

Using a disruption framework to analysis the feasibility of Virtual Reality in medical use

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Abstract

Virtual reality (VR) technology is considered as one of the next big things in the Internet field. This technology can be applied in various fields. This thesis studies the feasibility of using VR technology in the medical field, especially in the medical therapy area. This thesis also discusses the nature of disruptive innovation.

The analysis is based on a literature review of virtual reality and a framework called the disruption framework, which is devastated by an important terminology, disruptive innovation. The study uses trend charts and value networks to predict the feasibility of VR in medical therapy.

The result shows that the virtual reality technology can cause a disruption in the medical field, it will affect the existing value network into the medical field.

Keywords virtual reality, disruptive innovation, disruption, disruption framework, medical field, medical therapy

Preface

I want to thank Docent Matti Kalevi Kilkki as both supervisor and advisor, for giving me the idea to conduct such an interesting research topic, as well as the guidance to improve not only my academic writing skills but also the perfection of the content of my thesis.

I would like also thank my parents who give me this unforgettable opportunity to study and live in such a great country, Finland, which just celebrated its 100-year birthday during the period of my thesis work.

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Otaniemi, 09.01.2018

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Abbreviations

AR	augmented reality
CEO	chief executive officer
CPR	cardiopulmonary resuscitation
CRT	cathode ray tube
FDA	Food and Drug Administration
GPU	graphics processing unit
GUI	graphical user interface
HMD	head mounted display
IEEE	Institute of Electrical and Electronics Engineers
NBA	National Basketball Association
PTSD	post-traumatic stress disorder
VR	virtual reality

1 Introduction

1.1 Background

With the rapid development of the Internet technology, all industries are facing Internet transition, which means that every day there will be some technical innovations that may change the industry. Many of current innovations have Internet properties, which give a chance to incumbents to consolidate their market position. The innovation also offers an opportunity for some start-ups to create a new market. Any disruptive innovation can make an impact on industries. For instance, 3D printing, smartphones, the Internet of Things, driverless cars, virtual reality (VR) and augmented reality (AR). Some of them have already changed our daily lives and created a big market, and some have the potential to become the next trend.

The term "VR" is widely circulated over the Internet since Facebook spent around two billion dollars on purchasing Oculus Rift in 2014, a startup who makes virtual reality helmets [1]. Virtual reality is not a new technology, its history can trace back to 50 years ago. VR technology is a new type of human-computer interaction that may change the world. If this technology is developed accordingly, it can become a disruptive innovation in existing markets [2], and build a whole new business model and value network through industries. With the saturation of the smartphone market, the industry begins to find out next trends that will change or even overturn the market, and virtual reality is likely to be one of them. Virtual reality technology can be used in many different fields, not only for video games, 360-degree videos, but also for medical, therapeutic, educational and artistic fields. Virtual reality quickly becomes a hot topic, and all the leading venture capital investments begin to invest in this technology. As a result, large tech companies such as Facebook, Google, Samsung, HTC, and Sony have all developed and announced their products or platforms in the market in hopes of gaining market share in VR technology.

According to the report of CB Insights, the VR/AR investment in 2016 was about 1.8 billion U.S. dollars, which was the largest source of funding since 2012 [3]. As the console VR helmet released to consumers in 2016 [4], last year was considered as the starting era of the virtual reality. Venture capital and manufacturers had high expectations, but the results did not achieve as expected. According to Super Data Report, only 6.3 million VR devices sold in 2016 [5], which directly led to the slowdown of investment in the first quarter of 2017 [6]. In 2016, the main market for VR was video games, which was supported by the console type of VR helmets. However, only about 20 percents of the total sell devices are console type VR helmets [5]. The result shows that although VR vendors want to enter the home video game market, the outcome is not good. As there are other areas where VR technology can be applied, it may be worth looking for a new market.

1.2 Objectives

The objective of this thesis is to apply the virtual reality technology in the medical field. According to a research report about Virtual and Augmented Reality in 2016 [7], in addition to video games, healthcare will be the second largest market for VR/AR technology. So, it is worth bringing this disruptive innovation into the medical field. The framework derived from the theory disruptive innovation will be the key research method, combined with the literature review to assess whether VR technology in the medical field will lead to a new market.

1.3 Research questions

- What is virtual reality and why it has the potential to be a disruption innovation?
- What is disruptive innovation and how it overturns the industry?
- How will VR in medical use change the current value network?

1.4 Thesis structure

This thesis consists of 5 chapters. Chapter 1 is the introduction, which shows the background and motivation of this study. Chapter 2 will introduce the history of virtual reality and its application in the field of medicine. Understanding the development of virtual reality technology is necessary for the framework analysis. Finally, the explanation of disruptive innovation theory. Chapter 3 will explain the methodology in this thesis, what is the disruption framework, and how to use it in research questions. Chapter 4 will serve as the analysis section to show the results. Chapter 5 will give a conclusion and discussion of this thesis.

2 Literature review

The purpose of the literature review is to familiarize readers with three background information related to the research topic. Section 2.1 presents the relevant details of the history of virtual reality technology, as well as the advantages and disadvantages of this technology and its applications. Section 2.2 explains in detail about how VR technology can be used in the medical field and what kind of things and benefits can be done. Section 2.3 reviews the disruptive innovation theory, which helps understand the current market situation, such as how a non-renowned startup can develop and grow into a market leader.

2.1 Virture reality

2.1.1 History of virtual reality

Virtual reality is the core technology in the research question. In order to use the disruptive innovation theory into the research analysis, it is essential to get to know the history of virtual reality first. It is also great to know the relevant technologies that might cause impact or connection to the virtual reality.

Virtual reality is a familiar word for those who read the technical news or familiar with the technology industry. Virtual reality is a technology that creates computer-simulated three-dimensional virtual images, gives the user an immersive experience in a virtual world. The scene in a VR display will change simultaneously when users move the head and the body. By using the controller or eye tracking technology, users can interact with the virtual world. A virtual reality system should include three basic features: immersion, interaction, and imagination [8]. Immersion means that simulated virtual environments are just as vivid as reality. Users find it hard to distinguish between virtual reality and reality, everything in this virtual environment is as natural as the real world. Interaction means that users can interact with everything in the virtual environment and they can receive feedback from it. Imagination means virtual reality can simulate all possible and impossible scenes, such as see-through viscera and blood vessels of a human body, or take an adventure to Mars, which is beyond what human can achieve right now. Three "I" is a guideline that distinguish between VR and other similar technologies.

Virtual reality is still a challenging technology because it is an integration of cross technologies such as display technology, emulation technique, graphical user interface (GUI) man-machine interface, multimedia technology, sensor technique and network technique. Only by perfecting all the related technologies can solve those challenges on virtual reality.

Under this section, the development of the virtual reality technology will be divided into three stages, from the 1950s to 1980s, 1990s, and 2010 until now.

1950s-1980s

In 1956, a machine called Sensorama was considered the first virtual reality system and was patented in the United States in 1962 [9], which was the starting point for virtual reality. The purpose of this Sensorama simulator is to create a computer simulated environment to train a labor force to use the heavy machine, which can help avoid unnecessary operation risks during training. The most significant evolution for Sensorama is the flight simulator nowadays, which has been widely used to train the pilot.

In 1965, Ivan Sutherland published an essay entitled "The Ultimate Display" [10]. "The ultimate display would, of course, be a room within which the computer can control the existence of matter." [10] Three-dimensional images need to be implemented, and when the perspective changes, the image should be adjusted to the right perspective and in the meantime, the computer should produce meaningful sound to create an immersive feeling. The display should also full of imagination, shows impossible things to users. Current VR devices have just achieved those wishes.

Just three years later, in 1968, Ivan Sutherland made the first virtual reality head-mounted display (HMD), called "The Sword of Damocles" [11]. Nowadays most of the VR device looks like that old device. The Sword of Damocles displays a 3D cube frame, and the viewing angle of this cube frame will change accordingly when the user moves his head. That is a remarkable achievement for a 50 years old system. A mechanical linkage head position sensor and an ultrasonic sensor have been used to capture the position of the head. Two different cathode ray tubes (CRT) display slightly different images with different eyes so that a good stereopsis can be created. This old HMD prototype also affected the future development of VR helmet.

Sometimes, the development of one technology must rely on the development of other related technologies. As mentioned above, the virtual reality technology needs cross technologies. A powerful computer can offer a better performance of VR. High-resolution displays can improve the immersive experience. Small and sensitive sensors can reduce the size of the device. Therefore, in order to review the history of the virtual reality technology, it is necessary also to mention some key products in related technologies.

Kenbak-1 is known as the first personal computer in the world [12]. It sold in 1971, which opened the consumer market for the computer. In 1973, Xerox Alto was introduced [13]. It is the first computer to support a graphical user interface and the first to use a mouse. Later in 1977, the famous Apple II was released [14], which was a successful product in the market. Apple II turns on the revolution of the PC industry. It aims not only for the science geeks or engineers but also for mass market. From this perspective, the popularization of the personal computer will help the promotion of virtual reality technology, because VR requires a computer to run the program. If every family in the future owns a personal computer, virtual

reality into every single family is not a dream. In the 1980s, small CRT monitors, PCs, improved graphics cards and enhanced precision tracking equipment could be purchased personally and separately. It provides a good prospect for the development of computer-related products, including virtual reality.

In 1978, MIT developed a virtual reality system map called "Aspen Movie Map" [15]. It is a system that provides users with virtual tours of the city called Aspen. This system map uses film cameras to capture every corner and angle of the city. In addition, the system has an interaction design for users. A touch-screen interface on the display allows users to change the map including browsing speed, viewing angle, steering, stopping and zooming in & out [16]. Computer generated 3D models also exist in some land views. This Aspen Movie Map is considered as the predecessor of the famous Google Street View nowadays.

In 1980, video game company Atari released an arcade game called Battlezone, which was considered the first virtual reality arcade game [17]. This game opens the development of the application of VR technology in video game industry. In 1982, Thomas G. Zimmerman [18] developed a pair of virtual reality glove called Data Glove, which gave a better interactivity in a VR environment. The keyboard and mouse is not a good choice for VR interaction considering that human eyes can only see computer simulated images. Based on that, the perfection of the same kind of technology is an important task at present, especially in some special situations, such as surgical training. Using a glove-type input device is better than other conventional controllers.

In 1985, Jaron Lanier founded a company called VPL Research, an abbreviation for Visual Programming Languages [19]. The goal of this company is to develop and sell VR devices, including Data Glove. Jaron Lanier is the one who coined the term VR and brought it to the public. Another important product is the EyePhone [20], a head-mounted display that looks very much like the current VR device. Its purpose is to create a feeling of immersion through computer simulations, which can also track the movement of the head. During an interview in 1989 [21], Jaron explained all his VR equipment and the future of VR technology. He believed that with the help of the VR technology, there should be no restrictions on the understanding of the world. Technologies can make unpredictable and astonishing things, the application field of VR is enormous.

To sum up, from the 1950s to 1980s, the term virtual reality was just created. Some genius minds came up with ideas and built VR prototypes, and theories related to virtual reality had just formed. Due to the development of the home computer, there will be more and more ordinary people can participate in developing this new technology, the potential of virtual reality technology is huge.

1990s

In 1991, a company called Virtuality introduced a VR entertainment system, which was the first mass-produced multiplayer and online VR gaming console [22]. Users wore goggles and controllers for an immersive experience. This VR gaming console achieved great public success within a short period of time because players were curious about it. However, it goes failure quickly because compared to the arcade game, more money needs to pay but less play time players could receive. Another reason is that the entire VR gaming console setup is complicated, players just familiar with how to play, time is up. At the same time, goggles are bulky and uncomfortable. The previous player gets wet quickly and leaves sweat for the next player, which brings a bad user experience. The virtual 3D world experience is still too weird at that time.

In 1992, a science fiction movie called *The Lawnmower Man* brought the virtual reality technology concept to the audience [23]. In that movie, VR technology was used for the treatment of psychiatric patients. In some perspectives, this film brings not only the virtual reality technology to the public but also mentions new applications for VR technology.

Another hot technology, augmented reality (AR), was also invented in 1992 [24]. There are obvious differences between VR and AR technology. Virtual reality creates a completely computer-generated 3D environment that users are unable to see the real world. However, users of AR can see the real world at the same time with the virtual image, and the virtual image can directly interact with the real environment. Augmented reality is also an important technique, it always mentioned together with virtual reality. Both of them require computers to create something virtual to augment or even replace the real world. Some of the real augmented reality devices on the market include Google Glass and Microsoft HoloLens.

Later, there were several VR devices on the market, most of which were released by video game companies. For example, SEGA released the Sega VR-1 in 1994 [25]. However, because of the development difficulties, it had never been to mass-produce the product. Nintendo released the Nintendo Virtual Boy in 1995. Although Virtual Boy was the first portable game console, due to the computer performance limitation, it could not bring a good game experience, and the display could only display red and black color. VFX1 virtual reality system was also announced in 1995 [26]. Despite its state-of-the-art technology such as wide viewing angle, which is an important indicator of current VR equipment. VFX1 also supports many games, which is another important indicator of nowadays VR development. Some shortcomings of the VFX1 system include the high price and the VR concept ahead of the time, which leads the product to the disappearance inevitably. In the early 1990s, video game companies began to give attention to the VR technology and wanted to open up a unique VR market to subvert the industry. However, due to the technological developments of the time, video game companies were unable to provide

a high-quality, immersive VR gaming experience. Thus, VR gaming consoles soon failed. From nowadays perspective, it is understandable that even for the current VR product, the VR experience is not perfect. The demand for a good user experience of VR is quite high and cannot be achieved at that time.

Therefore, a huge virtual reality bubble was formed in the 1990s. Several points of this VR bubble can be summed up. Once consumers lose interest because of the poor user experience on VR device, there is no consumer market. Companies are unable to reap benefits, so they stop the development of related products. At that time, consumers were more likely to play computer games and video games. Is it still worth investing in VR technology at the 1990s? The answer is no. As mentioned above, the development of VR technology depends on the development of other cross-technologies. If a company wants to succeed on the use of VR technology, it must invest and develop all relevant technologies. Based on the fact that video game companies already have a stable and rising market for the current product, and VR gaming cannot provide a better gaming experience, it is not worth for VR investment.

In addition to the limitations of technological developments, another issue of virtual reality is the concern about the influence on users. That concern still exists nowadays, which is the addiction to virtual reality [27]. Virtual reality creates a completely immersive virtual environment for users, they are isolated from the outside world. As more and more time spending in the virtual world, users may not distinguish virtual reality and reality. Eventually, they cannot live without virtual reality because the virtual world can satisfy all the fantasy of users. At the extreme, this addiction may danger the entire human race. The voice like that is so strong which limits the development of virtual reality.

The failure of game companies to open up the VR consumer market does not mean the end of VR technology. Virtual reality has been used in other areas such as medical and military fields. In 1977, a conference paper about the flight simulator system was published [28]. It called the Visually-Coupled Airborne Systems Simulator. The goal of this simulator system is to help reduce the cost of pilot training. In 1994, Max North published a paper on virtual reality medical therapy [29], which started the research of VR in medical fields.

The global Internet comes from the late 1980s. In the past, the Internet can be used only by the government. Then it could be used by research and educational institutions. Finally, in 1995, restrictions on commercial use of the Internet were ended [30]. With the popularization of the World Wide Web and Internet browsers, the rise of the global Internet has also followed. The connection on the Internet breaks the limitations of geographical area, distance and social ideology. As long as the computer connects to the Internet, people are able to access various ideas, cultures, and news all over the world. Nowadays society is based on this information revolution.

To sum up, from the late 1980s to 1990s, there is a rapid development of VR technology, especially in the video game industry. VR is a fresh new technology with a fascinating future, but it also creates a huge bubble. Virtual reality is a new way of human-computer interaction, but due to various reasons, it disappears in the public view. On the other hand, the strong development of the Internet has made people forget this temporary failure technology. A new information era in current society begins, which might help the development of virtual reality under the new environment.

21st century until now

Stepping into the 21st century, with the development of all the computer-related technologies, the birth of a new generation of virtual reality device with small size, lightweight, and affordable price becomes possible. Those computer-related technologies include mobile technology, high resolution and refresh rate display, small but sensitive and accurate sensor, powerful 3D graphics capabilities, powerful chips, and hardware.

Palmer Luckey, the founder of Oculus VR, hopes to build a high contrast, low latency, wide field of view, cheapness and lightweight head-mounted display. The very first prototype was completed in 2010 [31]. Two years later, that prototype was brought into the E3 video game show [32]. Once again, the virtual reality HMD was introduced to the public. Just two months later, the Oculus Rift project was launched on a public funding platform Kickstarter. In 2014, this startup company was acquired by Facebook, which brought a new competition for the next trend.

Since then, all major high-tech companies or manufacturers start to develop VR devices. In the console VR market, HTC and Valve announced the HTC Vive and it began shipping in 2016 [33]. Sony announced that PlayStation VR would be released in the second half of 2016 [34]. After two development versions, the consumer version of the Oculus Rift was also released in 2016 [35].

According to the sell report [5], the PlayStation VR sold the most among the console type VR in 2016. It is the cheapest among those three because the HMD connected directly to the PlayStation 4. Buyers who already have one PlayStation 4 do not need to purchase or upgrade any extra hardware. The second most sell is the HTC Vive. While it is the most expensive one, thanks to the partnership with the largest digital distribution platform, Steam, HTC Vive can offer a lot of high-quality VR games. Also, HTC Vive has a technical advantage. It has the widest moving range, which provides more moving space for players. Although Oculus Rift ranks last, after all, it is the first VR product of the new century. Facebook gives full support for it, which creates a stable and low-risk development environment. Based on the social property Facebook has, it might use Oculus Rift into the social sphere. Considering that virtual reality is an emerging market, it still has a long way to go.

Other companies like Google and Samsung focus on mobile VR. Google first announced a low-cost and simple DIY cardboard in 2014 [36]. After folding a cardboard, it can hold a smartphone so to have the basic VR experience. Hence, anyone who has a smartphone and wants to feel the basic VR experience only needs to pay very little money. This kind of behaviour looks a bit contradictory. Users want to try a new technology, but they are not willing to pay much money. Still, a cheap product cannot offer a good user experience. In 2016, Google announced a mobile platform called Daydream [37], specialized in virtual reality development on the smartphone.

Samsung develops Gear VR. By taking advantage of its brilliant selling strategy, sold unit ranking the first compared to all other VR devices including console VR [5]. The reason is that Gear VR has a reasonable price. In some of the regions, it is free to have one Gear VR if consumers preorder the Samsung flagship phone. The Gear VR is easy to use but it provides a more immersive experience than other mobile VR devices.

To sum up, with the advancement of the related technologies, a high user experience VR device is easier to achieve, which makes virtual reality technology has the potential to be the next game changer. It seems that incumbents are quite positive on VR technology, daring to spend money and resources on it. In general, whether it is mobile VR or console VR, the current VR market is still relatively new. Products, platforms, and the entire industry chain of VR is not perfect. Currently, most VR products aim at entertainment purposes such as video games, VR videos, and pictures. Giving the fact that the unsmoothly market expansion in 2016, it is worth trying out the application in other fields.

The whole 2.1.1 chapter gives a thorough history of the virtual reality technology and some relevant technologies. Those are necessary factors to apply the methodology in chapter 3 and 4. Figure 1 shows the time frame of the development of VR and some relevant technologies.

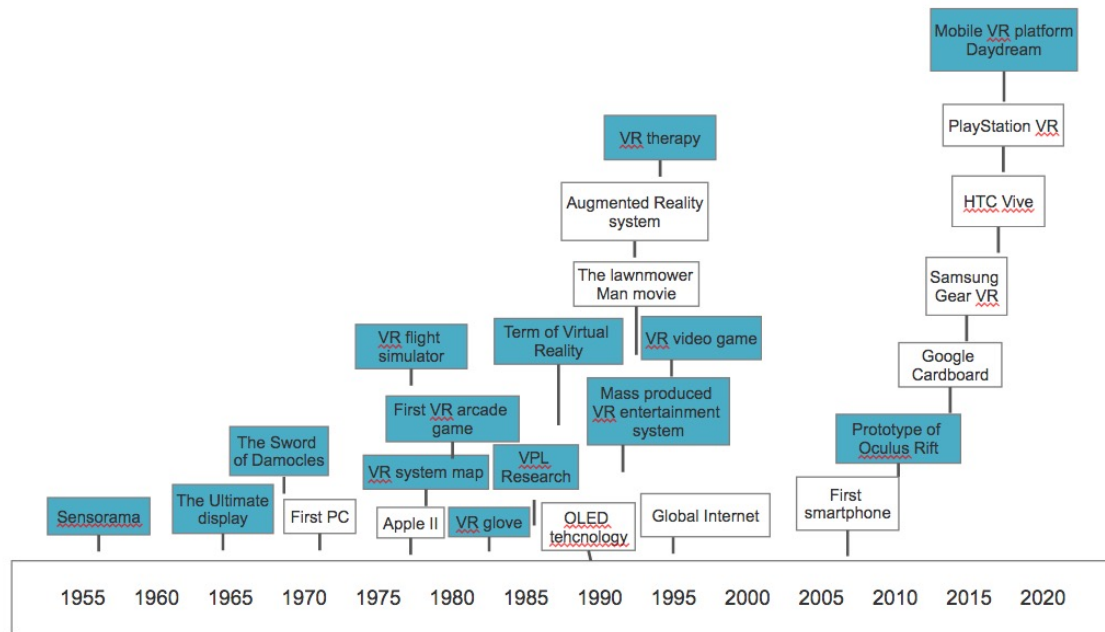


Figure 1: Timeframe for VR history

2.1.2 Why to pursue virtual reality

There are a variety of technologies nowadays. This section will discuss why and what brings virtual reality more and more popular. It will help explain the motivation why the research question is the feasibilities of using VR in medical use.

Nearly ten years have passed since Apple announced its very first smartphone to the world. The smartphone market has already saturated, something new must come out to be the next thing and lead a new trend. In human society, we always need a great revolution to push the entire society to a higher level. Both the industrial revolution and the information revolution have changed the way people live.

Different from the past, market leaders in related fields were more inclined to choose a conservative strategy, focused only on maintaining their position and market share. Current society is fast pace, so a company must keep innovating to catch up with the market demand. One example of a giant company is Google, which has a research facility called Google X [38]. The idea of that facility is to push a bold idea to make it real and becomes a disruption in the industry. The rising star of the electric car company Tesla is another example case. The electric car is much more environmentally friendly than the traditional car and will no doubt affect the automobile manufacturing industry. Another example is Airbnb, which offers hospitality services, rents rooms or apartments. It turns on the sharing economy. Virtual reality has a similar nature, although it is not a new technology. The reason why virtual reality failed to become popular before was technical limitations, but with the current developments, it would become perfect within the expected time.

Another reason why to pursue virtual reality is the human-computer interaction. As long as people make tools or systems to help deal with daily life, there exists interaction with machine or computer. The machine can be any physical machine or any computer system. There should be a way to link the interaction between human and computer, and the goal is to achieve user-friendly, ease of use and nearly zero learning costs. In the information age, the mouse and keyboard are used to control the computer. This type of interaction continues until now, so there is no reason to doubt its importance. The computer interface also changed from the command line to the graphical user interface. Touch screen technology is another great way to interact with smartphones or tablets or personal computers nowadays. Touch screen offers a natural way for humans to slide and press on a screen with fingers.

At present, the interaction with a smartphone or a laptop is limited to a two-dimensional screen, while the virtual reality can bring this interaction to a three-dimensional experience. Although VR is a computer simulation environment, it is hard for users to recognize virtual reality and reality. Virtual reality provides a completely immersive environment in which everything is real and more natural gestures can be used. Long-term development of VR not only provides visual and auditory feeling, but also brings smell and taste. The computer processes and reacts all human actions, such as head, vision, gestures, and motions, and then output all feedback to users.

Finally, virtual reality technology can be widely used in many fields such as video games, live broadcast, entertainment, retail, real estate, healthcare, medical, education, military, and engineering. As just mentioned, the purpose of innovation is to make life easier, the following applications of VR will explain how this technology change the original field in a new way.

The first application of VR is the video game industry. Back to the 1990s, the first rise of virtual reality was caused by the competition of those video game companies. The development of video games is closely related to the development of the computer graphics technology [39]. From the very beginning of text games, users could only interact with the computer through the command line. Then the computer can showcase some simple shapes like point, line, 2D and now 3D games. The quality of the image on the screen is more vivid than before, players need that feeling to be immersed in the game, and virtual reality can better fulfill this need. That is the reason why both 1990s and right now the VR market focus on the video game industry, the immersive gaming experience is always been the pursuit of players. According to the Global Game Market Report published by Newzoo, the global game market is expected to reach 108.8 billion U.S. dollars in 2017 [40]. A trend that will continue to grow in the coming years, which confirms the exploration of VR market in the game industry.

The next application of VR is the live broadcast, such as sport games and concerts. VR will give the audience a new experience, especially for those who cannot be on

the scene. For example, National Basketball Association (NBA) tries to use some new ways or technology to enhance its watching experience. In 2015, NBA brought a 360-degree video on the court [41]. Audiences wear the VR HMD and enjoy the video just feel like sitting on the courtside. Moreover, in 2017, NBA corporates with NextVR to bring a more advanced broadcast experience [42]. Audiences can not only see the actual scene but also some simulated images on the HMD, such as team data or player data. This VR live broadcast brings a new and cool experience. A similar scenario can be applied to other types of sports and concerts. VR can meet the needs for some audiences who are unable to be on the scene but want to watch games or listen to concerts.

The next application of VR is the retail industry. Nowadays more and more people are willing to buy things online because it is convenient. People do not need to go outside, they just need to click few buttons, and the item will be delivered to the home. E-commerce retail sales in 2016 reached 1.915 trillion U.S. dollars [43]. The market potential of the application of VR technology in the retail industry is huge. There exist some problems when buying things online, for instance, clothes. For different brands and types of clothes, the size is slightly different, so buyers do not know whether the clothes are suitable or not. If buyers bought the wrong size, it becomes inconvenient to return and deliver the right size again. Virtual reality technology can solve this problem. A simulated virtual figure will be generated based on the measurement body data of the buyer, and this virtual figure can try the virtual clothes on to see if it fits. This solution will minimize the possibility of buying the wrong thing. There is one cooperation between Apple and IKEA recently that might inspire the related development of the retail industry [44]. They are trying to create a mobile application that allows customers to use augmented reality technology on a tablet or a smartphone. The purpose of that mobile application is to let customers see if IKEA products fit in a room, so customers can decide whether to buy the product or not.

The next application of VR is the military field. VR technology has a long history of military applications [45]. It can be used to practice tactics or familiarize with combat areas, which helps reduce the risk and casualties when the real combat happens. VR can also be used for military machine training, such as fighter or tank. On the one side, with more functions added on the military machine, the operation of it becomes complicated. So, in order to train soldiers more efficient, VR simulator could be used [46]. On the other hand, the maintaining cost of those military machines after training can be prohibitively expensive. The use of virtual reality technology can help save unnecessary costs.

Education is also an important area for the VR application. In addition to the traditional face-to-face teaching, there are some new ways of teaching in the information age. For example, physical books might be replaced by a tablet, which could help stimulate students' inspiration. Useful resources and online applications can help students learn new knowledge or finish projects faster. Some courses or subjects need

to read through objects, such as three-dimensional mathematical figure, or some ancient sculpture. All those can be presented in a more interacting way through VR. Virtual reality can make the class more fun and efficient.

Another important application for VR is healthcare and medical use. It is the core research target in this thesis, so more thorough analysis will be discussed in the next section.

To sum up, although VR is not a new theory or concept, it has some unique advantages that prove its disruption potential. This technology may bring our society to a higher level by changing the new way of human-computer interaction. Virtual reality technology can be applied to a large number of fields, and it is likely to see some changes in some fields during the coming years.

2.1.3 Challenges of virtual reality technology

Virtual reality technology can be applied to many areas, so there is the possibility to subvert the current industry. This technology also faces some challenges, only by solving those challenges could help VR win the market.

The first concern is that virtual reality device right now should focus more on mobility or immersion. At present, the development of VR technology cannot achieve both. Manufacturers may only focus on one of them, either mobility or immersion. Mobile VR is portable, but it can only provide the most basic VR experience. An immersive VR experience requires a powerful graphics processing unit (GPU) to render the 3D scene, but the current mobile GPU cannot achieve this need. Because the mobile headset lacks position tracking function, users can only change the viewing angle with the gyroscope on the smartphone, which is not accurate enough. The console VR HMD does offer an extraordinary immersive user experience, but it requires connection to the PC via one cable. The GPU on the desktop renders the 3D image and transmits it to the HMD through the cable. However, this long cable causes a restriction. Users cannot walk freely in the room because they may keep worrying about been stumbled by the cable. Wireless transmission is a good solution, yet based on the current wireless standards, the bandwidth cannot meet the requirements of low latency and massive data transmission. If the delay is not low enough, users may find the image out of sync and feel dizzy and uncomfortable. The perfect wireless transmission can only expect the new transmission technology to be implemented as soon as possible, whether 5G, Li-Fi, or the new wireless 802.11 standards.

Another challenge on VR device is the feedback system. The haptic feedback system regenerates a touch feeling to users by force and vibration [47]. The simplest application of this feedback system is the vibration on the smartphone. Vibration feedback is given when the user touches or presses the phone screen. It is important because people use all senses to feel the real world. When users touch the screen, they

need to know if their operation has been performed or not, and vibration feedback can eliminate this doubt. As for the VR device, the current visual and audio feedback is good but lacks perfect tactile feedback. The conventional controller on the VR device can only apply vibration, but it cannot provide a lifelike "touch" feeling in the virtual world. A considerable number of companies strive to provide a complete haptic feedback solution that allows users to touch objects in the virtual world, feel the texture, temperature and more.

In addition to some technical issues, there are also some concerns about the influence of VR technology on the human. One of which can be traced back to the 1990s. As mentioned above, the virtual reality addiction may endanger the entire human race, but this opinion is difficult to stand on the ground. People spend more and more time on smartphones, but smartphones do not have bad influence on the entire community. There might be some concerns about social anxiety disorder. People are more willing to stay in their own virtual world but refuse to get close to others in real world. Another uncertainty is the health issue. In addition to the risk that users may get stumbled by the connected cable, there are some videos online show that some users fall down and get injured by immersing themselves in a virtual environment. According to some early literature reviews [48] [49], simulator sickness or cybersickness does exist. Those sicknesses can cause users uncomfortable feeling such as headache, dizziness and sweating. Although many different factors cause these symptoms, the possible health issue caused by VR prevents many potential users from trying this new technology.

Last but not the least, there is the privacy issue of VR technology. The Internet is so advanced and open nowadays, and many Internet-related technologies face the privacy leak problem that more and more people are beginning to pay attention to protect their privacy. For example, if VR technology is applied to retail or healthcare fields, users undoubtedly need to upload their personal information, which can result in a privacy leak. From one perspective, it is hard to judge. Since users start to surf the Internet, use social network applications, share their every moment and pictures on the Internet, there is no privacy anymore. Although large companies continue to improve privacy policies and use end-to-end encryption to protect user data, there still exists the risk of exposing users' personal information.

To sum up, this section discusses some challenges and concerns about the virtual reality. Some challenges can be solved by the evolution of the technology, some of them remain unknown to solve. Some concerns are just like a double-edged sword, which makes it hard to judge right or wrong.

2.2 Virtual reality application in medical field

In this section, a brief history of the application of virtual reality technology in the medical field will be presented. Based on extensive literature, why and how virtual reality technology is used in the medical field will be discussed.

In general, virtual reality has four main applications in medical fields: VR therapy, medical education for medical students, virtual surgery practice before the real operation and live broadcast the whole surgery process through the VR technology. The rest of this section will explain why and how VR technology works in all four areas.

The first application of VR is the virtual reality therapy. As mentioned in section 2.1.1, the early thinking to put virtual reality technology into medical use can be traced back to 1990s. The early 90s is the first wave of VR, at the time, virtual reality technology was considered mature and could be applied to different areas. Max North first proposed a virtual reality therapy in 1994 [29]. The purpose of VR therapy is to harness computer-simulated virtual environment to help treat mental illness. Placing patients in a virtual environment and design tasks to be done during treatment, and those tasks would help with the treatment. This type of mental illness includes post-traumatic stress disorder (PTSD), anxiety and fear. In the same year 1994, the psychologist Ralph Lamson and his medical team successfully conducted an experiment to heal the fear of height [50]. Based on the results, 90 percents of patients overcome this fear and are likely to continue this benefit for longer periods of time without relapse.

Another example of VR treatment is the treatment of post-traumatic stress disorder. PTSD is a mental disorder that happens after some traumatic experiences, such as warfare or the feeling of death [51]. Patients generate some unpleasant thoughts, feelings, nightmares or some overreaction in unusual circumstances. Based on the data, about 77 percents of U.S. soldiers suffer some degree of PTSD problem [52]. Thus, there is no wonder why the military pursues VR treatment, not only for virtual training mentioned in section 2.1.2 but also to treat this PTSD issue. A famous case study called Virtual Iraq proved that the virtual reality exposure therapy decreased the symptom of PTSD distinctly [53]. Many publications and reports also reach the same conclusion that VR therapy is beneficial for the treatment of PTSD [54] [55] [56]. In general, the treatment effect will be better if the simulated environment of VR is more real. Existing VR products can provide this excellent solution.

In general, virtual reality therapy has several advantages over the traditional approach. In the traditional treatment, psychologists need to talk face-to-face with patients, guide them with their thinking, bring their old memory back, and give the appropriate treatment, which can be a bit difficult. However, considering that images are the perfect tool to show real things and bring memories more effectively, this is virtual reality capable of. VR can also build a completely secure environment for the treatment. Another benefit of VR therapy is that this new treatment can be done remotely, it can be done anytime, anywhere. Concerns about VR therapy also exist. The first concern is the network disease, and the other one is how to use this VR therapy properly. If the treatment can be done remotely, does this mean that patients can do it themselves without the help of a professional? Last but not least, VR therapy itself is still developing. In the medical field, a new treatment, technology

and medicine will take a long time to prove its safety and availability. The relevant institutions such as the Food and Drug Administration (FDA) in the U.S. has strict rules before one medicine or treatment can be used to the public.

Another application of virtual reality is the pain management and related fields. People who suffer injuries can feel pain, such as burns and chronic pain. When treating wounds, uncomfortable feelings of the patient are strong, as well as distress and anxiety. A report published in 2000 showed that the use of virtual reality technology could reduce those uncomfortable feelings [57]. A control experiment with two young patients with pain received wound care. One of them wore a VR head-mounted display and the patient could play video games in an immersive environment. The result shows that all monitoring indicators on the patient who wear the VR HMD, including most severe pain, average pain, unpleasantness, worry, anxiety and time to think the pain are significantly reduced than the one without VR HMD. Since then, all other studies and literature show the same result [58] [59] [60], demonstrating that virtual reality helps relieve pain and anxiety by distracting patients' attention into an immersive virtual environment.

The next application involves surgery. According to one report in 2013, about 440,000 patients died in the hospital care in the United States [61]. Within those figures, some patients died from the medical mistake, such as surgery mistake. Even a skilled surgeon cannot guarantee 100 percent perfect surgery without error, especially under some complicated situations. Medical mistakes cannot be avoided entirely. However, with the help of VR technology, the error rate can be reduced as much as possible.

Some studies and publications have conducted comparative experiments showed that VR trainees made fewer mistakes in surgery practice than others [62] [63]. Even for beginners, after practice, they could improve accuracy during the simulation [64]. Simulating a virtual surgery with only the HMD is not enough. A precise tactile force feedback system is also needed, combining the functionality of a specially designed controller like a scalpel and other tools used in surgery. Surgeons can genuinely simulate the real surgery environment, resulting in the perfect surgical practice. In the future, the use case might work like this. A patient is seriously injured and needs surgery. After scanning the body of the patient, a three-dimensional model is created. Surgeons and other specialists discuss the surgical plan. There may be different plans, but surgeons can use virtual reality to simulate surgery. On the one hand, it can help decide which surgical plan is better. On the other hand, it helps the surgeon to avoid some potential mistakes and risks. So in real surgery, the patient is likely to get an excellent treatment. From this perspective, virtual reality technology can play a crucial role in this high-risk area.

Next application is to use VR to train medical students. Medical students can receive an immersive environment to learn the human body. By visualizing all the human body part via detailed 3D map, medical students can see through the skin, observe every organ, bone, and cell. This new way of education is much more efficient

compared to only read the content of the traditional images in the book. Medical students also need to do the autopsy practice, even with some fresh human body, which might be difficult to accept at first for those students. Virtual reality can solve this problem by starting to dissect the virtual body, then to the real one. Some studies also proved that virtual reality could improve the medical education [65]. On the market, one VR company called Next Galaxy has cooperated with Miami Children's Hospital to develop a software aims to medical guidance [66]. This software helps medical workers better handle some emergency treatments like cardiopulmonary resuscitation (CPR). After one year, the Chief Executive Officer (CEO) from the hospital claimed that those doctors and nurses went through the VR training still remembered 80 percents of the content while the traditional training group forgot those treatments quite fast.

The last main application is to broadcast a surgery via VR technology. In 2016, with the permission of the patient, doctor Shafi Ahmed completed the world's first surgical broadcast using virtual reality technology in London [67]. Viewers can watch this operation on a smartphone or any other VR HMD. This on-site broadcast surgery may be a revolution in the medical field. This broadcast surgery can show three major advantages of VR technology. First of all, this technology can help narrow the gap between surgical techniques in different regions, and allow other surgeons to learn skills without distance limitation. Second, it is hard for medical interns to watch an operation in the operating room because the space is limited. Through the use of VR broadcast, medical interns can observe the entire surgical procedure. Third, some patients' families have no trust on the skill of surgeons, and some do not understand the difficulties of doctors. If these people also look at the operation, they might establish an invisible trust to doctors.

In some aspects, the use of VR in medical applications can avoid some of the deficiencies in VR technology. In the gaming industry, latency and freedom are two important indicators. When a player moves head quickly, the computer cannot fully render the desired image immediately, which would cause a bad user experience. The console VR needs to connect to the computer through a cable, which limits the freedom of the player. However, those flaws can be avoided under the medical use. Whether it is for treatment, surgery or medical training and education, users do not need frequent walking or moving, and thus, side effects are minimized.

In summary, VR technology as a disruptive innovation in the medical field has a wide range of applications, from treatment to pain management, from surgery practice to medical education. Although the number of related studies and articles about the VR application in the medical field is limited than other fields, the current research proves its feasibility and usability. Virtual reality can help treat mental illness more efficiently than traditional treatment, distract the feeling of pain to the patient while medical treatment, reduce risk and error rate, provide better surgical results and bring a more vivid and realistic environment for medical students. The use of VR technology has the potential to change the medical field completely.

2.3 Disruptive innovation

This section will introduce the core theory in this thesis. Disruptive innovation is the basic theory to discuss the application of virtual reality technology in the medical field. Based on the review of the literature, this section will analyze the definition, characteristics, basic patterns and impact of disruptive innovations. Some cases study will be shown to help better understand disruptive innovation.

2.3.1 The definition of disruptive innovation

The terms "disruptive technology" and "disruptive innovation" are well known in the book "The Innovator's Dilemma" published by Clayton Christensen in 1997 [68]. Disruptive innovation refers to the innovation of a product or service through technology and science. Disruptive innovation usually uses a low-price character targets to specific consumers, breaks down value networks of a company or an existing market. Then the product begins to enter the major market, eventually overthrows the existing business. Disruptive innovation is a powerful tool that opens and expands an entirely new market. However, on the other side, this innovation also has the risk of failure, it might break the connection to the existing market. According to the analysis by Christensen [68], this kind of innovation does not necessarily need to use new advanced technologies. Technically, disruptive innovation is concise. This innovation creates a simpler solution than before. It uses existing components in combination with the new product architecture. In the beginning, disruptive innovation targets to marginal consumers rather than the mainstream, so it can contribute to some emerging or non-mainstream markets.

Since then, more and more researchers started writing articles about disruptive innovations, while others defined similar definitions [69] [70] [71] [72]. Although the focus may vary, some common aspects can be concluded. First, disruptive innovation is based on a new value network. This innovation provides different value experiences for new or low-end customers in non-mainstream markets. Second, with the development of innovation, disruptive innovation will move upwards to the mainstream market and gradually erode market share, which may replace the original technology or business model. Third, disruptive innovations change business models and competition rules in existing industry. Due to customer-oriented constraints, the strategy of the incumbent cannot be adjusted in time, which results in a strategic failure. In summary, disruptive innovation is an unsustained technology or business model, it offers a brand-new value experience to the customer and therefore changes the rule in the industry. Disruptive innovation undermines the basis of the current corporate competitive advantages, which leads to the continuous development of the industry.

2.3.2 Characteristics of disruptive innovation

Some notable features of disruptive innovation lead to the conclusion [73]: First, the gross margin of disruptive innovation is low. At first, entrants pursue this benefit

because incumbents overshoot those small margins, leave a chance for entrants to survive. Second, the target market of disruptive innovation is small. Low gross margin means that the target market is also quite small, it is not enough for incumbents to consider high profits. Third, disruptive innovation offers simple products and services at first. As mentioned above, disruptive innovation usually integrates products or services using existing components. There are certain types of customers, who do not have the high demand for products or services, as long as the product meets their basic needs and the price is reasonable, they will buy that product.

Besides the outside characteristics, there exist some implicit characteristics of disruptive innovation. First, disruptive innovation has relativity character. Disruption is relative to the current mainstream technologies, customers, and businesses. Once this disruption has a specific trajectory of improvement, it will develop into sustaining innovation, followed by another new disruptive innovation. Some disruptive innovations aim to disrupt one field but result in a disruption to another field. Second, disruption is a process. The speed of technological improvements always exceeds the speed of customer needs. Therefore, with the continuous improvement of disruptive innovation products, the new properties will meet the needs of mainstream users, attract more customers and cause damage to incumbents. For example, compared to the fixed-line telephone, the mobile phone is a disruptive innovation. Although the first generation mobile phone has drawbacks such as high price and poor signal, the portability of mobile phone is good. So in the beginning, the mobile phone does not shake the mainstream telephone market. However, as the mobile phone technology continues to improve, more and more mainstream market turns to use the mobile phone. It is important to point out that the definition of disruptive innovation does not include the need for one product to replace another. So after so many years, the fixed-line telephone still has its certain demand in the specific market. Third, even in academia, there are misunderstandings between disruptive innovations and radical innovations, so it is better to distinguish disruptive and radical innovations [74]. Disruptive innovation is based on value innovation, emphasizes new value structures and exceeds customer expectations. However, due to market promotion, cost control and other aspects, the increase of this innovation is unnoticeable at the beginning, venture capital should be more patient. On the other hand, radical innovation is based solely on innovation and focuses on overcoming obstacles of the current product. This innovation gains a technological breakthrough that leads to new theory and application, such as the breakthrough of traditional spherical TVs to flat-panel TVs.

2.3.3 The classical model of disruptive innovation

Figure 2 below is the classic model of disruptive innovation theory [75]. First of all, one concept needs to explain, the sustaining innovation. Sustaining innovation is based on existing technologies or products, it does not affect the current market. Sustaining innovation can meet the needs of the most demanding customers. On the other hand, disruptive innovation creates a "new" market. This new possibility could

mean an entirely different regional market or the least demanding customers in the market. Maintaining the track of sustaining innovation is the current development trend of incumbents. As an incumbent, it already has a high-quality product or service, which can satisfy the need for the most demanding customers. Therefore, the profit can reach the highest, yet it might overshoot the least demanding customers and some of the mainstream customers. The overshoot part creates a breach, so entrants with the disruptive innovation can find a small-profit market. Over time, entrants also improve their performance and move upmarket. Finally, entrants can challenge the original incumbents and even overthrow them.

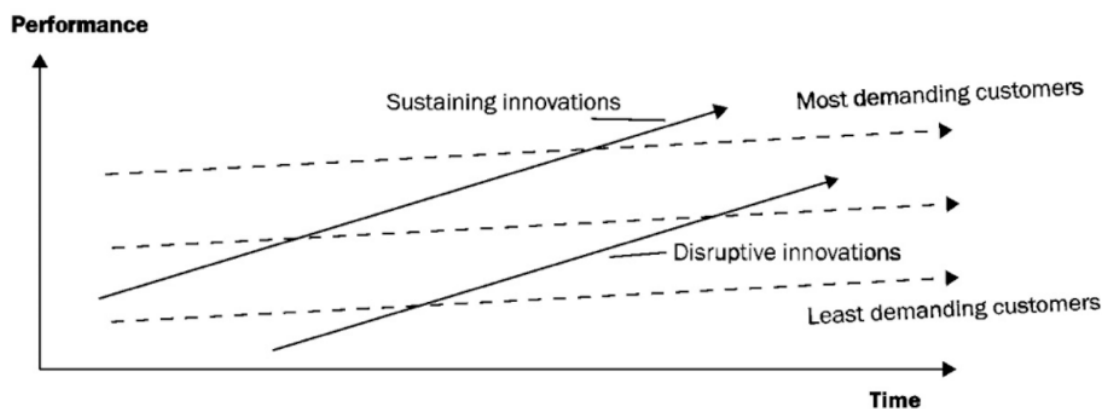


Figure 2: Classical model of the theory of disruptive innovation

2.3.4 Identify the disruptive innovation

Based on the theory of Christensen, there are two rigid indicators to determine whether an innovation is disruptive or not. This innovation can only start from a low-end foothold or a new market foothold. Otherwise, it cannot be called as a classic disruptive innovation [75]. As the above analysis, the low-end foothold is easy to explain. The low-end foothold clients have the lowest requirements, and the margins are relatively low that can be ignored by the incumbent, in which case entrants can offer a relatively good and cheap product to these customers without worrying about the threat from the incumbent. On the other hand, the new market foothold is based on a new business model that shifts non-consumers or potential consumers to consumers and creates an entirely new market.

There are different voices about disruptive innovation. An article even claims that the definition of disruptive innovation only applies to the old linear business [76]. There is an interview with Clayton Christensen about to explain some doubts and help to distinguish what the real disruptive innovation is [77]. In other words, it is important to determine what kind of innovation can be called as disruptive innovation. Christensen first thought in 2003 that three key points must be observed [78]. Such innovations can lead to a simple, convenient but acceptable product, sold for less money. Then the target group of this innovation must be small. Last point is that the business model of disruptive innovation is different from incumbents. Thomond, Herzberg, and Lettice in 2002 shared another thought about disruptive innovation

[79]. First, this disruptive innovation must meet some of the neglected needs of current products. At the very beginning, innovation is not enough to reach the mainstream market and it can only develop in the marginal market. As the marginal market increases, a niche market has taken shape, and the number of customers in this disruptive innovation is constantly expanding. Next, the mainstream market begins to pay attention to this disruptive innovation. Finally, disruptive innovation will replace current products, services, and business models.

To summarize, whether an innovation is a disruption or not can be valued by these four aspects: technique, product, market, and competition. [80]. On the technical aspect, a technological innovation behind disruptive innovation must rely on a new technological trajectory. In order to catch up with sustaining innovation, there must be a rapid performance improvement on disruptive innovation. It is not necessary to provide a perfect technology than existing products or higher prices, but this innovation must provide a new value structure for the corresponding customers. As the performance of disruptive innovation improves, the new value structure will become the new standard in the industry and eventually overturn incumbents. On the product aspect, in the initial stage, the disruption product should have low-end, simple, and customer-oriented features. Those low-end features make the product unnoticeable in the presence of the incumbent, avoids fierce competition in the most demanding markets. Simple means low cost, the price is reasonable for potential customers. Low cost also creates a good market condition, ensures the product can spread to new a market easily.

On the market aspect, disruptive innovation initially targets emerging or non-important marginal markets. Just like the product aspect, the incumbent will not be too concerned because the entire profit is not worth deploying to this marginal market. Although the gross profit margin is relatively low, for companies that start with new technologies or business models, net profit is enough to sustain their existence and development. This profit helps to lay the foundation for future market disruption. Finally, on the competition aspect, disruptive innovation does not compete directly with mainstream competitors. This innovation only attracts some non-consumers and potential consumers in the beginning. The incumbent will easily overlook or tolerate the development of those entrants with disruptive innovation. Once the development of disruptive innovation reaches a certain level, it will attract customers in the mainstream market. Due to the differences in technology, business model, and customer value, the incumbent finds it hard to counterattack. It is too late to adapt to a new market environment by changing the strategy, so the incumbent can only defense passively or even close down.

2.3.5 Why incumbents fail

Although not all disruptive innovations succeed, some disruptive innovations lead to failure and bankruptcy to some incumbents. It is worth mentioning that, why those incumbents have the highest demanding customers, highest profit margin and

market share end up with failure. In the book "The Innovator's Dilemma" [68], it claims two possible explanations: the resource process allocation and organizational resources, processes and values. Reale Dean also summarizes five "C" analyzes [81]. The five "C" includes core revenue streams, comfort and complacency, cost of doing business, controls over operations, and culture and compensation. Assink also listed many obstacles in 2006 to face disruptive innovations [82].

In general, here are few points about why incumbents fail to identify the potentially disruptive innovation threat. Some incumbents recognize that there is a new threat, but still end up failing. First, it is natural for large companies to pursue high-profit margins, they listen to what their customers need most. However, this will make incumbents lose sight of low-margin, low demand or even no demand customers. Second, even if the incumbent recognizes a gap that could potentially create a new market, because of the unpredictability, there is no previous data to analyze the growth of this potential market. It is too risky to put resources on the potential market. Resource allocation is important for large companies. All resources are focused on maintaining the existing market. It is difficult to allocate some resources to this uncertain innovation, which may reduce the growth rate of the original product line. Finally, the rivalry between competitors is the competition of sustaining innovation, which company can update new products faster, which will attract more customers.

To sum up, it is not wrong for incumbents to maintain the status quo, maintain market position, and avoid all possible uncertainties. As a result, it is reasonable for putting most of the resources on sustaining innovation and fighting against competitors. No matter how well the management team can find a new potential market, the priority is still to maintain the highest interests of the company. At least in a company or an organization, it is tough to make some changes on disruptive innovation because the risk is too high.

2.3.6 How to face the disruptive innovation

It is necessary to find a way to face the disruptive innovation because it has such a huge influence on incumbents. There are lots of literature about what a company should do after encountering disruptive innovation. Christensen suggested setting up a small enough independent group to run disruptive innovations [68]. In the meantime, this independent group should try to profit to prove its potential. Another solution is to buy a small company. This small company can get rid of the restrictions of old mainstream customers and focus on the new value network.

Management commentary on disruptive innovation shows that, first and foremost [83], it is worth assessing the value of disruptive innovation, even with a potential innovation. Second, the management team should choose whether or not to enter a new market based on existing capabilities of one company. Third, the incumbent could try to work with potential entrants. Jay Paap and Ralph Katz show some tips in their work [84], which focus on technology drivers, understand innovation and try

to gather information about potential changes. Greg Satell even gives four direct methods [85]. First is the acquisition, incumbents directly purchase potential entrant such as the Facebook bought Oculus Rift. Next is the Co-Option, like Disney and Pixar. Then is the spin-off, just like IBM, which splits some of its business. The last one is the Bayesian strategy. Giving a rough aim at first, with more and more data collected and experiment test, end up with the best solution on disruptive innovation. None of those methods is easy to decide, especially for incumbents. The decision of the incumbent about the disruptive innovation requires a deep understanding of the future market, even if the market does not yet exist.

2.3.7 Case study of disruptive innovation

A case study will help to understand disruptive innovation further. In the book “The Innovator’s Dilemma”, several cases have exhibited [68]. For instance, the disk drive industry, mechanical excavator industry, and minimill steel. Those cases are quite old, so it is best to study a case close to the current market. In here one example in the new century will be presented, which is the success of iPhone. Even Christensen initially misunderstood the success of iPhone. Thus, it is quite interesting to see that under the background of the rapid development of the Internet technology, what will the disruptive innovation be like and perform.

In 2007, Apple announced its first mobile phone, which has been recognized as the start point of the smartphone industry. The reason why Christensen considers iPhone is not a disruptive innovation is that he thinks iPhone does not fit either low-end or new market foothold. The price of iPhone is high, and it is still in the telephone industry. On the telephone market, there are other good options such as Nokia, its product covers from the low-end to the high-end market. However, the goal of iPhone is to integrate all the features of laptops into the phone. Users can do anything on a mobile phone that they used to do it on a laptop. So iPhone is low-end compared to the laptop industry, but a completely new market to the feature phone industry. Using the method on how to identify if one innovation is disruptive innovation or not in the section 2.3.4. On the technical side, although iPhone brings the touchscreen to the smartphone at that time, this technology already exists. All the components on iPhone are not new or high-tech, but most of its features influence all the late generation smartphones.

On the product side, iPhone performs less well than a laptop but is more powerful than a feature phone. Therefore, the laptop industry chooses to ignore this smartphone because it is not a threat. At that time, feature phones use a physical keyboard to type the word, and iPhone switches to a touchscreen. The feature phone industry considers iPhone lacks necessary functions on a mobile phone and also chooses to ignore it.

On the market side, the entire value chain of laptop industry is matured. Mainstream customers have performance requirements on laptops. Those customers need

productivity and use all kinds of software to handle their day-to-day things. It is obvious that small machines such as iPhone cannot meet the needs of mainstream customers. However, some people may not be able to buy a laptop or consider it is too heavy, while the emergence of iPhone can meet the needs of cheap, portable, and acceptable performance. A new market begins to arise. On the other hand, the feature phone industry at the time still focused more on bringing new forms or colors to the mainstream customers, which gave Apple time to improve the performance of its product.

Last one is the competition side. The laptop industry thinks iPhone is a mobile phone instead of a laptop, so there is no threat to the laptop industry. Feature phone industry considers that iPhone lacks the key components, such as the physical keyboard and short battery life, it is also not a threat because the quality of iPhone is worse than other products. However, the market and trend about iPhone shows the different result. The market size of traditional feature phone incumbents like Nokia and RIM has dropped significantly. Although incumbents are trying to fight back by adding a touchscreen feature or developing a new operating system, the change is too late. The laptop industry cannot even fight back because these are two different industries. Since 2007, the smartphone industry has seen phenomenal growth, more and more people spending most of their time on the smartphone instead of PC or laptop. The feature phone market only presents in some poor areas nowadays. So yes, iPhone is a disruptive innovation.

To sum up section 2.3. A comprehensive explanation of disruptive innovation has been introduced. The definition of disruptive innovation is given, characteristics of disruptive innovation are shown, and the classic model of this innovation is explained. This section also introduces how to identify whether an innovation is a disruption or not, why mature incumbents fail to compete against the entrant with disruptive innovation, how to prevent failure and a simple case study to help understand the term disruptive innovation. With the rapid development of Internet technology, disruptive innovation is now more likely to emerge. Some technologies with the convergent technological developments and the Internet properties could combine with a powerful innovation. Christensen stresses in his book that disruptive innovation is not technical. The purpose of disruptive innovation is to use a technology product to create a new value network and a new market. It is the new value network and the business model makes incumbents fail. Therefore, in order to survive, no matter for the incumbent who wants to keep their market position, or for the entrant who is eager to overturn the industry, disruptive innovation is worth for their attention.

3 Methodology

This chapter describes some methods that will be used to analyze research questions. The motivation for this thesis is to use a disruptive innovation framework to analyze the possibility of using virtual reality in the medical field, which leads to two core research questions:

- Can virtual reality create a disruption in the medical field?
- What is the nature of the possible disruption?

The first question should give a detailed historical review of the development of VR technology. The second question is to analyze the core nature of disruptive innovation, so a framework type methodology will analyze every aspect of the VR disruption in the medical field.

The literature research methodology is used for historical review and theoretical explanation in Chapter 2. Figure 1 is a timeline map that shows the overall development of the virtual reality and some relevant technologies. Based on the literature, the advantages and disadvantages of virtual reality, the challenges of it and the application of it have been described in detail. Analysis of VR applications in the medical field is also based on some medical research. Those studies included some rigorous control experiments and concluded that in some applications, the virtual reality technology could help in the corresponding scenarios. The document-based approach explains what disruptive innovation is. The book “The Innovator’s Dilemma” and other research papers influenced by this book provide a comprehensive look at all aspects of disruptive innovation.

Based on the disruptive innovation theory, a paper called "A disruption framework" was done by the supervisor of this thesis [86]. Within the paper, a disruption framework has been created to help understand the disruption into different layers. Authors of this paper believed that this framework could not only be used to analyze the changes made in the past, but also for the analysis of the technology or innovation being developed. Virtual reality technology should be a typical case, so this framework will help analyze the use of VR technology in a medical field. Figure 3 [86] shows the framework structure, which will be explained in detail later.

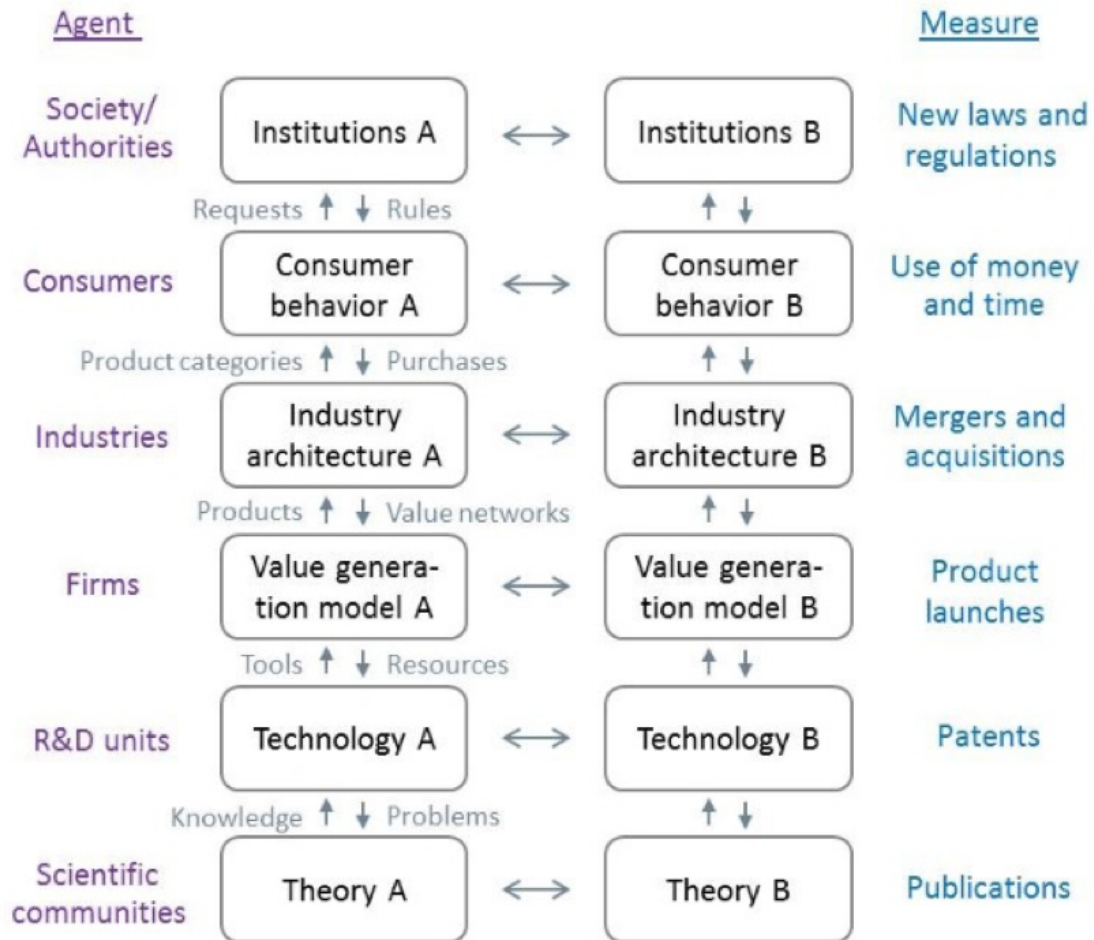


Figure 3: Disruption framework [86]

Another method is to collect relevant publications by years, and the data from it can form trend charts. Here are few reasons to do this. First, the classic disruptive innovation model is a trajectory trend chart, which is a useful tool to view breaking trends and even make reliable predictions. Second, why need to collect publications by years? Although virtual reality technology has a quite long history compare to some other technologies, the second wave of hype just arrived in less than five years. The virtual reality-related market is new. Thus, it is hard to use data like revenue and product sales to make a proper assumption of this technology. For this new market, it is more convincing to use those publications to look at the theoretical or research-level trends. The large digital libraries used in this thesis including the Institute of Electrical and Electronics Engineers (IEEE) Xplore Digital Library, which provides high quality literature on engineering and technology in the world. Another source is the United States patent database, which is where inventors must register if they want to commercialize their patents around the world. The third source is PubMed, which is a search engine contains databases with references and abstracts for medical-related work. Since this paper aims to analyze the use of VR in medical

applications, it is reasonable to examine the PubMed source.

Based on the analysis of the literature review, a great deal of research has been conducted on disruptive innovation. There are quite a lot research about how to identify the disruptive innovation; if this terminology is still useful under nowadays environment; how to help predict disruptive innovation and how to use this disruption to change the industry. However, there lacks a comprehensive and straightforward methodological framework to analyze disruptive innovation, from the birth of theory to the impact on society. There are only few framework-based studies, such as Keller and his co-worker gives a framework to analyze the disruptive potential [87]. Dowling with his coworkers also analyzes the potential of disruptive innovation [88]. Klenner with his coworkers is about to analysis when is the right time to use the disruptive innovation [89]. Based on this situation, the supervisor of this thesis participates in one research to offer this disruption framework. The result shows in Figure 3. Although it is a new framework, it can successfully analyze some case studies such as photographic digitization and 3D printing. Because this is a new study, it is necessary to explain this framework before using it to analyze the core research questions in this thesis.

This framework is divided into six layers. From the ground to the top, it includes theory, technology, value generation model, industry architecture, consumer behavior and institutions. Those layers are corresponding with six different agents: scientific communities, research and development (R&D) units, firms, industries, consumers and society/authorities. The measurement standards are publications, patents, product distribution, mergers and acquisitions, capital and time use, and finally new laws and regulations.

On the layer of scientific communities, it is easy to understand. All things run behind a solid scientific support, all things build based on scientific theory. Scientific communities offer knowledge either for scientific use or commercialized use.

For a disruptive innovation, it gives a revolutionary knowledge to the upper layer, which is the second layer, R&D units. Mid-level managers in a company play an important role at this layer, they need to decide which knowledge is worth developing or which knowledge is able to transform to innovation. If there are some problems during the R&D phase, they can be traced back to scientific communities to find solutions. In the research and development phase, any progress can be patented, which is a powerful weapon to protect and enhance the competitiveness of one enterprise. At this stage, mid-level managers in a company should first identify the possible knowledge and then try their best to obtain resources for further development. As a potential disruptor, it is difficult for managers to persuade their superiors to start building a product. However, once it succeeds, the innovation can become part of an existing product or a new product line.

The innovator's dilemma starts to happen between the R&D units layer and firms

layer. The strength of R&D in one company is quite strong, it has the resource to develop many inventions, yet mid-level managers and senior management tend to choose the innovation that closes to their current product line. The goal is to sustain continuous innovation, so some daring and future inventions may fall into a downturn at this stage. One of the reasons Nokia failed can go back to this layer. New technologies like the touchscreen have already achieved in R&D phase within the company. However, as customers seemed to need the physical keyboard at that time, the touchscreen technology was not the priority for its sustaining innovation. On the other hand, new entrants are not likely to try out different inventions or resources similar to existing ones, so they can easily choose one disruptive innovation and make it into a new product category.

Next layer is the layer of firms. The CEO of a company and top management should decide whether to pursue this potentially disruptive innovation. Because disruptive innovation needs to subvert the existing system, it requires substantial capital and resources to reform the company. Most importantly, disruptive innovation creates a new value generation model, it may coexist with the current value model, but most of the time it completely changes the old one. There is no doubt that the new value model will create a new commercial market. Enterprises use the new technology from the R&D layer as a tool to build value generation model, and it also works as resources to the value network model. As the measured outcome, new product launches to the market, which will bring the new value model to affect the industry layer.

A mature industry always has a sophisticated industry structure. The relationship within an industry structure is quite solid, it is hard to break, even with a new product that has the disruption property. In the short term, the industrial structure at the industrial level is stable. Therefore, this new product with disruption property may temporarily cross the industry layer, directly cause a huge impact on the consumer layer. This huge market need will then pull back for those firms change their original industry architecture. After the launch of a new product with the new value generation model that contains disruption property, for an industry, in order to survive, it should transform into a new industrial structure to adjust the new market. This change also brings new value network for the value generation mode of the enterprise. In order to cope with such disruptive changes within or across industries, companies may undergo mergers and acquisitions. Incumbents may fail, only maintain small market share or even bankruptcy.

Then is the consumer layer. The new industry structure reinforces disruptive innovation and brings new product categories to the mainstream market. This disruptive product can either be a tangible or intangible product or service. More and more consumers will purchase this new product with the prove of using more money and time on it.

Last one is the society/authorities layer. Not all disruptive innovations are perfect,

they all have flaws, which might influence people's quality of life. For example, Airbnb hospitality service has completely changed the hotel market, but it exists side effects to the society. First of all, it may cause troubles for the neighbors. Strangers come and go cause an unsafely feeling to the neighbors. Second, renting personal apartment may violate some laws and affect the local rental market. Some apartments can be rented for a long-term, but locals may find it difficult to rent one due to the popularity of the short-term renting. All those lead to a protest that consumers require authorities to take action on those inappropriate behavior. As a result, Airbnb is positively cooperating with authorities to improve this situation. In general, disruptive innovation not only changes the value network or industry structure of an enterprise, but also causes a huge impact on society. Old orders, rules, and balance may break down. In extreme cases, the social order in a country may also be disrupted. Therefore, government regulation is necessary, it not only protects consumers but also coordinates stakeholders, maintains fair market competition and safeguards social peace.

The above is an overview of the disruptive framework, which covers from the creation of disruptive innovation to its impact on the society. This framework creates a clear mind map that helps understand the relationship between disruptive innovations at different layers. This framework is very useful for analyzing disruptive innovation. The scientific community and the R&D unit are the foundations of disruptive innovation. They provide the basic theories and resources for the development of disruptive innovation. Businesses and industries are where real disruptions occur, and value networks are the most important role of these two layers. Consumers and society/authority are more likely to be the result and boundary of disruptive innovation.

4 Results

As mentioned in the literature review section, virtual reality has few main applications in medical fields. In order to conclude a more precise result, it is best to choose one specific application for further analysis. This thesis selects virtual reality therapy. The data collected and the results shown are based on the application of VR in the medical therapy area.

There are quite a lot patents by only searching the keyword "virtual reality", but no result by searching both the keywords "virtual reality" and "medical therapy" at the same time. The reason for this outcome might mean that the use of VR in medical therapy is focused more on research. Another possible reason is that some patents in VR can directly apply to the medical therapy, so there is no need for further patents. Thus, in the result section, no data collection from the U.S. patent database.

Due to the reason that IEEE focuses more on fields like computer science and electrical engineering, there are 574 results in total by searching keywords “virtual reality” and “therapy” at the same time. The earliest conference publication IEEE recorded about VR was in 1992. The trend chart shows in Figure 4. Although the trend looks unstable, it does get the similar trend in the historical review in Figure 1 about the virtual reality.

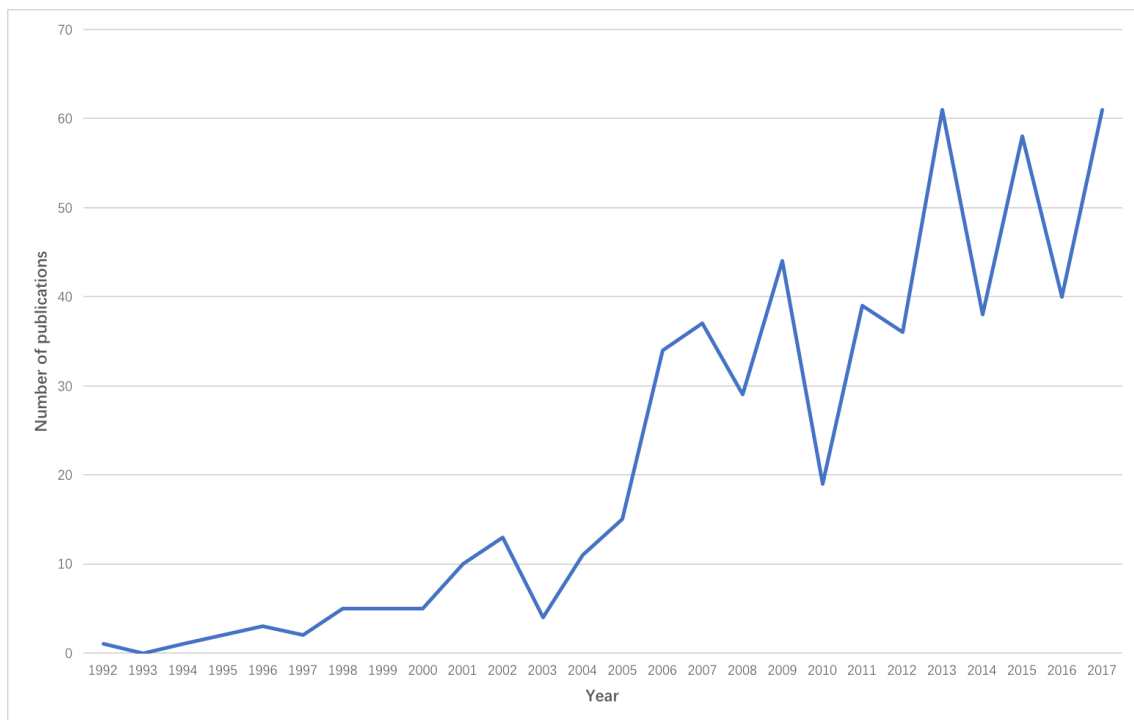


Figure 4: IEEE search result about the number of publications related to VR and therapy.

Another free search engine PubMed is much more suitable for the relevant data

collection. The core theme fields of PubMed engine includes life sciences and biomedical topics, as well as other medical areas. There are nearly 3000 articles in total that discuss virtual reality in therapy use. Figure 5 is the only therapy related articles trend chart, and Figure 6 is the research combined with virtual reality.

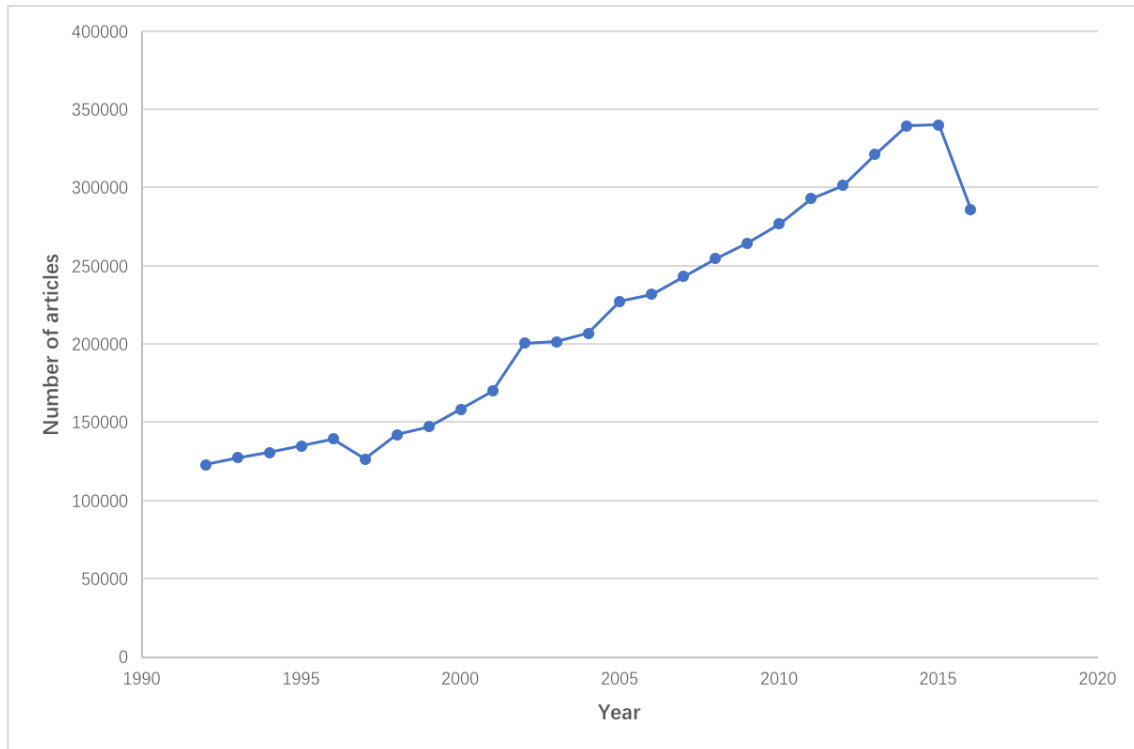


Figure 5: PubMed result about the number of articles related to therapy.

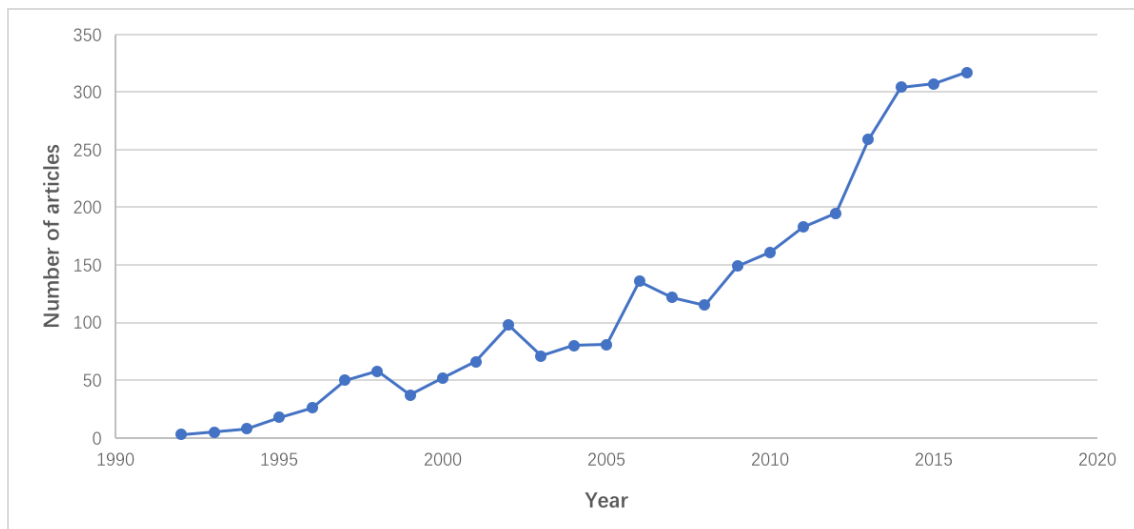


Figure 6: PubMed result about the number of articles related to VR and therapy.

It is meaningless to compare only the number of research articles between the traditional therapy and VR related therapy. The former one is still taking most of

the position no matter from the actual treatment or the research, and the latter one just becomes a hot topic again after the fast development of the consuming VR device. The trend of VR therapy in PubMed database is worth looking at, especially after 2010. The slope of the trend for VR therapy is higher than the traditional one. The growth rate shows in Figure 7 and Figure 8. Figure 7 is the number of articles related to medical therapy from 2008 to 2010. There are 425 articles involves the research with VR technology from 2008 to 2010, the share is approximately 1:2000 compared to the general medical therapy. While from 2014 to 2016, as shown in Figure 8, the number of VR therapy articles is 928, the share is about 1:1000. VR therapy is still a small share compared to the traditional therapy, but it grows quite rapidly.

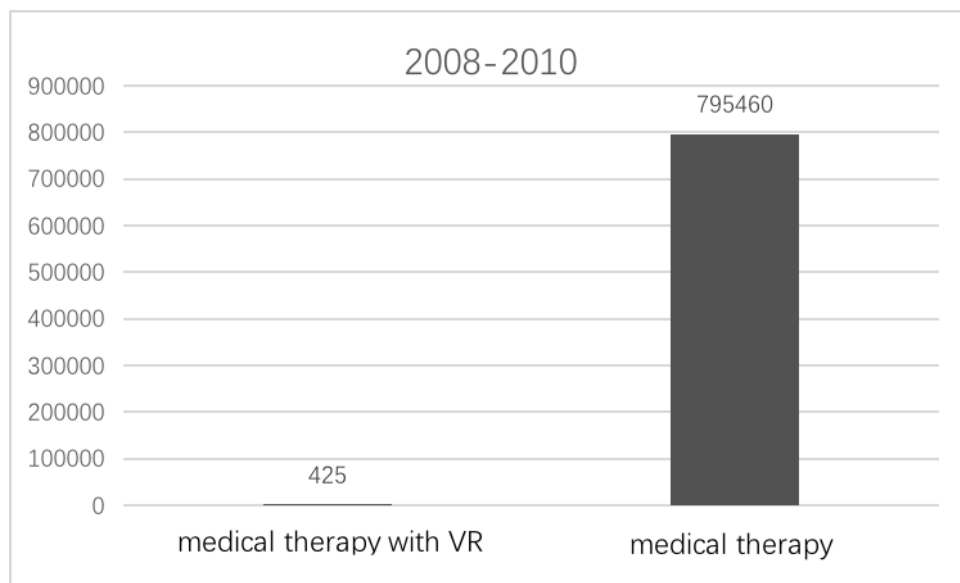


Figure 7: Share of articles with VR among all therapy papers from 2008 to 2010.

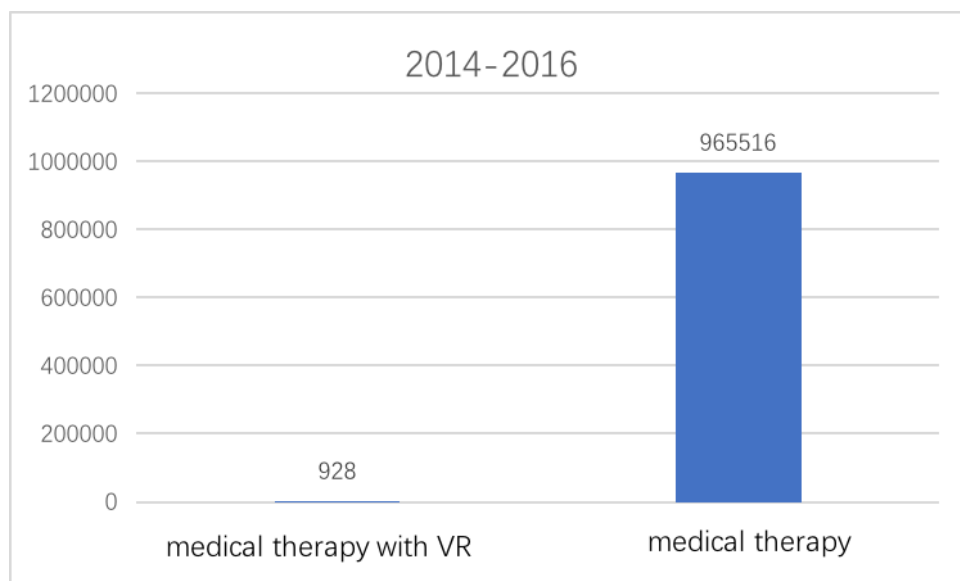


Figure 8: Share of articles with VR among all therapy papers from 2014 to 2016.

There are some keywords about the VR application in medical therapy: change the rules, mature period and cross-field disruption. One patient feels mental illness, he asks a therapist for help and receives treatment. That is the current process for a sick people asks for medical help, Figure 9 reveals some problems and concerns by the patient, so the user experience needs to improve.

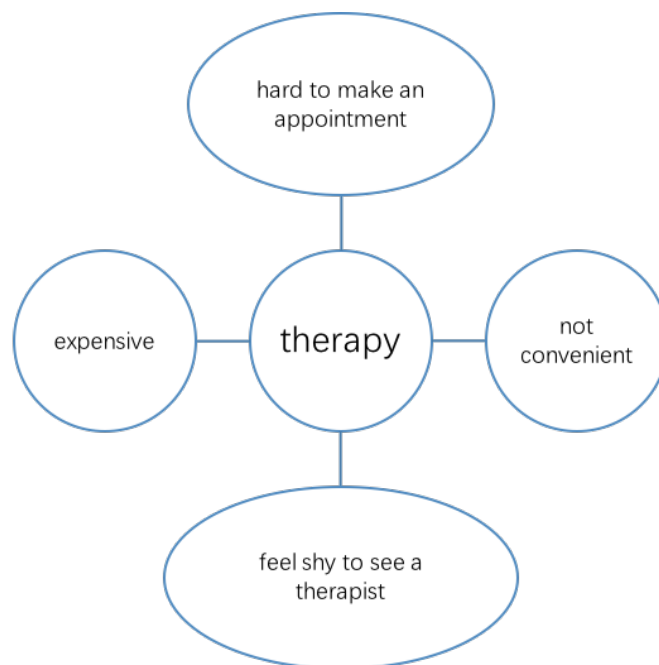


Figure 9: Problems to see a therapist.

There are four major issues about the current medical therapy. First, the number of therapists are limited compared to the number of potential patients. It is difficult for patients to make an appointment with an ideal therapist in a short period of time. Second, the charge of a therapy per hour is expensive. In some major cities in the United States, such as New York City, the average cost can reach 250 U.S. dollars per hour [90]. Many health insurances do not cover the therapy fee, therefore, the patient has to pay the full amount of money, which is not affordable for lots of people. Third, there is a group of people with mental issues, but they are afraid to tell others or fear being known by others. They would rather suffer the mental issue by themselves than ask for professional help. Such behavior could cause serious problems if those patients delay the treatment for a long time. Last but not the least, it might be quite far and difficult to go to see a therapist due to some personal reasons or long distance to the therapists' place, which causes inconvenient to some patients.

Those four factors are actual problems in the current medical therapy treatment. What patients need is to eliminate those problems. Virtual reality applications can solve some types of psychological problems, such as PTSD, fear of height. By visiting the therapist for the first time, a further treatment plan can be determined. Patients

can rent or purchase a VR device for the treatment. With the help of the specially designed software, a patient can do the therapy remotely with therapists. This kind of application has shown to the audience in the TV series “House of Cards” [91]. The character in it uses a VR equipment to treat PTSD, which indicates the trend in the near future.

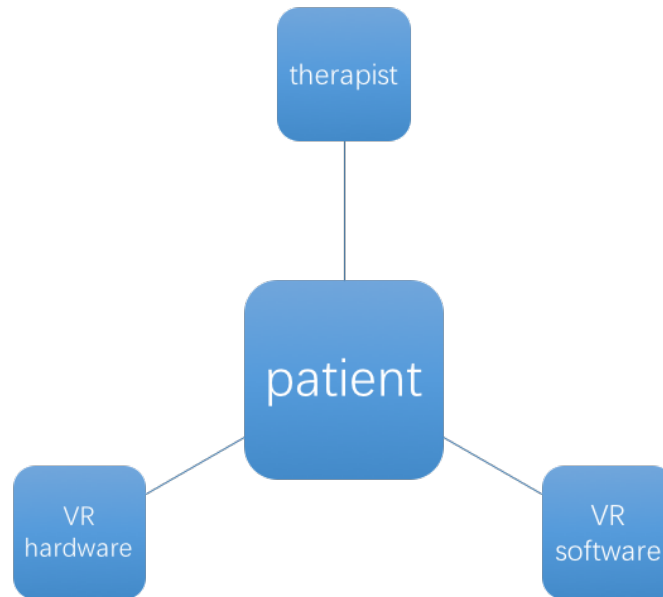


Figure 10: Virtual reality as disruptive technology in therapy.

As shown in Figure 10, the new model is not therapist based. It is a patient-centered design, the core of this disruption is to put patient’s experience first. In the current society, especially the Internet industry, the user experience is the core to develop products or services based on the needs of users. So under the case of VR medical treatment, the therapist will guide the patient with the remote treatment. The VR hardware may be purchased or leased by the patient to serve the medical therapy. Medical facilities can work with the VR software provider to design the appropriate software to treat the patient. As a result, the cost of patients will be reduced significantly if the fee for VR hardware and software is reasonable. The interests of therapists may be affected, but this new model brings in two new beneficiaries, VR hardware and software suppliers. All those might form a new value network in the medical therapy field.

5 Discussion and conclusion

This study strongly indicates that virtual reality can create a disruption in the medical therapy field. By comparing Figures 1, 4 and 6, although they come from different sources, such as historical review, IEEE publications and PubMed articles, they all have the same trend. By comparing Figures 7 and 8, there is a significant increase of VR study in the past few years. This trend means more and more medical institutions start to conduct some research on the use of virtual reality technology in the medical field.

The nature of a possible disruption is to use innovation to open a new market and based on that, overturn the existing incumbent. The core nature of disruption is to observe and find what people really need. The innovation tries to create a product or a new business model to satisfy the needs, in the meantime, lower the cost of the product and improve quality of experience of customers. On the industry side, the nature of the disruption might be the introduction of a new type of business model or a new value network. The new model can make a company more efficient and adapt the new environment to replace the old one. As for normal individuals, a disruption will bring an easy, convenient, cheap but high-quality way to satisfy their needs.

Hence, the use of VR in medical therapy not only changes the old rule, from therapist-centered to patient-centered, it also brings a new business model to challenge the old mature industry. This change also indicates that virtual reality can create a disruption in the medical field. There is no doubt that with the help of the Internet technology and the rapid development of the internet industry, virtual reality technology has the feasibility to become a disruption in medical fields. Using VR in the medical therapy field, it replaces the traditional face-to-face talk type therapy. For some types of therapy like PTSD, fear of height, it will be sufficient to use VR to treat those mental diseases. Second, if buying or renting VR hardware and software is much cheaper than paying few hundred dollars per hour to the therapist, VR therapy would significantly ease the burden on patients and quickly win the market. Third, third-party VR hardware and software manufacturers generate a new business model into the medical field. VR industry has a chance to enter the second largest VR application market [7].

There are similar studies also discuss the application of virtual reality in the medical field [50] [53] [56] [57]. Some of them make control experiments to prove that under some circumstance, VR technology can help achieve a highly effective treatment, low-risk surgery, and reduce the pain after an injury. However, few studies discuss the disruption property of virtual reality in the medical field. On a large scale, virtual reality not only improves the medical treatment but also brings a new business model and value network to the medical field.

This study also has limitations. This study only provides some insights into the impact of the medical therapy field. Thus, other areas of the medical field deserve

further research to see if VR can also cause a disruption. Moreover, due to the limited resource, this study lacks inside interview with the medical professionals. Those professionals could offer a more convincing opinion on the application of this VR technology, which may affect the stringency of this study. Moreover, considering that virtual reality is still a developing innovation, relevant articles and research and actual applications for VR in the medical field are still limited. Most of the articles remain in the experiment or test level, which makes the study harder to discover and gather more useful information about the impact of VR on the medical industry.

In conclusion, this thesis introduces the development of virtual reality and its application in the medical field. This thesis also presents the theory of disruptive innovation and why this innovation is a critical theory nowadays. Using the disruption framework based on disruptive innovation, it proves that virtual reality technology can create a disruption in the medical area, especially in the medical therapy field. This study not only brings the fact that virtual reality will have a potential massive use in the medical field, but it might also shake the whole medical field that a new value network will make an impact on the current medical value chain. The study in this thesis is not perfect, further research on the detailed business model and value network is needed.

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