The Technology Analysis of Vacuum Cleaning Robots

Course Title: Technology Forecasting
Course Number: ETM 532/632
Instructor: Jisun Kim, Ph.D.
Term: Winter
Year: 2013

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ETM OFFICE USE ONLY
Report No.:
Type: Student Project
Note:

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Abstract

Though vacuum cleaning robots have been regarded as the most promising product which can penetrate the consumer market as a robotic product, the technology of vacuum cleaning robots seems not to be developed enough to snuggle into customers' choice yet. And, the Technology development of vacuum cleaning robots depends on several factors driven by technological improvements in order to be adopted in the market. Therefore, this study questions why the technological factors cannot meet consumers' expectation and how much improvements are required for these factors. For these questions, this study explored the problems which customers recognized on vacuum cleaning robots by customers' voice analysis, and investigated current status and trends of vacuum cleaning robot technology developments. The results showed that some of technologies are not enough matured and developing actively for customers' expectations.

Introduction

The impressive development of technology during the last century has brought to the society more comfort and reduced the humans' efforts significantly. The times when thousands of people were needed for constructing buildings or many individuals were necessary for doing repetitive, continues, and boring work are behind. Nowadays, robots are replacing humans' physical functions, and doing repetitive functions. One of these cases is floor cleaning robots. Floor cleaning robots can be categorized into two groups: home cleaning robots and industrial cleaning robots. Home cleaning robots are designed with private use and they are not typically equipped with sophisticated equipment which makes them smaller, lighter, and cheaper than industrial cleaning robots. Home cleaning robots can be subcategorized into three areas based on its applications: vacuum cleaning robot, sweepers, and floor scrubbers or pool cleaning robots [1]. The focus of this research is on the vacuum cleaning robots (VCRs).

Vacuum Cleaning Robots are invented with the idea to replace the human work for cleaning floors. The development of VCRs is important since this lead a new product concept where specific tasks needs to be accomplished using a complex combination of mechanics and electronics to bring a product capable to make physical work but autonomously (the intelligence component). There are many VCR manufacturers in this market such as iRobot, Samsung, Neato, LG, and Electrolux. Roomba developed by iRobot Corporation is a great example of home vacuum cleaning robot as one of the most selling vacuum cleaning robots and also widely available in the markets right now [2]. Roomba is capable of moving around autonomously on a home floor, brush, and vacuuming dirt into its dust bin as it goes [3]. These VCRs seem to be ideal for consumers who rarely have time and need a product to assist their cleaning tasks in their homes while offering them extra free time to do other activities [4, 5].

VCRs were considerably to be the most promising product idea for home cleaning market with the size of market estimated to be enormous [1]. A vacuum cleaner generally is considered an everyday necessity rather than an extravagance to consumers. In 2011, in every two households at least have one household has one or more vacuum cleaners [6]. Based on the Euromonitor International report, vacuum cleaners reached 42 million by growing 2% in 2012, and in 2013, the value sales see a 3% increase to reach US$4.6 billion, demonstrating a moderate increase volume. Due to high pricing, robotic vacuum cleaners are considered extravagant.

Furthermore, automatic operation is typically considered novel, but unessential. However, vacuum robot cleaners was a growing fast category in small appliances over 2006-2011, illustrating an 18% CAGR (Compound Annual Growth Rate) in volume, and was the fastest in value at 29% CAGR [7]. Even during the economic crisis it still performed well. Robotic vacuum cleaners showed the strongest growth of volume in 2012 increased by 4% to 699,000 units. The current value growth of vacuum robots in the Q1 of 2013 increased by 6% to push retail sales up to US$131million [8]. The Figure 1 below illustrates the sales of VCRs units from year 2006 to 2012.

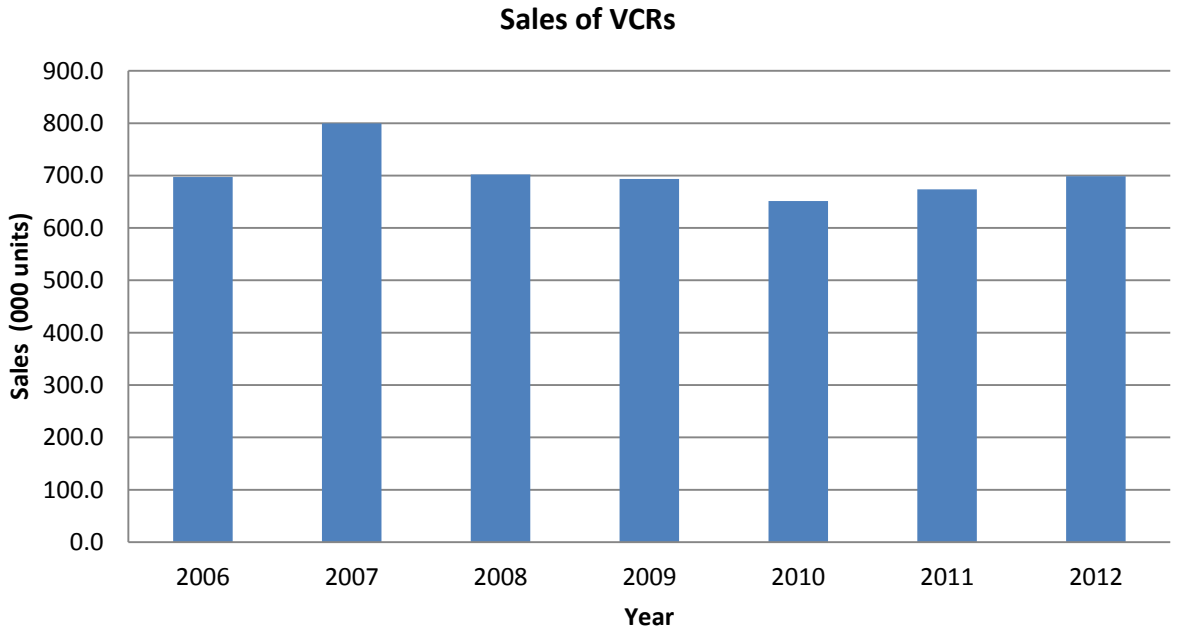


Figure 1: The total sales and trend of VCRs from 2006 to 2012 [8]

In 2006, iRobot Corp, one of the pioneers in robotic innovation, commanded a 72% volume share. As the market showed a strong performance, competition with higher capacity from large global players to gain retailing space, such as Samsung, LG and Electrolux, and iRobot's volume share declined to 52% at world level in 2011 [7]. The volume share of robotic vacuum cleaners mostly comes from developed countries such as the US, South Korea, France, and Japan, accounting for 68% of total robotic vacuum cleaners' volume sales in 2011 [6]. The U.S. was holding a 39% share of total volume sales, the main market for robotic vacuum cleaners in 2011. However, Western Europe grew from 33% of total volume to 66% CAGR from 2011 to 2016, as the largest market in the forecasting. Also, Asia Pacific countries are considered

as the second high potential market with 42% CAGR in 2016 [7]. The common factor in these developed countries is transition of household format and lifestyle. As the number of one or two person-households grows and double-income families continue to rise in developed countries, many consumers have begun looking to robotic vacuum cleaners for the convenience to maintain a clean and tidy house without much human involvement.

iRobot Corporation even includes a strong statement in their annual reports saying that the company's goal is to replace all of the conventional vacuum cleaners with their vacuum cleaning robots, Roomba, rather than supple them [9]. In the past, many said that the technology of VCRs was already there and expected to see the first commercial product in the market very soon with an estimate of the rapid market growth but it never happened as anticipated until another decade passed for consumers to be able to actually see the first commercial VCRs available in the market [1]. Even though, the use of vacuuming robot is now becoming more acceptable socially due to many factors such as the technology improvement and the decline of price, however the market trend of VCRs still has not increased much or even tends to decline slightly overall, according to the Sales of Robotic Vacuum Cleaners: Volume 2006-2012 in the U.S. which make iRobot's goal to replace conventional vacuum cleaners seems difficult to be accomplished [8, 10, 11].

In this paper, the objective of this paper is to investigate the core technologies in VCRs that still cannot offer the level of performance which meet consumers' expectations. We started with the literature review, looking into different aspects of related studies of VCRs, such as market analysis-market adoption, technology forecast of robots-quantitative/qualitative analysis, social factors-customer expectations, and performance and technological areas. In the following section, after investigating the existing problems with the current VCRs from consumers' reviews, we categorized the problems into three main technology areas: navigation, vacuuming, power systems. We then identified the gaps between the current technology capabilities causing low performance and consumers' expectations on VCRs. Moreover, we proposed the use of patent analysis as our primary tool for investigating these three core technologies in VCRs mentioned earlier in order to determine the current trends and developments.

Literature review

There are four important groups of topics associated with the objectives and analysis of this paper:

– Market analyses and technology market adoption

– Technology forecast of robots

– Social factors and customer expectations

– Technological performance and technological areas

In the market analyses and technology market adoption, the topics in general are associated with sales, market growth, consumer attitudes, supply structure, market segments, and analysis of market adoption. The documents and papers describe the market potential from 2003 to the present. The available information of VCRs is very restricted and difficult to obtain continually for every year; however, these documents and market reports give valuable information about the sales of VCRs. [12] and [13] present the information of the market robots focusing on domestic robots and vacuum cleaning robots. These documents conclude that VCR has the market potential that was projected to grow from 2006, and will have a significant growth by 2020. More elaborated information is given by [14]. [14] analyzes the robot industry from macroeconomic and microeconomic perspectives considering different factors such as government policies and the importance in different types of robots including service robots. The analysis considering the market, economic, policies, and technological implications are considered by [14], and other studies like the sociological aspects by [15] who focuses on demand pull and technological push analysis. In the particular case of VCRs and market analysis, [16] provides important information about the capital and operation costs of VCRs considering technological aspects. At the same time, [16] includes an analysis of the market adoption of the VCRs finding out the causes of the slow adoption.

In the area of technology forecast for robots, the studies have been done considering quantitative and qualitative analysis. The quantitative analysis is more focused on industrial and domestic robots (assembly industry, robotics). These studies can define two important aspects: forecasting robots technologies as a part of a production system, and forecasting the robots as a

product or unit. [17] defines a model for automobile industry considering robots technologies. This analysis is important since it shows that predicting the development of robots depends on the interaction of many elements including the relationship with other technologies. Other studies, such as [18], focus on patent analysis. [18] shows the process of gathering the patent data for robot technology in Japan regarding collaboration within research institutions. The process, analysis, and validation of the data are important for the quality of final analysis of the patents. There are few studies modeling for forecasting robots quantitatively. One of these intents was made by [19]. Accordingly, the paper quantifies the robots infrastructure changes using biographical analysis, and patent analysis using the S curve under various models such as Pearl and Gompert.

There are few Qualitative Analysis regarding service robots. Most of the studies are roadmaps for the global robotic industry, which include the service robots as a part of the roadmap. The roadmaps are analyzed from different perspectives: national robotic industry perspective, robotic industry perspective, and national perspective. For example, [20] is a roadmap for the service robotics market accomplishing the U.S. robotic industry technological policy. The roadmap is built under the market consideration considering as drivers for technology development. Another important roadmap is that [21] focuses the analysis considering economic, social, ethical, and legal aspects in Netherland. This roadmap uses SWOT analysis to evaluate the robotic technologies including the service robots in a national context. Identifying the barriers for the industrial robots has been done by [22], who build a technological roadmap providing information for future research associated with robots. As can be seen, there was no study about VCRs. Most of the qualitative and qualitative analyses have been done in an industrial, macro economical, and policy context.

One of the main important aspects is to identify the characteristics of customers. Identifying the social factors and customer expectations is not an easy work, but there are several studies describing the social factors involving the use and adoption of robots and the analysis of the people's expectations about this type of technology. In this context, [23] describes the public opinion about how robots need to be and emphasizes that future robots need to do more complex work. Additionally, there are many studies regarding the psychological attitudes of customers about robots [24, 25]. [25] explains the adaptation cycle of a robot at home since the robot

introduction, robot adaption, and the importance of the interaction of human-machine for the robot acceptance. [26][27] and [28] analyze the perspective and expectations of customers on robotics in the future from economical and physical perspectives. These scholars analyze the human behavior and attitudes when they live with robots. The analysis includes gender perspective, gender attitudes, and economical perspectives. Many of the studies are made by surveys and ethnographic analysis. Also, most of these type of studies analyses the behavior of customers, needs, and the interaction considering many technological factors such as language, noise, and shape of the robots. In addition, there are some studies specifically about vacuum robot cleaning and the customers' interactions [29, 30, 31, 32].

Regarding the technological performance and technological areas, these papers describe the components of robots, focusing on sensor parts, motor control, robot control, and safety. The description of the main components and features are made by area or group of components. Some studies analyze the particular use or tasks of robots and the technical components. The studies also include the analysis of robots efficiency. These are technical, and academic papers and few focused on VCRs. The technological improvement is directly associated with the peoples expectation; in this context, there are many studies linked to the technology development and customer interaction especially in the care service. [33][34][35] analyze the peoples' behavior about care robots, and these papers describe the technological capabilities of robots for performing personal care activities and the interaction with people, majority elders, from a psychological and technological points of view. Additionally, the technological aspect as a result of human interaction with robots are provided by [36][37] who describe the technological aspects under domestic environment focusing of different aspects such as technological detection, algorithms, driving mechanisms. [38] and [39] made a more specific analysis of the main technologies for cleaning robots, they performance, and the association with customers' expectations.

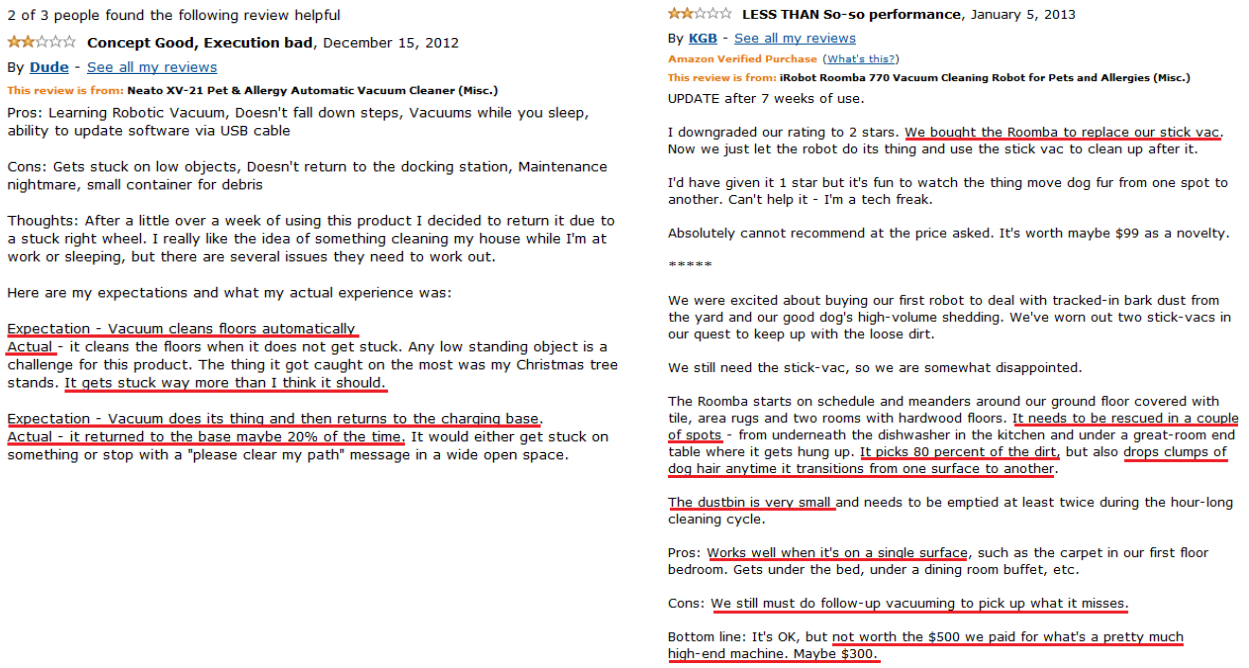
Customers' Voice Analysis

The VCRs have more 15 years of development and have been in the markets for years but the adoption is still low or remains the same and the market size has not grown as anticipated [1, 7]. Technology improvement as one of the adoption factors of VCRs [2]. In this paper, we explored and investigated the technology-related problems in current VCRs in the market that cause dissatisfaction to consumers and potentially cause the slow adoption of VCRs. In order to analyze customers' voice of VCRs, we used mining customer reviews technique to identify the problems and customer's expectations. Mining customer reviews technique is typically used for helping consumers make a decision on selecting or buying a product by ranking products based on the product's feature comparison [40]. In this paper, we adapted this technique partially to help us easily obtain the technology-related problems and consumer's expectations of VCRs specifically instead of ranking them. In the process of mining customer reviews, we first sought for features offered in VCRs and identified subjective sentences expressing directly about consumer's experience on VCRs features. We then listed all the identified problems with their frequency and consumer's expectations and filtered them to obtain only the technology-related problems which finally could give us the gaps between current problems and consumer's expectations on VCRs.

We have selected Amazon.com as our main source for customer's reviews for VCRs since nowadays; many consumers are becoming more and more interested in online shopping because it is easy, convenient, and fast. Moreover, online shopping website like Amazon.com also offers consumers abilities to write reviews of their experience on products. These reviews are text describing and a rich source which is more unbiased, honest, and comprehensive than manufacture product's descriptions [40].

In the process of reading through reviews on Amazon website, we first selected Roomba 770 and Neato VX21 as our product of focus. These two VCRs are the top-of-the line and 2 best-selling VCRs in the market currently and they are exclusively equipped with the latest technologies and offer superior performance and luxury features. The rating of reviews or stars can be used as an excellent guideline for seeking the problems or complain about the VCRs however, we still considered to include 5 star-rating reviews as well since there are some consumers state their minor complains and suggestions in improving VCRs in the next

generation to meet their expectations. Some of reviews are particularly important to capture since some consumers are tech freaks which can provide better insights in specific problems of VCRs. We then started reading from low-rated reviews or 1 star first because these reviews usually provide poor experiences or complains about VCRs and move to 3, 4, and 5 star reviews respectively. During the process of reading, we mainly sought for the technology-related problems and consumer's expectations of VCRs but we also included other kind of problems such as customer service. The Figure 2 illustrates an example of consumer's review on Amazon.com and the problems.



2 of 3 people found the following review helpful

★★☆☆☆ **Concept Good, Execution bad**, December 15, 2012

By **Dude** - See all my reviews

This review is from: **Neato XV-21 Pet & Allergy Automatic Vacuum Cleaner (Misc.)**

Pros: Learning Robotic Vacuum, Doesn't fall down steps, Vacuums while you sleep, ability to update software via USB cable

Cons: Gets stuck on low objects, Doesn't return to the docking station, Maintenance nightmare, small container for debris

Thoughts: After a little over a week of using this product I decided to return it due to a stuck right wheel. I really like the idea of something cleaning my house while I'm at work or sleeping, but there are several issues they need to work out.

Here are my expectations and what my actual experience was:

Expectation - Vacuum cleans floors automatically
Actual - it cleans the floors when it does not get stuck. Any low standing object is a challenge for this product. The thing it got caught on the most was my Christmas tree stands. It gets stuck way more than I think it should.

Expectation - Vacuum does its thing and then returns to the charging base.
Actual - it returned to the base maybe 20% of the time. It would either get stuck on something or stop with a "please clear my path" message in a wide open space.

★★☆☆☆ **LESS THAN So-so performance**, January 5, 2013

By **KGB** - See all my reviews

Amazon Verified Purchase (What's this?)

This review is from: **iRobot Roomba 770 Vacuum Cleaning Robot for Pets and Allergies (Misc.)**

UPDATE after 7 weeks of use.

I downgraded our rating to 2 stars. We bought the Roomba to replace our stick vac. Now we just let the robot do its thing and use the stick vac to clean up after it.

I'd have given it 1 star but it's fun to watch the thing move dog fur from one spot to another. Can't help it - I'm a tech freak.

Absolutely cannot recommend at the price asked. It's worth maybe $99 as a novelty.

*****

We were excited about buying our first robot to deal with tracked-in bark dust from the yard and our good dog's high-volume shedding. We've worn out two stick-vacs in our quest to keep up with the loose dirt.

We still need the stick-vac, so we are somewhat disappointed.

The Roomba starts on schedule and meanders around our ground floor covered with tile, area rugs and two rooms with hardwood floors. It needs to be rescued in a couple of spots - from underneath the dishwasher in the kitchen and under a great-room end table where it gets hung up. It picks 80 percent of the dirt, but also drops clumps of dog hair anytime it transitions from one surface to another.

The dustbin is very small and needs to be emptied at least twice during the hour-long cleaning cycle.

Pros: Works well when it's on a single surface, such as the carpet in our first floor bedroom. Gets under the bed, under a dining room buffet, etc.

Cons: We still must do follow-up vacuuming to pick up what it misses.

Bottom line: It's OK, but not worth the $500 we paid for what's a pretty much high-end machine. Maybe $300.

Figure 2: 2-stars consumer's reviews of Neato VX 21 and iRobot Roomba 770

After reading through more than 400 reviews in Amazon.com, we identified all of 11 problems that many consumers complained see Appendix 1. We then eliminated non technology-related problems and categorized the rest of problems into 3 technology areas: navigation (intelligence), cleaning, and power management systems based on how frequency these problems are mentioned. Figure 3 below illustrates the percentage of current problems with VCRs based on online consumer reviews on Amazon website.

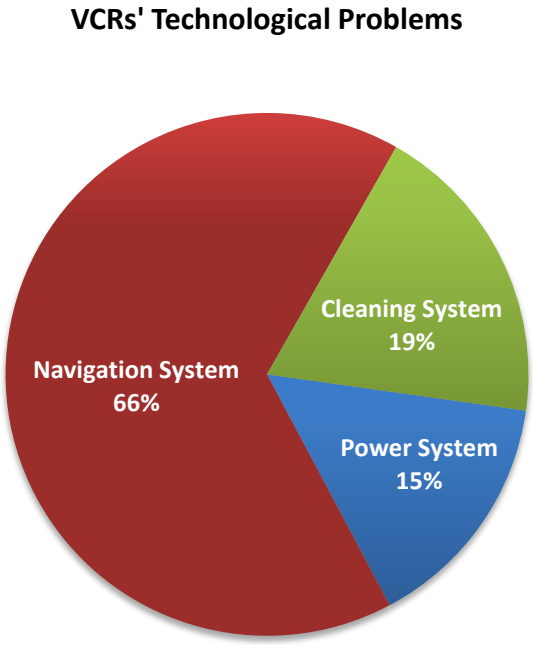


Figure 3: The percentage of VCRs problems in 3 main systems [41, 42]

From Figure 3 navigation or intelligence system is the first and major problem found in current VCRs account for 66 percent in total. In navigation section, most consumers found that their VCRs often get stuck in some situations during performing cleaning tasks and they usually cannot find a way back to the docks for charging. Cleaning system also presents as the second problem overall with 19 percent. In cleaning section, most consumers criticize about the inability of VCRs to vacuum heavy dirt or long hair and being unable perform cleaning well on rugs or carpets. Lastly, power system is accounted with 15 percent of the overall problem with the most complain about short battery life and inability to complete cleaning a whole floor area per room in a single charge.

The Table 1 below illustrates the technology gaps with summary of all the problems in details for each technology system, technology components behind those technology problems, and the consumer expectations or desired performance from consumer's reviews in Amazon website.

Table 1: Technology gap analysis based on customers' opinions [43, 44, 41, 42]

Technology Area	Issue	Technology Components	Gap	Desired performance
Power System	Short battery life	Battery	Higher density or capacity of battery	Battery should last longer per single charge
Navigation System	Still missing spots left unclean	Global Path Planning Algorithm	Better algorithm	Clean the whole area completely
	Get stuck and cannot figure the way out	Local Path Planning Algorithm	Better algorithm	Avoid any obstacles and figure a way out in any environment
	Cannot find the way back to the base	Algorithm, Sensor	Better algorithm Better sensor	Can find a way back to the base every time
	Won't clean on dark carpet	Sensor (infrared)	Better or new sensor	Can clean on carpets or floor regardless to colors
	Poor transition between different kinds of floor	Sensor	Better or new sensor	Can go onto any kinds of surface or floor
Cleaning System	Not high power suction. (can't suck sand and long hair)	Vacuum engine	Higher power vacuum engine with the same size	High power suction to clean any forms of dirt
	Small bin (capacity)	Bin size	Ability to contain more dirt with the same bin size	Can contain a lot more dirt in one bin, dirt bin self-cleaning
	Cannot clean well on different surface	Cleaning components such as brushes	Better cleaning solution or component	Can clean on floor regardless to any kinds of surface

From the Table 1, we can see that the current VCRs offer the performance that still cannot meet most of the consumer's expectations. Especially in the intelligence or navigation system, most consumers buy VCRs because they have an expectation that these VCRs will be smart or fully autonomous and require minimal human inventions to have their time cleaned. However, in the real practice, VCRs still cannot clean the whole areas completely leaving missing dirt to be cleaned by humans' follow up tasks and they often get stuck or lost in some situations or even cannot figure the way back to its charger station which eventually require human interventions again to get them back to work. Therefore, many consumers are not satisfied with the current performance of this technology area in VCR at this price point because they need to get the products that offer performance that meet their expectations for the money they pay for which eventually result in the likelihood not to adopt the VCRs [11]. Therefore, we can conclude that VCRs are still far from their majority stages of development to provide superior performance for which consumer expect.

Patent Analysis

Another approach to analyze VCRs' current technologies is patent analysis. For patent analysis, first of all, the technology structure of VCRs was built. And then, with the technology structure, each core technological feature, function and component was reorganized by the technology identifications in customers' voice analysis, which is defined as technology clustering. The keywords drawn by reorganization were used for inputs to gather patent information of each technology cluster. Finally, number of each technology cluster's patents is collected in annual. Figure 4 represents this procedure.

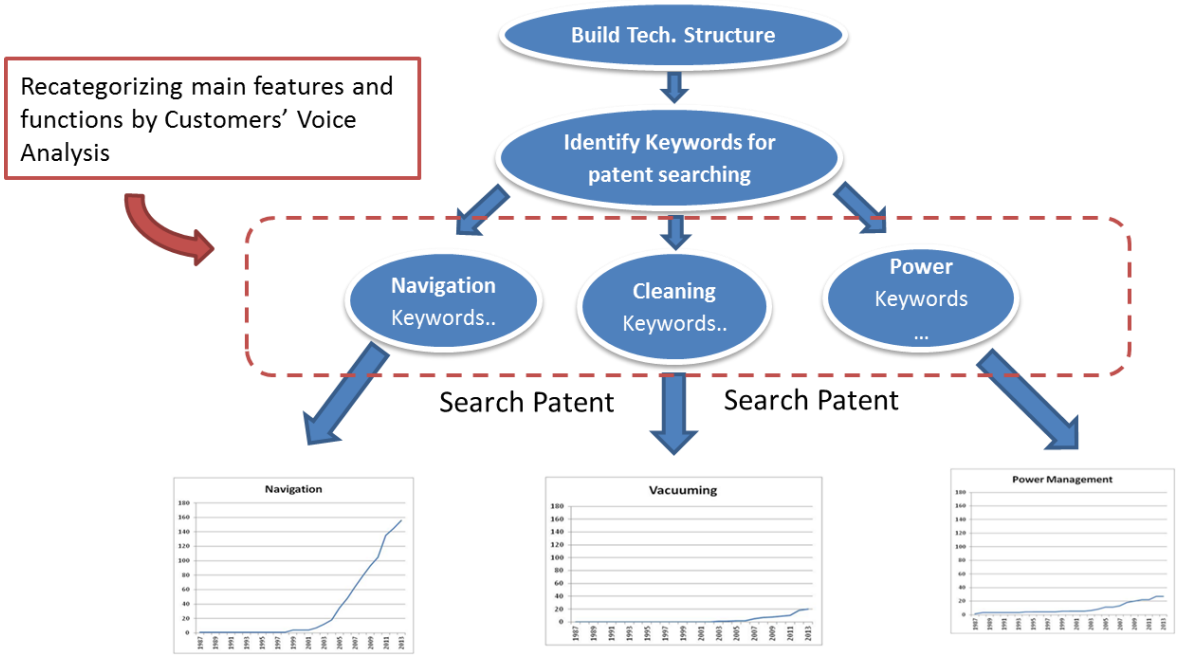


Figure 4: Patent Analysis Procedure

Before building technology structure of VCRs, various technical and engineering publications about main functions and structures of mobile robots and vacuum cleaner robots were studied to understand fundamental technologies of VCRs [45, 46, 47]. Based on these publications, technology structure of VCRs was constructed like Figure 5. This technology structure consists of core technological features, functions and components. Each element of the technology structure was divided into three technology clusters like the Consumers' Voice Analysis section; Navigation system, Cleaning system and Power system. Navigation system functions mainly to determine the size of room and calculate the amount of time for cleaning, and generate the cleaning paths and real-time paths for avoiding obstacles, and stairs. This

system includes mapping, planning and driving subsystem. For these subsystems, there are variety kinds of mechanical, electronic and software components. Cleaning system designed to detect, vacuum, and store any forms of dirt into its dust bin consist of mainly brush, vacuum units and dirt bin. And Battery and charging units are main components for Power system designed to store and supply power to VCRs. In addition, various sensors are used for each main system such as infrared (IR) sensors.

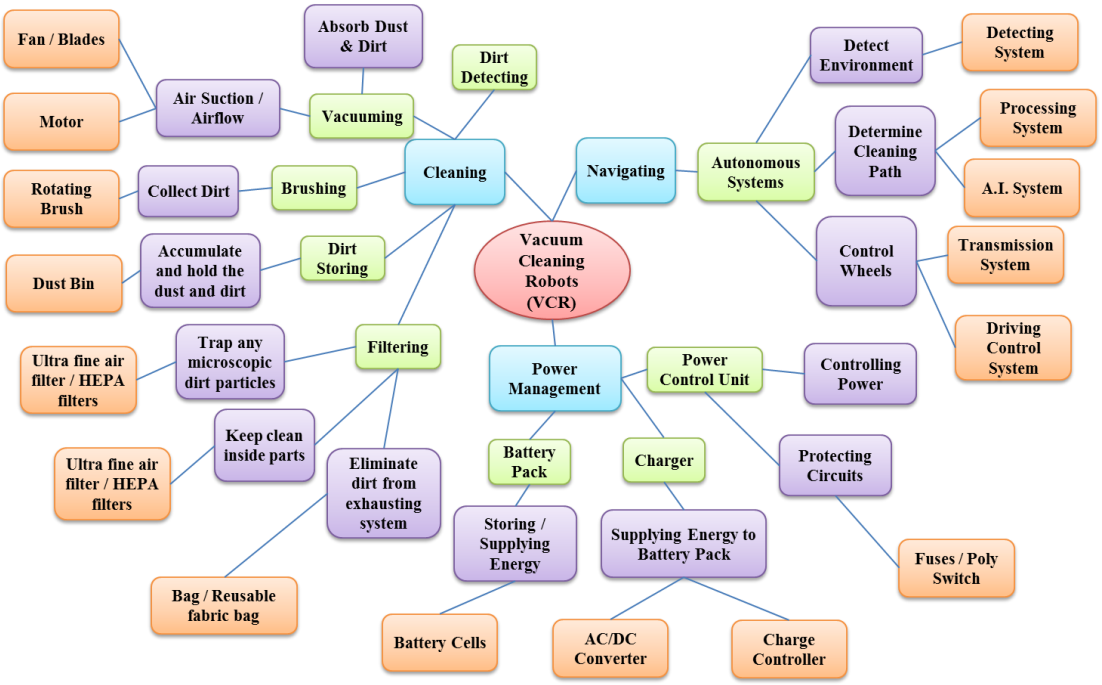


Figure 5: Technology Structure for VCRs

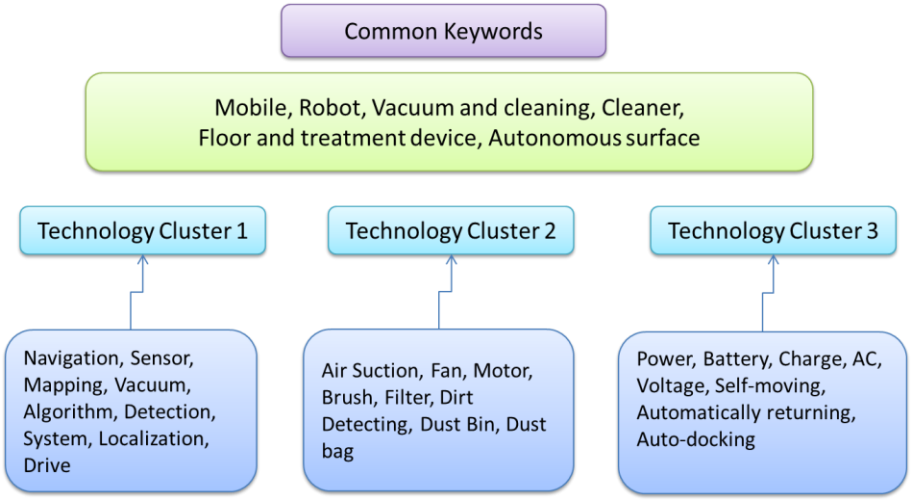


Figure 6: Technology Clusters for VCRs

Varied combinations of these components define specific functions of each VCR, and the ideas can be organized through patents. Therefore, appropriate selection of keywords from those combinations enables this analysis to be more credible. For keywords selection, the terms of each element enumerated on the technology structure were transformed into patent terms under each technology cluster. Furthermore, some common key terms which indicate mobile and vacuum cleaning robots were identified separately as Common Keywords. Figure 6 presents the results of technology clustering.

To gathering patent data with these core keywords, the database of the United States Patent and Trademark Office were used for this work because the focus of this research is limited on the consumer market in the US. And, the focusing time period is from the year 1991 to the year 2012. This selected period allows this study secure enough data to analyze technology trend of each technology cluster as well as VCRs. A web-based tool was employed for collecting patent data. This tool enables users to gather date more conveniently by providing several functions such as browsing selected items instantly, storing, sorting and exporting of search results. In particular, the exported patent date can be refined by deleting duplicated patents and examining correlation at spread sheet software such as Microsoft Excel. This procedure was conducted separately by each technology cluster. Table 2 shows the results of this data gathering work. From the year 1991 to the year 2012, a total of 187 VCRs patents were issued on the USPTO patent database.

Table 2: The results of data gathering

Clusters Number	Cluster feature	Representative Keywords	The number of patents in the cluster
1	Navigation System	Navigation, Sensor, Mapping, Vacuum, Algorithm, Detection, System, Localization, Drive	**145**
2	Cleaning System	Air Suction, Fan, Motor, Brush, Filter, Dirt Detecting, Dust Bin, Dust bag	**18**
3	Power System	Power, Battery, Charge, AC, Voltage, Self-moving, Automatically returning, Auto-docking	**24**

Figure 7 presents the annual patent counts and cumulative number of VCRs patents. In Figure 7, the cumulative numbers of VCRs patent have increased rapidly since the year 2003. Also, the patent counts of VCRs have gradually increased since the year though these have fluctuated.

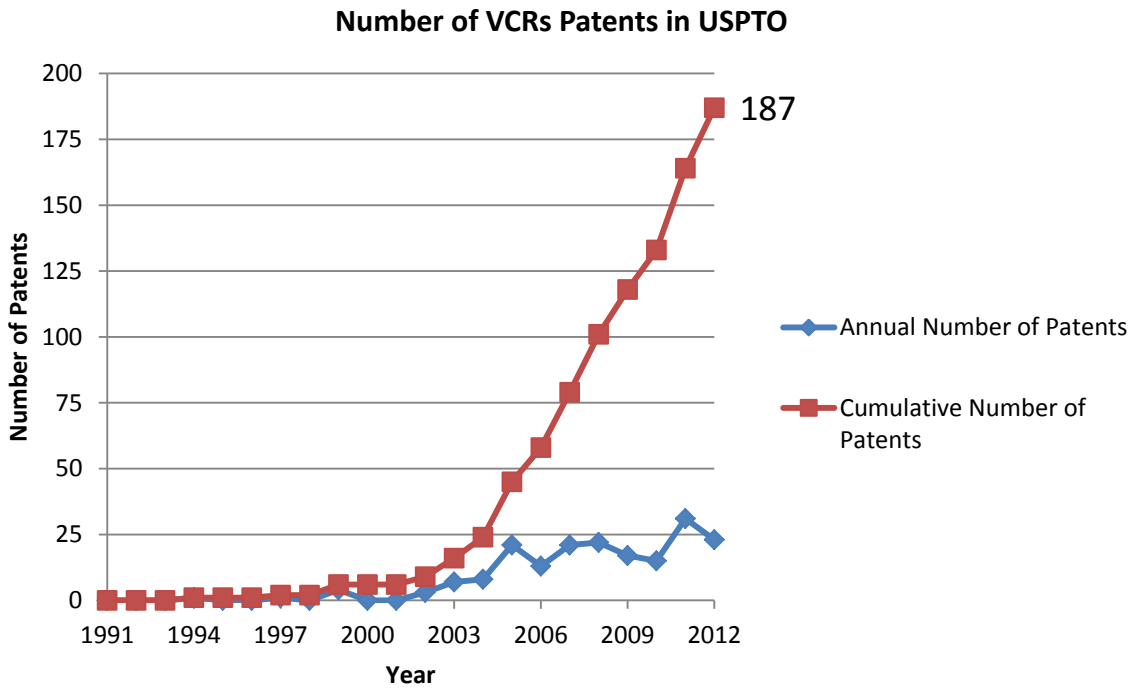


Figure 7: The annual patent counts and cumulative number of VCRs patents

After examining total number of VCRs patents, the annual patent counts and cumulative number of each technology cluster patents were presented in Figure 8. The cumulative numbers of the technology cluster 1, navigation system, have also increased drastically since the year 2003. And, the annual patent counts of the technology cluster 1 have been issued steadily since 2005. Also, the cumulative numbers of the technology cluster 2, Cleaning system, began to increase from the year 2003 and have increased sharply since the year 2006. And, the patent count of the technology cluster 2 during the year 2012 is suddenly increased. Finally, the cumulative numbers of the technology cluster 3, Power system, have increased gradually since the year 2003 unlike the technology cluster 1 and 2. And, the numbers of issued patents related to this cluster has also somewhat increased slightly though fluctuating.

In general, the total number of patents has increased by 2005 driven by the increase of number of patents of all of the three areas, but more significantly influenced by the growth of number of patents in the navigation system.

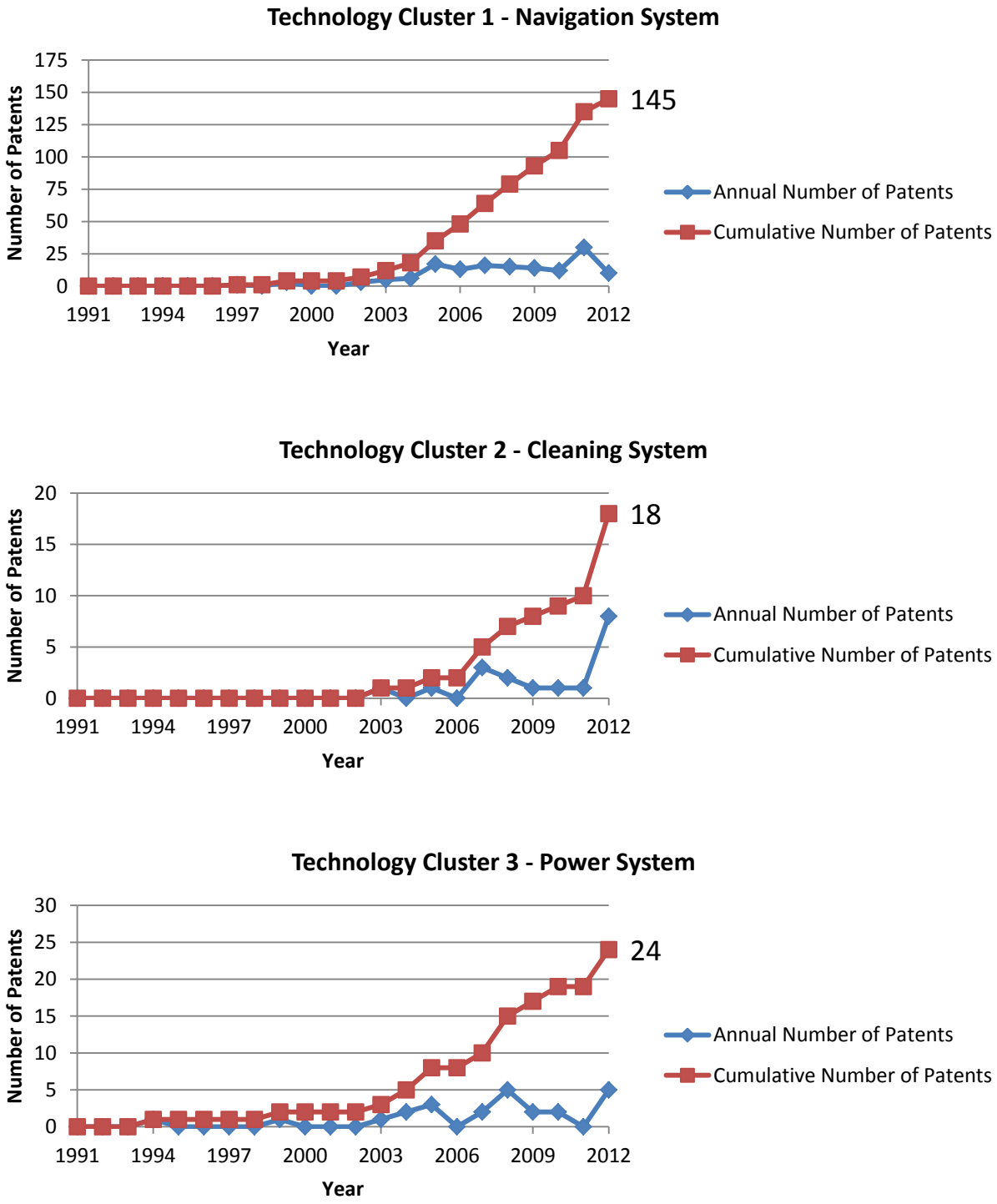


Figure 8: VCRs patents and cumulative patent number on USPTO database

Discussion

Based on the results of customers' voice analysis and patent analysis, this research suggests that the technology cluster 1, Navigation system, has the highest portion in both the customers' voice analysis and patent analysis of VCRs. In addition, both results have similar distributional pattern though each technology cluster has different percentage between both analyses. Figure 9 shows the comparison between both results.

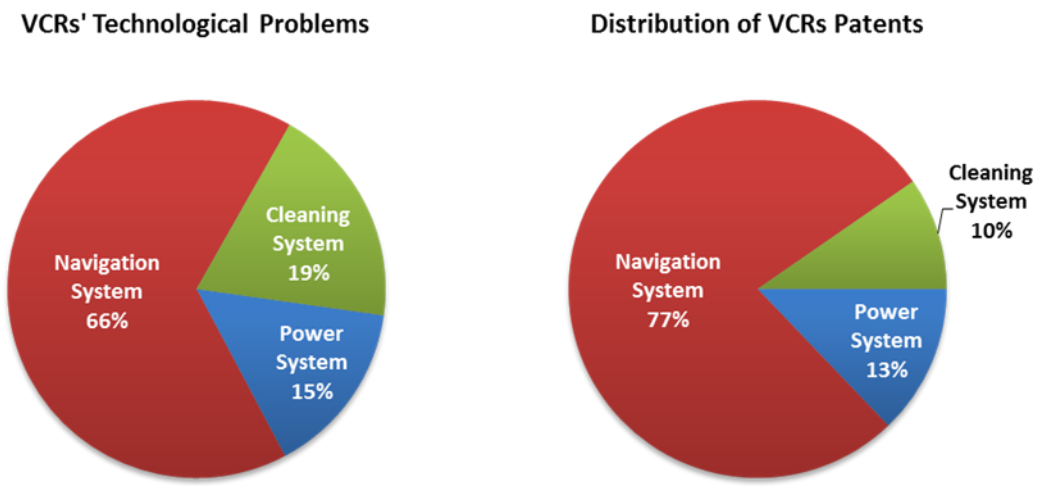


Figure 9: The result comparison between customers'voice analysis and patent analysis

Cumulative numbers of patents for all technology clusters began to increase distinctively from the year 2003. This seems to be related to the fact that the iRobot introduced its first vacuum cleaning robot series, Roomba, in 2002. Though the robots are not the first commercial vacuum cleaning robots in the world, Roomba series made a breakthrough in accelerating the pace of VCR technology developments as well as penetrating the consumer market. In practice, since Roomba series, lots of VCRs have gone into the consumer market.

Lastly, the slope of the cumulative curve of the technology cluster 1, navigation system, is relatively steeper than other two technology clusters like Figure 10. This means that the technology development of navigation system is the main factor leading VCR technology. Whereas, the cumulative curve slopes of other two technology clusters, cleaning system and power system, are somewhat gentle. In fact, these two systems have depended on typical technologies. For example, most of cleaning technologies have been derived from the cleaning parts of conventional manual vacuum cleaners though these technologies have been modified for

mobile usage. Of course, some crucial technologies such as dirt detecting systems and corner brush designs have been developed steadily. Also, main parts of power system depend on battery technologies and low power design techniques relevant to conventional external technologies. Therefore, the paces of technology developments in the technology cluster 2 and 3 are slower than in the technology cluster 1.

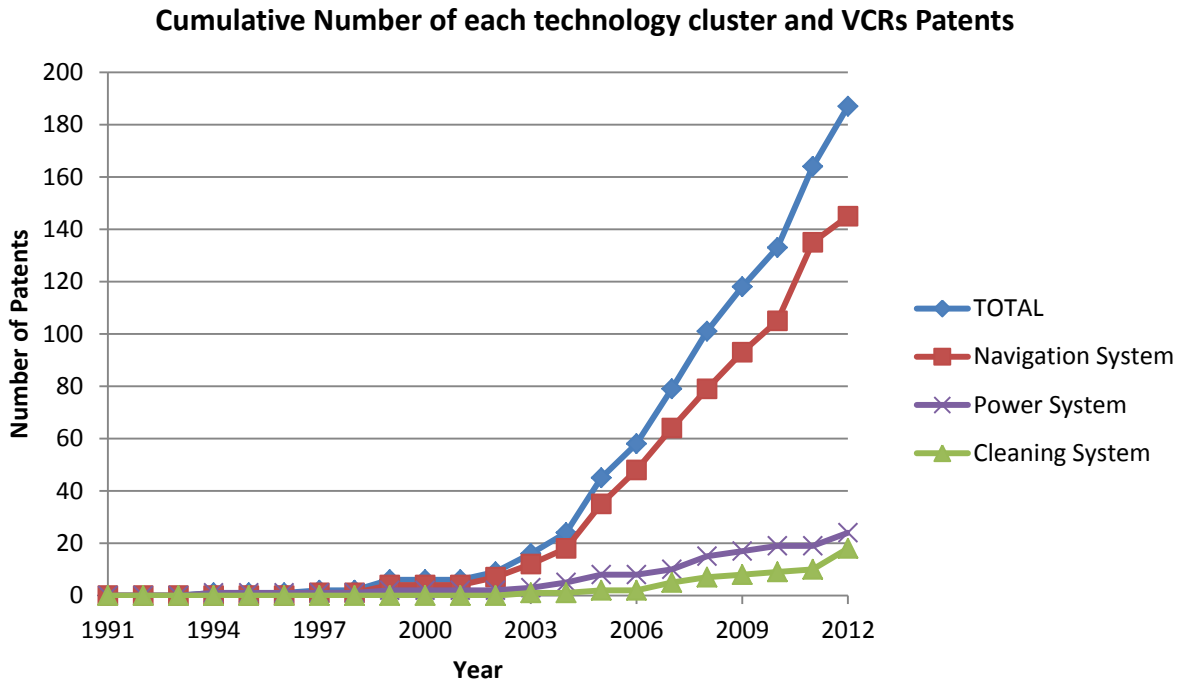


Figure 10: Cumulative Number of each technology cluster and VCRs Patents

Conclusion

In the past, many believed that VCRs would be coming soon in the market since all the technologies required were there already. However, the first commercial VCRs came out to the market when another decade already passed. Even though people are becoming more accepting to have VCRs in their homes to assist their cleaning tasks, the market size of VCRs has been the same without any significant increase for years.

In this paper, we investigated the consumer's voice on the VCRs by using mining customer reviews on VCRs and we have found that current VCRs still offer the performance that still cannot meet consumer's expectations. Many problems were identified such as navigation (intelligence), cleaning, and power systems which created gaps between current problems and consumers' expectations. Especially, navigation system as the core technology that defines autonomous system and also distinguishes VCRs from conventional vacuum cleaners is presented to be the biggest problem in VCRs. Many VCRs still cannot clean the whole floor completely, get lost or stuck in some situations, and cannot even find the ways back to the dock for charging power which contrasts the expectations that VCRs to be intelligent and clean their homes with minimal human interventions.

Also, the technology structure of VCRs was built to extract important keywords for patent analysis. The keywords were reorganized by the three technology clusters identified with the customers' voice analysis before patent analysis. Also, some experts who have researched and developed relevant technologies confirmed these works. And then, patent analysis was conducted to analyze current status of related technologies for VCRs. As the result, we have found that, in the navigation system, there are many patents published with greater in numbers than other two technology clusters.

This result reveals the correlation between the navigation problems that we found from customers' voice and the highest numbers in patents from the patent analysis that the problems in navigation area still exist and many VCR manufacturers are trying to improve their VCRs navigation system. From the patent analysis, navigation system in VCRs still has more space for further development to reach its potentials. In other two technology areas: cleaning and power

systems, these technology areas are adopted from other technologies which result in the slow rates in development and therefore, there is still a long way for further development.

However, this research has several limitations. First of all, the area of the identified technology cluster 1, navigation system, is broader than other two technology clusters. Navigation system can be divided into several subsystems such as mapping and planning algorithms, and driving mechanism. And, for customers' voice analysis, we tried to access some commercial market reports dealing with abundant information of VCRs, but most of these reports are too expensive. Therefore, without the information, this research referred to just abstracts of the reports. Finally, in this study, some experts contributed to validate technology clustering.

To overcome above limitations of this study, based on this study, other methodologies such as publication analysis, bibliometric analysis and Delphi method can be conducted. And, while this study focused on only the US market, other patent databases such as European, Japanese, South Korean and Chinese patent database can be explored for the VCR technology.

Appendix 1

Technology Area	Issue	Counts	Total
Power System	Short battery life	30	30
Navigation System	Still missing spots left unclean	24	132
	Get stuck and cannot figure the way out	53	
	Cannot find the way back to the base	30	
	Won't clean on dark carpet	4	
	Poor transition between different kinds of floor	10	
	Wheels get stuck	12	
Cleaning System	Not high power suction. (can't suck sand and long hair)	21	38
	Small bin (capacity)	11	
	Cannot clean well on carpet	18	
Customer Service	Poor quality service	11	11

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