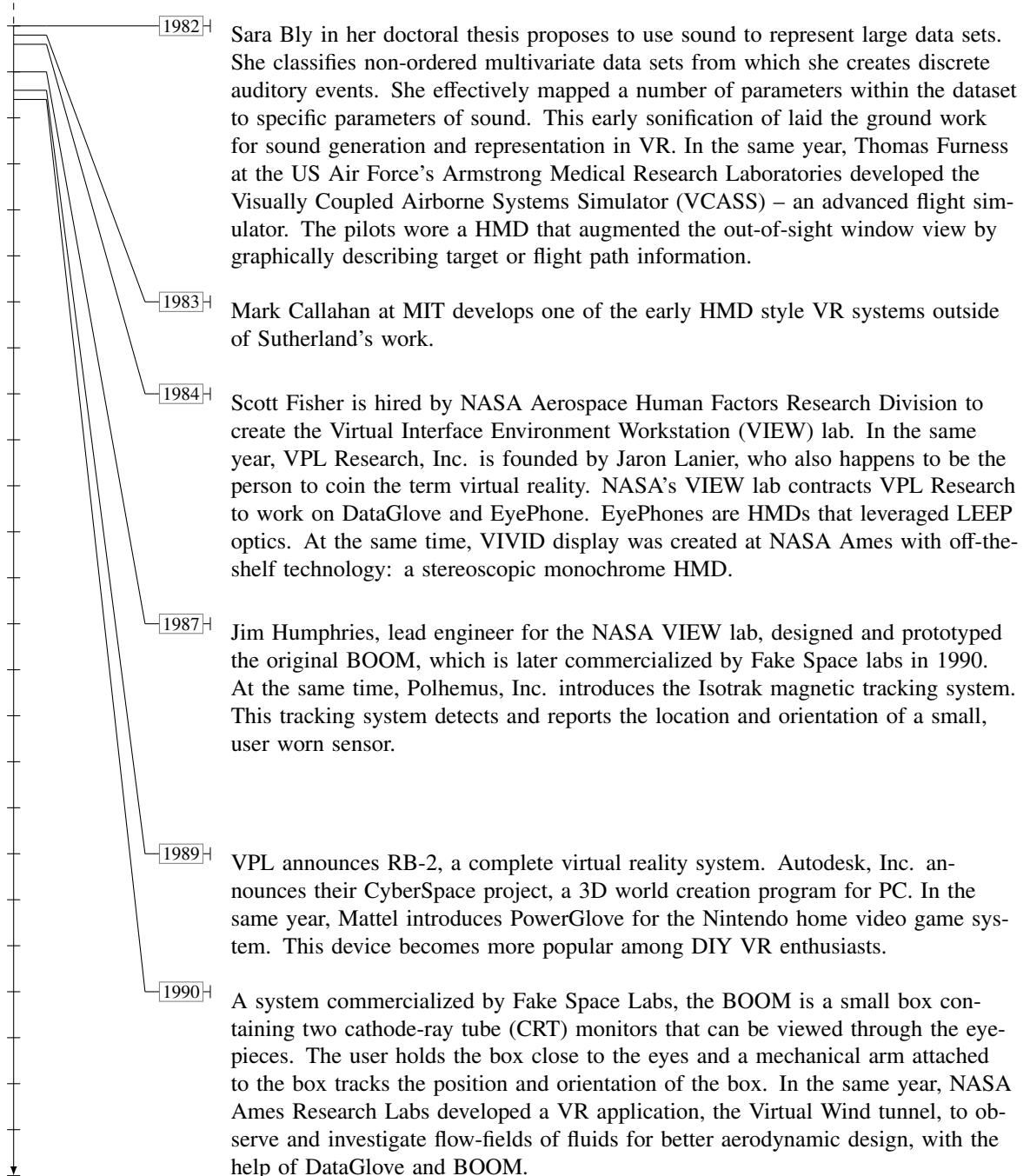
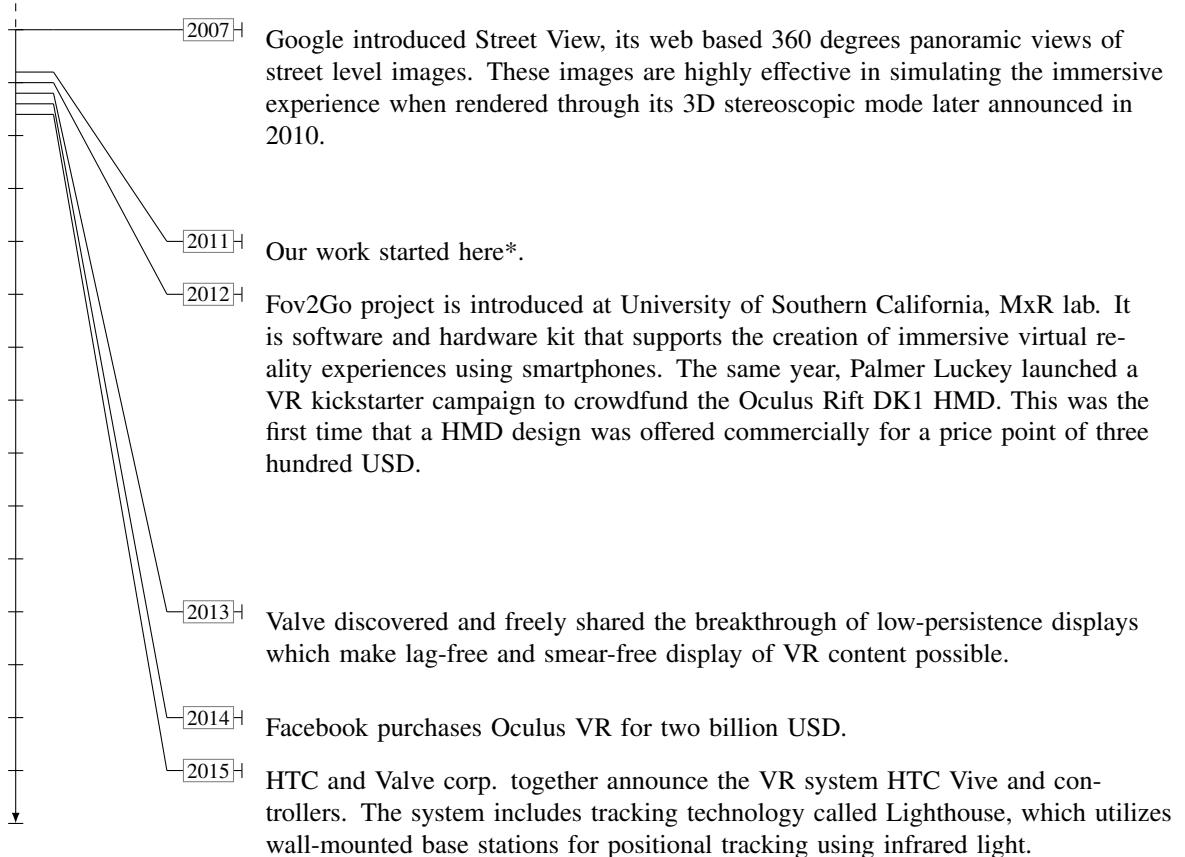


Table 1.1: VR timeline (cont.)

<p>1991</p>	<p>Virtual Research System, Inc. releases the VR-2 flight helmet. This was the first time when HMD price point came down to less than ten thousand USD.</p>
<p>1992</p>	<p>Projection VR is presented at SIGGRAPH'92 as an alternative to head-based displays. The main attraction was the CAVE system. CAVE is a virtual reality and scientific visualization system using multiple wall projected stereoscopic images as opposed to HMDs. It introduced the superior quality and resolution of viewed images and has much higher field of view in comparison to HMD based systems.</p>
<p>1993</p>	<p>The first two academically oriented conference are held for the VR community. The VRAIS'93 in Seattle and Research Frontiers in Virtual Reality IEEE workshop in San Jose. Later VRAIS and Research Frontiers in VR simply merged to be known as IEEE VR. Also, SensAble devices releases the first PHANTOM device. The PHANTOM is a low-cost force display device developed at MIT.</p>
<p>1994</p>	<p>The VROOM venue at SIGGRAPH demonstrates more than 40 applications running in CAVE VR system.</p>
<p>1995</p>	<p>Virtual I/O breaks the one thousand dollar price barrier for a HMD with VIO displays. These displays include an inertial measurement unit providing the head rotation information.</p>
<p>1996</p>	<p>Ascension Technologies corp. introduces the MotionStar wireless magnetic tracking system at SIGGRAPH'96. This new system had receivers for 14 different parts of the body and was targeted for largely motion capture industry.</p>
<p>1998</p>	<p>Disney opens up its DisneyQuest family arcade centers. These centers featured both HMD based and projection-based VR systems. In the same year, the first six-sided CAVE-style display is installed at the Swedish Royal Institute of Technology, Center for Parallel Computers.</p>
<p>1999</p>	<p>The ARToolKit, a free open source tracking library, primarily targeted for Augmented Reality applications, is released with collaboration between the HIT lab and the ATR Media Integration. Although designed for AR, the tracking library provides inexpensive solution to do position tracking with just a webcam.</p>
<p>2000</p>	<p>The first six-sided CAVE system in North America was installed at Iowa State University.</p>

Table 1.1: VR timeline (cont.)



ment of immersive VR experiences [1]. This system used a smartphone device as the display and its internal IMU sensors tracking head orientation. For the first time, a truly untethered VR deployment was achieved outside of a controlled laboratory setting. This setup provoked a host of other researchers to follow suit. For example, Evan Suma's MuVR [17] system has a similar build that support low-cost, ubiquitous deployment of immersive VR applications. Bachmann et al. [4] have been working with their portable immersive virtual environment system that utilizes IMUs placed on the feet and head. They use zero-velocity updates to derive nearly accurate positions and orientations from the sensors. In outdoor applications, a GPS is used for position tracking, and an ultrasonic transducer is used to plot the landscape in front of the user to create redirected walking paths and prevent the user from walking into obstacles.

This timeline embodies VR evolution through limitation. The standardized need to render and interact with a virtual 3D model evolved slowly but steadily over time. The concept of interacting with a virtual entity (3D models, environments, etc.) with real-time (60 FPS or higher) feedback is the basis of all VR experience.

2. What constitutes a VR experience?

The key elements in experiencing VR are a virtual environment, immersion, sensory feedback and interactivity.

2.1. Virtual Environment

A virtual environment (VE) is the content and the subject matter of any virtual experience. It comprises of virtual entities (objects) and their descriptions. A VE 'capitalizes upon natural aspects of human perception by extending visual information in three spatial dimensions,' 'may supplement this information with other stimuli and temporal changes,' and 'enables the user to interact with the displayed data' [19]. VEs offer a new inexpensive communication medium for human machine interaction. For example teleoperation tasks, such as in a laparoscopic surgical simulation, requiring coordinated control of the viewing position benefit from a VE interface as opposed to physically recreating a surgical simulation. VEs are considered a communication medium that has broad applications ranging from education and training to exploratory data analysis/visualization to entertainment. Furthermore, VEs are an essential tool in psychophysical, physiological, and cognitive science research, providing these fields with the backdrop to conduct experiments.

Definition: Virtual environments are a description of a collection of objects in a virtual space and the rules and relationships governing those objects.

2.2. Immersion

Part of having a virtual experience demands the user being *immersed* via VR apparatus into an alternate reality. In general terms, *immersion* refers to a state of mind, a temporary suspension of disbelief which allows a user to move at will from real to virtual and vice versa. Good novelists exploit this fact to pull readers into their story. But none of this immersion is direct and is often presented from a third person point of view. In VR, however, the effect of entering an alternate reality is physical rather than being purely mental. For example, the process of putting on a HMD physically separates the peripheral vision of a user from the real to the virtual. A VR experience typically comprises both forms (physical and mental) of immersion. The VR community simply refers to mental immersion as *presence*. The terms *immersion* and *presence* are often confused and interchangeably used but Mel Slater [12] defines the terms as follows:

- *Immersion refers to the objective level of sensory fidelity a VR system provides.*
- *Presence refers to a user's subjective psychological response to a VR system.*

2.3. Sensory Feedback

VR as a medium allows its participants to experience an embodied perspective [11]. For example, in a flight simulator, the user embodies a virtual flight through direct control of a virtual cockpit. In order to elicit a perfectly immersed virtual cockpit, the VR system needs to track the user's head gaze and synchronize the ego-centric perspective to match the user's head gaze. This is a form of sensory feedback by a VR system. Sensory feedback is essential to VR and a VR system provides direct sensory feedback to the user based on their physical position [Figure 2]. The most predominant form of sensory feedback is visual, but there are other VR experiences that are based exclusively on haptic (touch) and aural (spatial audio) experiences. With regards to the scope of this dissertation, we will be discussing only visual sensory feedback.

Definition: A VR system is an integrated collection of hardware, software and content assembled for producing VR experience.

Definition: Position tracking is the sensing of the position (and/or orientation) of an object in the physical world.



Figure 2: This is an example of a real-time position tracking using a five camera OptiTrack system (Flex 3 cameras) with retro-reflective markers being tracked at 100 FPS. This picture is courtesy of the old Virtual Experiences Lab at the University of Georgia.

2.4. *Interactivity*

A VR experience is authentic only when the user feedback loop [11] is closed. In other words, when immersed inside a VE, the user should be able to interact with the VE and the VE should respond appropriately. Virtual experiences are associated with the ability to interact with the VE by changing locations, picking up objects and manipulating them, and closely following physical reality. There are many forms of interactions that contextually vary depending on the simulation subject matter. For example in a flight simulator, flipping the switches on the control panel of the virtual cockpit makes logical sense and should be interactive as part of the flight simulation virtual experience.

3. Ubiquitous VR design

The vision of ubiquitous computing in Mark Weiser's words [18] is that 'a good tool is an invisible tool. By invisible, I mean that the tool does not intrude

on your consciousness; you focus on the task, not the tool.’ For VR systems to achieve such invisibility as described by Mark Weiser, the number of hardware (wearable) components has to be minimized so that the VR users can focus better on tasks. In 1991, it was quoted [8] that ‘the field of virtual reality research is in its infancy, and will benefit greatly from putting the technology into as many researchers’ hands as possible.’ This marked an important shift in the conceptualization of VR system design with a focus on minimalism and the idea of using off-the-shelf hardware components to build an inexpensive VR system that would be highly accessible and affordable to users and researchers.

3.1. A brief history of ubiquitous VR system design

With an increased focus on motion-based and natural interfaces, the gaming industry has created a wide variety of readily accessible, off-the-shelf virtual reality equipment. This off-the-shelf equipment has vastly reduced the barriers of entry into immersive VR development, reduced costs in the virtual reality industry, and increased the ubiquity of virtual reality devices. While this trend has received much attention [6, 20], it has a humble beginning with Randy Pausch’s initial effort back in 1991 [8].

Pausch’s ‘Five dollar a day’ VR system was built using an 80386 IBM-PCTM, a Polhemus 3Space IsotrapTM, two Reflection Technology Private EyeTM displays, and a Mattel Power GloveTM. At the time, the entire system cost less than \$5000. The system displays could render monochrome wireframe of virtual objects at 720x280 spatial resolution. Pausch’s work focused on offering a seamless VR experience rather than focusing on high resolution graphics and stereoscopic displays. Pausch quoted ‘low-latency interaction is significantly more important than high-quality graphics or stereoscopy’ [8]. Pausch’s work revealed the importance of user experience and what really matters to the users in terms of having a consistent VR experience. Another important aspect of Pausch’s work is accessibility and its redesign of VR systems so that they can be easily democratized. Pausch said ‘the field of virtual reality research is in its infancy, and will benefit greatly from putting the technology into as many researchers’ hands as possible’ [8].

In order to design a universally accessible VR platform that offers seamless experience to users, we need to evaluate each individual components; namely, displays, user input schematics, and VR software. Pausch started with the evaluation of HMDs and stationary displays and their respective impacts on user performance [9]. To simplify the study design, Pausch merely compared a head-tracked versus non-head-tracked camera controlled searching task in a virtual room. Pausch

found that head tracking reduced task completion time by allowing the subjects to build a better internal representation of the environment.

Building on Pausch’s early works, we conceptualized a new framework of collaborative computing in 2011 called the Ubiquitous Collaborative Activity Virtual Environment (UCAVE) [1]. UCAVEs are portable immersive virtual environments that leverage mobile communication platforms, motion trackers, and displays to facilitate ad-hoc virtual collaboration.

Following our UCAVE framework, Anthony Steed published his work on design and implementation of a smartphone based VR system in 2013 [13]. In this work Steed described the development of a HMD-based VR system that is integrated into an iPhone-based platform. Steed’s design of the system is novel in that it exploits the iPhone itself as an unseen touch controller. Steed’s main implementation challenge was to align the two different IMU sensors; one from the smartphone and the other from the Freespace head tracker. Given that there were no external frame of reference to utilize, the user interface had to be adapted as discrepancies in yaw between the two sensors rapidly grew. To overcome these limitations, Steed introduced two mechanisms: a gesture to automatically realign the coordinate systems crudely, and a clutch to manually realign them precisely. Steed’s system can operate at 60Hz for VEs with a few thousand polygons and latency is acceptable at approximately 100ms.

The limitation of different IMU sensor registration was resolved in our following work introducing a wearable electromagnetic (e-m), six degrees of freedom (6-DOF) single hand (position and orientation) tracking user interface that is inexpensive and portable [2]. The e-m tracker was integrated successfully with our UCAVE framework. The e-m tracker provides a single frame of co-ordinate reference thereby offering fully untethered and self-contained configuration. The e-m tracker does not track user position in real world, which is not a mandatory requirement towards seamless VR experience.

At the same time, Judy Vance published her work on the potential of low-cost VR equipment [7] delving into various combinatorial feasibility analysis of consumer-grade video-gaming hardware such as Razer Hydra, Wiimote, and Microsoft Kinect. Vance’s findings are, that in addition to providing 3D motion tracking, having analog controls and buttons are useful to create a more fluid interface for users.

Following the previous work, Suma et al. published his work on a multi-user VR platform [16]. Suma argued that factors such as poor accessibility, lack of multi-user deployment capability, dependence on external infrastructure to render and track, and the amount of time to put all these factors together restrict ubiq-

uitous deployment of immersive VR experiences. Suma's MuVR platform offers to solve all logistical hindrances in deploying immersive VR experiences. Suma's prototype is similar to our UCAVE prototype [2] with the difference of Oculus Rift DK1 dev kit as the HMD and the smartphone device being attached to the hips using a wearable harness. Suma's proposed system pushes the ideology of ubiquitous, immersive VR setup in the right direction by conceptualizing a modular setup towards democratized VR design.

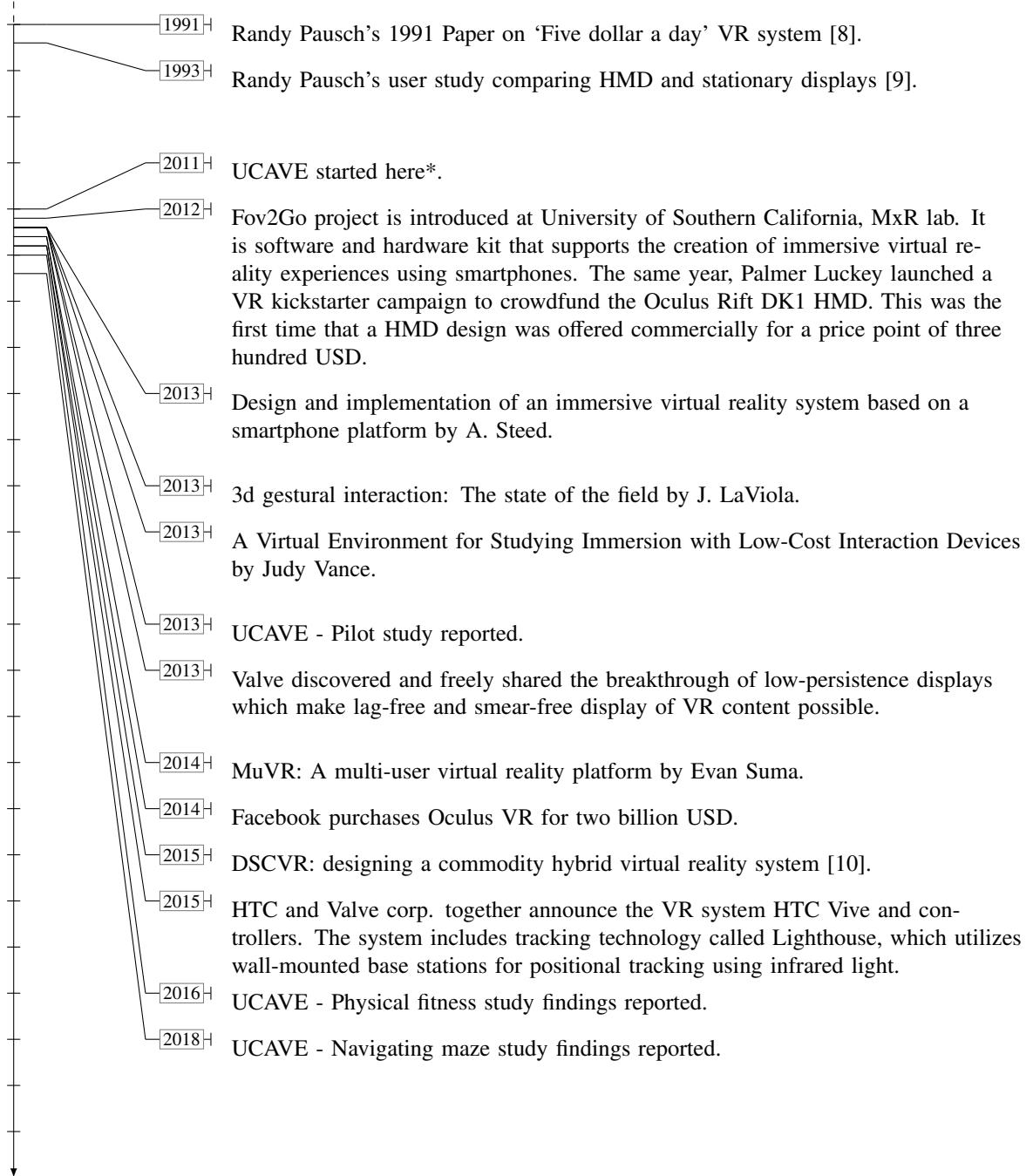
In 2015, Ponto et al. introduced DSCVR [10], a commodity hybrid VR system. Ponto's work presents design considerations, specifications, and observations in building DSCVR, a new effort in building a fully democratized CAVE [3] like setup using commodity grade technology. Even though Ponto's work is not directly related to mobile, ubiquitous VR design, it follows a similar trend in that it is an attempt to democratize VR technology.

4. Current trends in ubiquitous VR

The ubiquitous nature of computer graphics workstations capable of driving complex real-time graphics, three-dimensional displays with higher frame rates and overall cost effectiveness and miniaturization of hardware resources are some of the key reasons behind the current push toward modern VR systems. 3D displays and VR systems existed before but the paradigm shift occurred with the advent of smartphones and the app store. For example, the earlier flight-simulators such as the VCASS [5] had significant graphics capability but have been expensive in deployment and required high maintenance to upkeep. Flight simulators are generally developed keeping in mind a very specific application such as training for particular military plane. They need to be programmed and micro coded in an assembly level language to reduce the overall graphics and CPU cycles required. This limits the code maintainability and further restricts potential upgrades both in terms of software and hardware. A majority of such systems such as VCASS are proprietary and thus are limited to a specialized class of users such as the military.

In the last decade, personal computing has evolved to provide higher accessibility and to provide an entry pathway to a larger domain of users who can contribute and open up other potential domains such as Education and Public Health. In contrast to their predecessors, current VR systems are much more efficient in design and performance, yet there is a fundamental lack of knowledge as to how and why users react to immersive VR in the way they do. With the introduction of mobile VR systems into the foray, we can understand the usability aspects of users engaging with VR and its content better than before. More features in VR

Table 6: Ubiquitous VR timeline



technology does not correlate with better VR experiences. With the continued advancement of hardware, the VR community has reached a certain threshold where more insight in user analytics is required.

Future Work

The author intends to keep the article up to date as and when appropriate.

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References

- [1] BASU, A., RAIJ, A., AND JOHNSEN, K. Ubiquitous collaborative activity virtual environments. In *CSCW '12 Computer Supported Cooperative Work, Seattle, WA, USA, February 11-15, 2012* (2012), pp. 647–650.
- [2] BASU, A., SAUPE, C., REFOUR, E., RAIJ, A., AND JOHNSEN, K. Immersive 3dui on one dollar a day. In *2012 IEEE Symposium on 3D User Interfaces (3DUI)* (March 2012), pp. 97–100.
- [3] CRUZ-NEIRA, C., SANDIN, D. J., DEFANTI, T. A., KENYON, R. V., AND HART, J. C. The cave - audio visual experience automatic virtual environment. *Commun. ACM* 35, 6 (1992), 64–72.
- [4] HODGSON, E., BACHMANN, E. R., WALLER, D., BAIR, A., AND OBERLIN, A. Virtual reality in the wild: A self-contained and wearable simulation system. In *2012 IEEE Virtual Reality, VR 2012, Costa Mesa, CA, USA, March 4-8, 2012* (2012), pp. 157–158.
- [5] KOCIAN, D. F. A visually-coupled airborne systems simulator (vcass)-an approach to visual simulation. Tech. rep., AIR FORCE AEROSPACE MEDICAL RESEARCH LAB WRIGHT-PATTERSON AFB OH, 1977.
- [6] LEE, J. C. Hacking the nintendo wii remote. *IEEE pervasive computing* 7, 3 (2008).
- [7] LU¹, C., DISSELKOEN, C., BUTLER, L., ROSENBERG, M., AND VANCE, J. A virtual environment for studying immersion with low-cost interaction devices.

- [8] PAUSCH, R. Virtual reality on five dollars a day. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 1991), CHI '91, ACM, pp. 265–270.
- [9] PAUSCH, R., SHACKELFORD, M. A., AND PROFFITT, D. A user study comparing head-mounted and stationary displays. In *Virtual Reality, 1993. Proceedings., IEEE 1993 Symposium on Research Frontiers in* (1993), IEEE, pp. 41–45.
- [10] PONTO, K., KOHLMANN, J., AND TREDINICK, R. Dscvr: designing a commodity hybrid virtual reality system. *Virtual Reality* 19, 1 (2015), 57–70.
- [11] SHERMAN, W. R., AND CRAIG, A. B. *Understanding virtual reality: Interface, application, and design*. Elsevier, 2002.
- [12] SLATER, M. A note on presence terminology. *Presence connect* 3, 3 (2003), 1–5.
- [13] STEED, A., AND JULIER, S. Design and implementation of an immersive virtual reality system based on a smartphone platform. In *3D User Interfaces (3DUI), 2013 IEEE Symposium on* (2013), IEEE, pp. 43–46.
- [14] SUTHERLAND, I. E. *Sketchpad, A Man-Machine Graphical Communication System*. Outstanding Dissertations in the Computer Sciences. Garland Publishing, New York, 1963.
- [15] SUTHERLAND, I. E. A head-mounted three dimensional display. In *Proceedings of the December 9-11, 1968, Fall Joint Computer Conference, Part I* (New York, NY, USA, 1968), AFIPS '68 (Fall, part I), ACM, pp. 757–764.
- [16] THOMAS, J., BASHYAL, R., GOLDSTEIN, S., AND SUMA, E. Muvr: A multi-user virtual reality platform. In *Virtual Reality (VR), 2014 iEEE* (2014), IEEE, pp. 115–116.
- [17] THOMAS, J., BASHYAL, R., GOLDSTEIN, S., AND SUMA, E. A. Muvr: A multi-user virtual reality platform. In *2014 IEEE Virtual Reality, VR 2014, Minneapolis, MN, USA, March 29 - April 2, 2014* (2014), pp. 115–116.
- [18] WEISER, M. Creating the invisible interface:(invited talk). In *Proceedings of the 7th annual ACM symposium on User interface software and technology* (1994), ACM, p. 1.

- [19] WILSON, J. R. Virtual environments applications and applied ergonomics. *Applied Ergonomics* 30, 1 (1999), 3–9.
- [20] WINGRAVE, C. A., WILLIAMSON, B., VARCHOLIK, P. D., ROSE, J., MILLER, A., CHARBONNEAU, E., BOTT, J., AND LAVIOLA JR, J. J. The wiimote and beyond: Spatially convenient devices for 3d user interfaces. *IEEE Computer Graphics and Applications* 30, 2 (2010), 71–85.