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ANALYSIS OF VIRTUAL REALITY TECHNOLOGY AND MARKET STRATEGY USING PATENT INFORMATION

Chieh-Han Chang[1] , Chieh-Min Chou[2]

Abstract- **For tremendous advances in technologies development and market attractiveness, many companies have been beginning to develop virtual reality (VR) products and seek to establish their patent portfolio for freedom to operate (FTO) and hamper competitors. Although VR market, especially in game sector, is continuously growing fast, there are few studies analyze firm's technology and market strategy in patent analysis approach. By investigating major companies' patents in VR industry, this study addresses the latest technology trend and market strategy adopted by major firms. With comparison of the Technology and Function Matrix, this study explores the technological development trend and patent strategy of the companies and explain the relationship between the technology patent strategy and business market competition. This study proposes a reference framework to articulate the strategic direction of market and technology development chosen by VR companies in terms of business and technology endowment.**

Keywords – Patent Analysis, Virtual Reality, Technology Strategy, Reference Framework

I. INTRODUCTION

Virtual Reality (VR) refers to a man-made, three-dimensional world which constructed by computers and equipped with elements such as audio sources and somatosensory manipulations to immerse users in a fictional digital world [1]. To achieve immersive experience, a user usually must wear a Head-Mounted Display (HMD), and operates with other devices such as: hand joystick, odor diffuser, etc. which can make the user get more realistic experience [10]. Previously, virtual reality devices were limited in many technical, environmental and cost constraints hence were not commonly available in the market. Nowadays, technologies such as processors, sensors, display panels and network performance and quality have been massively improved and costs have also dramatically reduced so that many industrial companies are interested in possible new applications and markets. Various key developers such as Oculus (acquired by Facebook), Facebook, HTC and Sony have been paying serious attention to the possibility of VR technologies commercialization and started developing related products [14].

The prospects for virtual reality commercialization are quite promising. According to the report by Grand View Research, The global virtual reality market size was valued at USD 10.32 billion in 2019 and is expected to grow at a compound annual growth rate of 21.6% from 2020 to 2027 [8]. Patent analysis is an appropriate technique to investigate the development and change of specific technologies and applications [13]. Based on the patent data, firms can obtain advantages from technological revolution through competitive analysis and deliberate strategic planning [24]. In high-tech industry, a firm's technological capability significantly influences its selection freedom of product strategy and business model which therefore impact firm performance [25]. Considering the VR technologies are already implemented in lots of computer game products and become an obvious differentiator for firms to gain

[1]*Graduate Institute of Management of Technology, Feng Chia University, Taichung, Taiwan, ROC*
[2]*Department of Business Administration, Feng Chia University, Taichung, Taiwan, ROC*

competitive advantages, this research adopts patent analysis to four well-known VR product companies HTC, SONY, Oculus and Facebook, which successfully develop virtual reality applications and products and position in quite different market segments. Due to Oculus has been acquired by Facebook in 2014 and still operating independently, this study analyzed the patent information of the two companies respectively with consideration of the integrative corporate view.

In the rest of this article, relevant literature is going to be reviewed in next section. Following an analytical framework and associated analysis are presented in section 3 and 4. We conclude different technology and patent portfolio strategies from the four firms' VR patents and infer that their possible market and product strategy to integrate their business advantages and find the roadmap. In the last section, we will discuss the implications and possible opportunities for further research.

II. LITERATURE REVIEW AND BACKGROUND

Bolter et al. point out that virtual reality integrates video, audio, and text through computer technology to create visual, audio, and other integrated virtual environments [2]. Participants can use the related equipment to interact with virtual objects and the virtual world may be composed of the image or illusion of the imagination. Burdea and Coiffet claimed some experience characteristics that virtual reality should introduce hence proposed I3 framework in 1994 [3], which means that the user's interaction with VR devices and environment can make the user obtain the characteristics of Interaction, Immersion and Imagination. The definitions provided by those authors are:

Interaction: refers to a variety of objects can be generated by the user input response, but also can affect the user's initiative to accept the user's response.

Immersion: the most important feature of VR which refers to that the users can get the general visual, auditory, touch and other sensory experience as in the real environment so that the users are unable to tell the virtual world from the real world.

Imagination: refers to the user receiving the computer's video output and other information, through linking to the user's past experience and memories to enhance the current experience.

Well-known VR companies such as HTC, Sony, Oculus (is merged by Facebook) and others have successfully developed their own consumer virtual reality products. Users can use those devices to acquire a certain extent of virtual interaction effects [2-4,12]. This study designed a patent data analytical framework, which focused on revealing the critical architectures and technologies adopted by current consumer virtual reality products, to match the individual firm's product and market strategy with the patent information collected from the United States Patent and Trademark Office (USPTO) database. With the analysis of the "Technology and Function Matrix" of each company's patent portfolio, this study can compare the firm's advantage/disadvantage respectively in terms of the fit of technology and product strategy.

A patent can be described as a technical document which includes detailed description of technology specifications, functions and classification and other information. Patent analysis can be used to discover industry technology trends and inner linkage among critical technical contents since firms always use patent, an important form of intellectual property, to protect their valuable technology assets and most competitive products [19]. By carefully analyzing the public patent information with sophisticated methodology, enterprises are able to understand the status quo of the technological development of competitors and the whole industry, and then can take it as the basis for their own research and development planning and generating patent portfolio for capturing innovation values [9,20-21]. Governments and industrial organizations can also use patent analysis to support the formulation of national or industrial level technology strategies for enhancing the overall competitiveness of countries and industries [6].

The value of a patent analysis lies in its ability to analyze the state of development of a technology and to predict future technological trends. At the firm level, intelligence drawn from patent analysis can not only help examine the strength of R&D capability and technology superiority, but also can help measure competitor's R&D directions and extent of innovativeness. Based on the information, firms can reach a higher quality of decision making on product development, technology roadmap, patent portfolio, and competitive strategy [23]. In addition, combining product and technology strategy can help firm draw out a clear roadmap for competition to strengthen advantage and result in better performance [26].

Patent analysis refers to the statistical analysis of patent data which is translated into a variety of analytical and interpretable chart and numerical information [5,18], and then uses the aggregated information to obtain business intelligence on the competition in various categories [11,17]. The results of patent analysis are usually presented as a combination of statistical charts and tables which usually are called Patent Map. A typical patent map consists of the time series patent trend analysis, assignee/company analysis, R&D intensity analysis, patent citation analysis, technology life cycle analysis, technology-and-function-matrix analysis, and so on.

The concept of technology life cycle, proposed by Foster [7], is basically divided into three stages in the relationship between technology and market. Stage 1: applying technologies to product development and design process. Stage 2: introducing the new product into the market. Stage 3: the product phases out and exits the market. This three-stage model is also known as S-curve life cycle model. Subsequently, Ernst applied the technology life cycle to the patent management practice to determine the development cycle of the technology based on the dynamics of the related patent statistics [6,16]. The analytics is to list the patent number as the vertical axis and the assignee number as the horizontal axis, and then observe changes in the decline of the patent in the specific technology field to estimate the technology development status in the market life cycle is at which stage. According to Ernst's research, the technology life cycle can generally be classified as five stages: Emerging, Growth, Maturity, Saturation, and Recovery.

Technology-and-function-matrix analysis is usually used by R&D department to find the appropriate direction for investing technical and financial resources on target technology fields. The analytics structure is composed of the technology classification and function classification for a particular technical theme thereby making a cross reference to figure out the patent distribution pattern. The practice is to retrieve all the related patent information and classify the patent into technology-function groups respectively. With the statistics of patent number of individual technology-function group, we can find out which technical and function categories are currently under development and important because most of patents are located in patent-intensive areas. Companies also can consider developing technologies and applying for new patents for those areas are not occupied by existing patent but having potential value if a company were able to fulfill the technology-function gap [15]. By using the technology-and-function-matrix, business and technology insights can be drawn from the analysis hence provides firms with valuable intelligence for conducting innovative new product development plan and competitive strategic planning. This study aims to explore important VR technology trend and individual company's product strategy through in-depth patent analysis to provide VR game developers relevant information and possible R&D directions.

III. Materials and Methods

The first step of patent analysis is to collect patent data from public patent database. Since the United States patent database includes the most advanced and latest technical information in VR field, we chose the United States Patent and Trademark Office (USPTO) database as research data source. The search target is the VR related patents of the four virtual reality developers. This study used partitioned combination of the individual technical component terms for our keyword search strategy because the virtual reality application is commonly regarded as a system-level product concept. According to the four companies' mainstream product designs, the virtual reality related patent search theme is divided into three main sub-themes: "head mounted device", "positioning device" and "controller". We conducted a search of companies' patents by arranging a combination of related keywords on three themes and "Virtual reality" keywords. After excluding the duplicate patents, the search results show 145 patents belong to HTC, SONY has 689 patents, Oculus has 266 patents, and Facebook obtains 851 patents. This study used PatSnap Analytics (https:// https://analytics.patsnap.com/) as patent search tool and the analysis unit is set to the number of patent family for avoiding redundant counts for the same patent applied for different countries.

In addition, the virtual reality application is a complex system which consists of various sub-systems, devices, components, software and technologies; hence the collection and classification of patents must be converged to more accurate level for analyzing. We merge the four companies' patent and then extracting the top 5 categories of patents by International Patent Classification (IPC) code. After doing that, this study further eliminate the inappropriate patents by manually screening patent contents and finally get 264 patents as the core dataset to analyze. The top 5 IPC ranking of our research patents show that the related patents are mostly classified into G06F 3/00 (electronic data processing, data transfer to interface device), A63F 13/00 (video game), G02B 27/00 (optical system, instrument), G06T 19/00 (3D models or images that manipulate areas of computer graphics), G09G 5/00 (visual indication control or circuit common to cathode ray indicators or other visual indicators). Table 1 shows the search syntax and the outcomes in terms of the number of patent family.

Table -1 Patent search syntax and results

Search Syntax	Patent Search Result			
	HTC	SONY	Oculus	Facebook
TACD:("virtual reality")AND AN:(Firm Name)	145	689	266	851
((TAC:(head mount*) OR TAC:(headset) OR TAC:(HMD)) AND TACD:("virtual reality")) AND AN:(Firm Name)	61	212	172	237
((TAC:(joystick) OR TAC:(controller) OR TAC:(glove) OR TAC:(move))AND TACD:("virtual reality")) AND AN:(Firm Name)	37	183	121	231
((TAC:(station) OR TAC:(sensor) OR TAC:(track*) OR TAC:(trace) OR TAC:(position))AND TACD:("virtual reality")) AND AN:(Firm Name)	100	395	159	328

IV. Analysis and Methods

Most of the recent VR-related technology patents are applied from 2013 and hit the peak from in 2017. SONY Corporation is the active first mover and mainly emphasizes its patent portfolio on head-mounted device's structure. Sony's VR-related patents include the operating modes of the left and right eye displays, the method of arranging the components in the head mounted device, the method of providing the device audio system, etc. According to the patent specification, the technology called "virtual reality" does not yet have too much free space for the user to operate. The virtual image presented by the display also has narrow space constraints. From 2014, the number of patents showed a clear trend of increase and the patent applications of key manufacturers such as HTC, Oculus and Facebook began to emerge. The patented contents in this period began to appear in different device-linked methods. In addition, the operation of individual devices such as joystick controllers, positioning devices, component configurations also occur during this period. By 2017, the number of patent applications reached its peak for all the key company in industry. The number of virtual reality developers and the investment in research and development has been on an unprecedented scale in 2017. It shows slightly decrease in number of patent in 2018 but still remain the position on the high level. Figure 1 shows the trend of the patent filing in VR-related field.

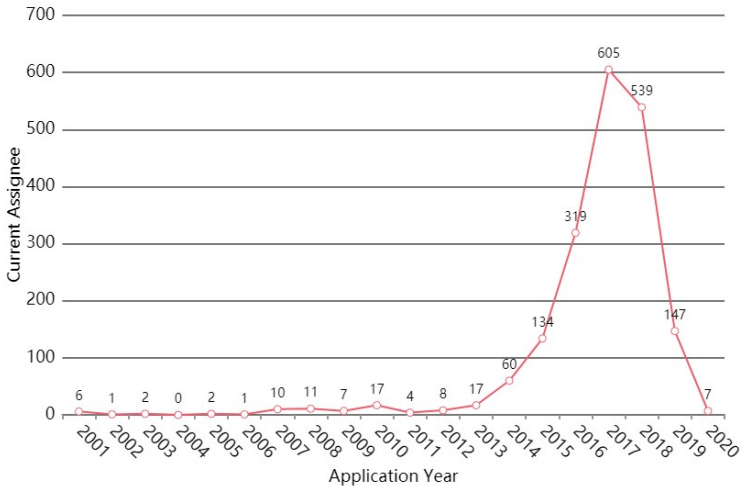


Figure 1. VR-related Patent Filing Trend

By examining the status and total number of patent applications of each company over the years, we can understand the company's ambition and potential competitiveness. Facebook owns the largest number, 851, of VR-related patents among the four firms. SONY is slightly less behind. However, in view of the history of industry research and development, SONY is the earliest starter to research and developed and followed by Oculus. An analytics called "R&D intensity analysis" that use the company with the highest score in patent number and citation strength as a baseline to set the developing capability as 100%, and to calculate the other companies' related score to the baseline thereby generate the related R & D intensity. The analysis result exhibits that SONY has the highest relative R &D intensity and capabilities, Oculus R&D intensity and capability is roughly 72% comparing to SONY. Patent citation reveals the relationship among related patents in specific technology field [22]. This research

calculated the forward and backward patent citations in a table to show the extent to which the four firms' patents are cross-referred among the total 1080 patents in the analysis data pool. The result is shown in Table 2.

Table -2 Mutual Citation Analysis

Cite/Cited	Facebook	HTC	Oculus	SONY
Facebook	2	0	0	0
HTC	0	0	0	0
Oculus	0	0	11	2
SONY	4	0	0	20

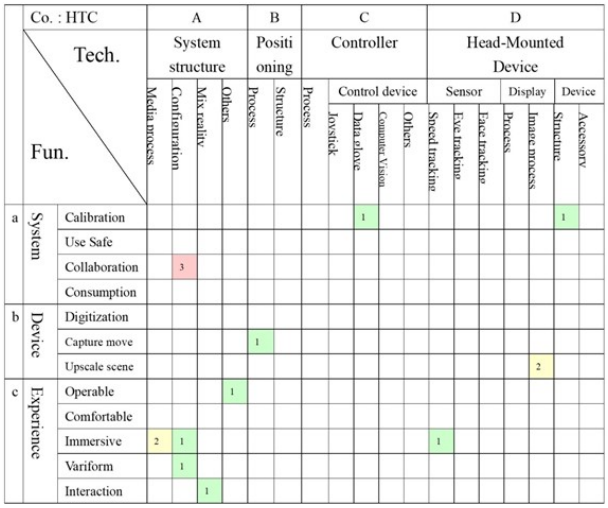
The four companies' patents do not have much interaction to each other. The number listed in the diagonal represents the self-citation of patents by the same company. It shows that most of the patent citation happened within oneself patent pool while are irrelevant with other firms. This phenomenon can be interpreted as companies in the development of VR-related technologies are all has its own direction. In addition, citing their own patents can also be regarded as the self-renovation and innovation in technology. Therefore, we can see Oculus and SONY have obvious ambitions in the improvement and innovation in VR technology.

Specially, this study also found that several patents its original patent assignee is Oculus, but now is Facebook due to the merger and acquisition. We predict that these patented technologies will likely be used in the patent portfolio and new product development of Facebook. Except the basic technical patent on the operation of the VR system, there are some special applications and methods. For example, one patent discloses a set of methods, allow several users to interact in the virtual environment, the user's facial image is the actual user's skin. Moreover, another patent is refer to contactless hand recognition method by the using of optical detection equipment. The user's hand can touch the interface of system in the air.

In Technology-Function Matrix Analysis, this study categorizes VR technologies into four groups – "System Structure", "Positioning", "Controller" and "Head-Mounted device". Each group of technologies can be further divided into sub-groups to make it easier for analyzing the relationship between technology and the effects it causes. To break down the technology architecture into an appropriate representative level, mapping individual technology to one or more product functions for addressing some kind of technical problem. Technology-Function Matrix is used to present the relationship between technology and specific functions and to calculate the number of patents that highly correlated with the technologies. For instance, some "face-tracking" technology may be developed for improving the user experience by increasing the sense of immersion and the technology was applied for a company's patent, then we can use the matrix to figure out how many patents already be applied by firms in the industry. Below we will analyze each company's technology-function matrix and discuss its patent strategy.

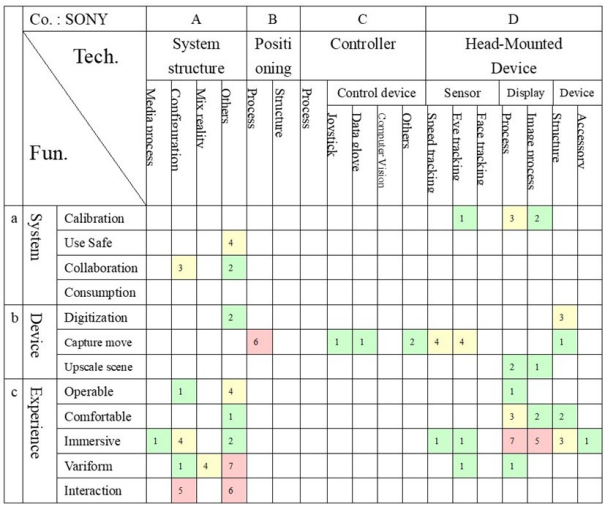
(1) HTC

HTC's overall patent number is less than the other three companies. The main focus of its patent portfolio is on the operating methods and processes between devices. Most of HTC patents are allocated in the down-left area, which means the company prefers using system structure technologies to provide user experience enhancing function. However, there are some system-level technologies that make a big difference compared to other commercially available products. For example, in the second quarter of 2016, HTC file a patent to utilize a system-level VR technology based on the user-wearing smart clothing which covered with wireless charging device for supplying energy. Recently, HTC leverages the same advantage to launch a new VR meeting App to help remote working during the COVID-19 lockdown. The patent distribution matrix is shown in Figure 2.



Co. : HTC			A				B		C						D						
Tech. / Fun.			System structure				Positioning		Controller						Head-Mounted Device						
											Control device				Sensor			Display		Device	
			Media process	Confirmation	Mix reality	Others	Process	Structure	Process	Joystick	Data glove	Computer Vision	Others	Sneed tracking	Eye tracking	Face tracking	Process	Image process	Structure	Accessory
a	System	Calibration									1								1	
		Use Safe																		
		Collaboration		3																
		Consumption																		
b	Device	Digitization																		
		Capture move					1													
		Upscale scene																2		
c	Experience	Operable				1														
		Comfortable																		
		Immersive	2	1										1						
		Variform		1																
		Interaction			1															

Figure 2. Technology-Function Matrix of HTC



Co. : SONY			A				B		C						D						
Tech. / Fun.			System structure				Positioning		Controller						Head-Mounted Device						
											Control device				Sensor			Display		Device	
			Media process	Confirmation	Mix reality	Others	Process	Structure	Process	Joystick	Data glove	Computer Vision	Others	Sneed tracking	Eye tracking	Face tracking	Process	Image process	Structure	Accessory
a	System	Calibration													1		3	2		
		Use Safe				4														
		Collaboration		3		2														
		Consumption																		
b	Device	Digitization				2													3	
		Capture move					6			1	1		2	4	4				1	
		Upscale scene															2	1		
c	Experience	Operable		1		4											1			
		Comfortable				1											3	2	2	
		Immersive	1	4		2								1	1		7	5	3	1
		Variform		1	4	7									1		1			
		Interaction		5		6														

Figure 3. Technology-Function Matrix of SONY

(2) SONY

SONY launched the earliest application for head mounted devices of VR technology. Although the description shows that the device can produce virtual 3D images, it can't further produce a deeper immersion and interaction with users. The product can play contents such as 3D movies, HD videos, to bring users a superficial experience in virtual environment which is a basis for the development of primary HMD later. By the middle of 2014, same as Oculus, Sony started to deploy the related patents of HMD in virtual reality product. It is including device's speed detection method, interaction method with the positioning tower, and the data flow to the console and so on. In 2015, SONY applied data glove technology for patent, equipped with physical feedback component, giving users the touch feeling after touching the virtual object. In addition, a finger motion recognition system was also applied. By using the camera on the bracelet worn by both hands to identify finger movements, users can interact with the virtual reality environment thereby realizes the zero touch control. Besides, SONY invents eye tracking device and the related technologies also exposed in the patent group. In user's safety area, when the user walked away from the gameplay area, Sony's device will give a safety alert. In 2017, Sony also has some patents regarding how to share VR contents with other players and remote transmission over long distances, there are lots of game titles already take advantages of the technology assets. Sony's technology-function matrix is shown in Figure 3.

(3) Oculus

Compared to the other companies, Oculus' patent portfolio is blanketing and flooding. As early as the end of 2014, Oculus began to actively file application for VR-related patents. Its early portfolio mainly covered motion capture, control processes for head mounted devices, headphone-specific devices, and controllers. Later, Oculus also patented technologies to address user experience issues to enhance the comfortability for users by emphasizing the user-friendly interface of head-mounted device, like helmet adjustment belt, adjustable telescope lens, etc. In 2016, more patents were deployed on the technology that provided excellent image quality for displays which include a set of methods to enhance the display resolution and quality which was in low acceptable level due to the limitation of lens performance with the conventional techniques. The eye tracking technology is in recent focus and its new patent portfolio can adjust the display focal length according to the user's gaze position to create a real-world shallow depth of field effect. Oculus also has some patents on data glove that can not only give input to the main system for control, but also can receive the dynamic feedback effect back to user. Oculus invests most of its resources to make devices to bring control intuitiveness and user-friendly for users. As an independent brand after merged by Facebook, Oculus's technology focus is to break the interface between human and machine for better performance in VR game industry. The technology-function matrix is shown in Figure 4.

(4) Facebook

Facebook is a new comer in VR technology field which started building patent portfolio in late 2015, after the merger with Oculus. It mainly considers using VR technology to strengthen its service and business of the online community platform, hence has a very wide patent distribution scattered in the technology-function matrix as shown in Figure 5 with no obvious focal point. Not like other companies in this comparative study, most related patents are about the operation of locator device and the VR applications in social interaction. For example, a patented technical approach presents the user in cyberspace with a virtual character which is projected on a virtual environment so that two or more users can interact in the virtual world just like physical contacts. In addition, Facebook also devoted to

develop gesture recognition technology for VR applications. A published patent disclosed how to capture the user's gesture and properly response that through the infrared camera outside the head-mounted device. The real gesture could be digitized to virtual world and get integration with virtual object. In sum, Facebook's R&D direction is to develop additional features on the HMD to replace the traditional handheld controller approach to enhance operating experience. To complementarily integrated with Oculus' technology, Facebook's patent portfolio tends to focus on giving people a real presence in the virtual world.

		Co. : Oculus	A				B		C					D						
		Tech. / Fun.	System structure				Positioning		Controller					Head-Mounted Display						
										Control device				Sensor			Display		Device	
			Media process	Confirmation	Mix reality	Others	Process	Structure	Process	Joystick	Data glove	Computer Vision	Others	Sneed tracking	Eye tracking	Face tracking	Process	Image process	Structure	Accessory
a	System	Calibration				4		1					1		3		2	1	1	
		Use Safe				1													1	
		Collaboration			1					2										
		Consumption																4		
b	Device	Digitization																		4
		Capture move					3	2	1		2		3	3	11	2			6	
		Upscale scene															4	5	3	
c	Experience	Operable								6	2	1								
		Comfortable							1	1	1				1		1		11	3
		Immersive							5		2		1				7	1	3	3
		Variform			1				1										1	
		Interaction																		

Figure 4. Technology-Function Matrix of Oculus

		Co. : Facebook	A				B		C					D						
		Tech. / Fun.	System structure				Positioning		Controller					Head-Mounted Display						
										Control device				Sensor			Display		Device	
			Media process	Confirmation	Mix reality	Others	Process	Structure	Process	Joystick	Data glove	Computer Vision	Others	Sneed tracking	Eye tracking	Face tracking	Process	Image process	Structure	Accessory
a	System	Calibration																		
		Use Safe																		
		Collaboration													1					
		Consumption																		
b	Device	Digitization				1														
		Capture move				3	1	2		1		3								
		Upscale scene																		
c	Experience	Operable																		
		Comfortable				1											1			
		Immersive				2										1			1	1
		Variform																		
		Interaction																		

Figure 5. Technology-Function Matrix of Facebook

V. CONCLUSION

This study investigated the technology strategy and patent portfolio of major firms in virtual reality industry there have been getting interests in the past years. The focal points in the early period were on the structures and operating methods of the key components and critical devices such as the head-mounted devices. Based on continuous market feedback and technology development, firm's patent portfolio spread toward the whole system which includes novel methods on the operation of the system, the inter-device linkage and configuration, techniques for better user experience, and so on. New operating modes and human-computer interaction methods have been emerging such as eyeballs tracking, face tracking, gesture tracking and recognition, wireless smart clothing and wearables, etc. The overall trend can be observed that it is moving towards more sophisticated techniques to deepen the immersive experience for users when adopting the virtual reality systems. Besides, recent VR-related patent map also shows that the firms have devoted to developing technology for enhancing the social interaction in virtual reality environment.

By analyzing the individual company's patent portfolio and mapping it to firm's product and market strategy respectively, we can find a clear picture to understand the firm's technology development direction and the fitness to the business strategy, as shown in Figure 6. Considering the VR technology is heavily used in game-related and entertainment applications at present, we mainly analyze two types of markets the companies attempt to serve: Commercial game market and home game market. Since the technologies firms used to develop different products for targeting particular segment, this study categorized the technology development directions as social oriented, game oriented and other supplement purpose. According to each firm's patent information, this study proposed a strategy map to explore the competition among the major VR game firms.

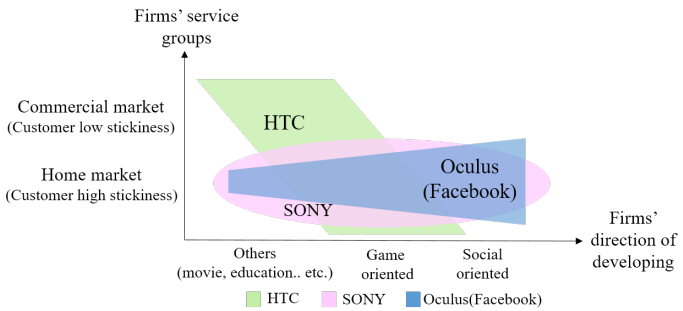


Figure 6. Market-Technology Patent Strategy of Virtual Reality Firms

First, HTC's patent portfolio seems mainly focused on protecting the system operation because of the lack of fundamental intellectual properties. Due to the strong presence in mobile phone market, HTC scatters its patent portfolio broadly to target both commercial and home game market. They have several patents show the possibility to be used in arcade game systems, especially the recent VR product PRO series HMD. As a contrast, SONY's R&D efforts are more dedicated to the head-mounted device's display quality and image processing techniques. It is eager to provide more realistic visual effects for users. Investigating their patent portfolio, we found large portion of the patents are located in a multi-person interaction method and an innovative use of the virtual reality. We predicted that SONY is making efforts on multi-person interaction technology to let users experience the VR environment together and to enter the virtual world through its popular PSVR platform.

This study combined Oculus and Facebook in the strategy analysis with consideration the two companies have already merged in 2014. Separately, Oculus mainly focus its technical efforts on the device level including a number of eye tracking technology in head-mounted devices, screen display technology, headsets audio supply technology and the joystick controller's shape design and motion capture methods, etc. Through these inventions, Oculus tries to deepen the immersion experience and to make the use experience more comfortable. Facebook's patents are mainly for VR applications such as interactive methods and forms that allow multiple users to interact in a virtual environment. Facebook-Oculus forges a strong patent fence to prevent competition from other powerful opponents in social oriented home game market by integrating both companies' patent portfolio.

To refer the findings provided by this study should be cautious because the data pool was collected only from the USPTO database. In spite of this database covers most of latest VR-related patents because the United States has the largest VR market in the world, it still has possibility on lack of completeness for the dataset. For future research, it is suggested to extend the coverage of patent database such as Europe and Japan patent office database. This study analyzed the major VR companies' technology development trend and the distribution of patent map respectively to contribute to provide VR game developers with a reference framework to understand the VR-related patent portfolio and major companies' business and market strategy.

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