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Using patent data for technology forecasting: China RFID patent analysis

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ABSTRACT

China is one of the world's largest manufacturers and consumers of Radio Frequency Identification (RFID) applications. Current estimates show that China will need over 3 billion RFID tags to satisfy demand in the year 2009. The applications for RFID patents have spread across a very diverse range of inventions and in the future it is likely that most products manufactured in China will contain an RFID tag. China's RFID industry has grown along with the demand and researchers are making significant technological advances. In this research, patent data from the State Intellectual Property Office of the People's Republic of China (SIPO) have been used to explore RFID technology development and its trends. Patent abstracts containing the keyword and phrase "RFID" and "Radio Frequency Identification" were collected for analysis, content extraction, and clustering. In total, 1389 patents from the SIPO database covering the years 1995–2008 were retrieved and archived for analysis. Patents provide exclusive rights and legal protection for inventors, play an important role in the development and fair diffusion of technology, and contain detailed specifications necessary to define and protect the boundaries of an invention. Through patent analysis, companies monitor the development of technology and evaluate the position of potential competitors in the market. This research introduce a methodology which combines patent content clustering and technology life cycle forecasting to find a niche space of RFID technology development in China.

A patent content clustering method is used to cluster different patent documents into homogenous groups, and then technology forecasting is applied to evaluate possible market opportunities for future inventors and investors. The results suggest that the cluster called RFID wireless communication devices has entered the saturation stage and thus provides limited opportunity for development. Four other clusters; RFID concepts and applications, RFID architecture, RFID tracking implementation, and RFID transmission apparatus, have entered the mature stage. The RFID frequency and waves cluster appears to be in early growth stage with good development potential. Since the technology related to basic RFID concepts and devices has reached a mature stage in China, the research and development seems to be targeting the improvement of the RFID frequencies and waves as a means to develop more reliable RFID systems and applications.

1. Introduction

Radio Frequency Identification (RFID) tags are small silicon microchips (often less than 1 cm) designed as wireless identification systems to store and broadcast information while tracking things or people. RFID tags equipped with an antenna send information to readers which can be placed hundreds of meters away. RFID technology has a wide range of applications including retail inventory management, drug security, customer service, national defense, and health care [1]. RFID greatly reduces management and labor cost and enhances the efficiency and security of business processes by adding a "voice" to the objects it is attached to. The barcode is being replaced by RFID technology and this substitution has increased the demand for related market applications, products, and services.

Since RFID automatically broadcasts signals, it facilitates a myriad of processes such as inventory control, delivery, pricing, product recall, and real time accounting [2]. Thus, the retail and logistics industries have accepted RFID technology as an important means to monitor, manage, and control business processes [3]. For example, BEA Systems predicted that Wal-mart would save up to US $8.35 billion per year after building RFID capabilities into their supply chain [4]. IDTeckEx reported that the global market scale for RFID products and systems was US $4.93 billion in 2007 and US $5.29 billion in 2008. The products and systems

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include tags, readers, software and services for RFID cards, labels, and chips [5]. ABI research estimates that global RFID expenditures will exceed US $8.49 billion in 2012 with the Asia–Pacific region to become the largest user of RFID tags [6]. Clampitt also claims that China will be the largest potential RFID market of the world [7]. Fig. 1 shows the RFID global market distribution in 2008 with China and the US leading the world in sales [5].

In 2008, China's Gross Domestic Product experienced a growth of 9% [8] and was the global leader in receiving foreign direct investment [9]. China is widely recognized as an important player in this high-tech industry [10], requiring the investors to better understand the marketplace and players before committing investments. China RFID technology was first deployed in the transportation industry and included rail car and freight container identification systems, entrance guard systems, parking lot control systems, and highway toll systems. Research by Wu et al. showed that the efficiency of global supply chain and the domestic logistics infrastructure and manufacturing operations would increase if China's manufacturers placed more RFID tags on pallets and cases [11]. Fig. 2 illustrates the scale of China's RFID market for the years 2006–2008 and forecasts the sales volume for the years 2009–2011.

Patents contain detailed specifications used to define and protect the legal use boundaries of an invention. Through patent analysis, companies can monitor the development of a technology and evaluate the position of potential competitors in the market. This research uses patent content analysis to map the current RFID technology development trends in China. The methodology first clusters patent documents into homogenous groups and then applies a technology forecasting model to evaluate possible market opportunities for new patent research and development.

2. Patent content analysis methodologies

Since patents provide exclusive rights and legal protection for inventors, patents play an important role in the development and fair diffusion of technology. Patent data analysis has been used to gain insights into various economic and social issues [12–15]. For example, Stern, Porter, and Furman [12] used patent data from the years 1973–1995 to model and explain the growth of innovation between seventeen nations. Crosby [13] used Australian patent data to discuss the relationship between workforce levels and economic growth and to predict the impact of subsidies and foreign technology. Marinova [14] discussed the patent activities of East European countries in the US and Jung and Imm [15] studied patents from 1988 until 1998 to compare the different patent application procedures in Taiwan, South Korea and the US.

Other researchers have used patent data to analyze the technological ability between competitors and within industries to help corporations form technology strategies [16–18]. Liu and Shyu [16] used patent data to study the technology development of Taiwan's LED and TFT-LCD and provide directions and strategies for business planning. Stuart and Podolny [17] applied patent data to analyze the technological abilities and evolution of Japanese semiconductor companies. Ernst [18] discussed the relationship between the quantity and quality of patents and business operations after studying 50 German machine tool companies. This research applies patent map analysis, patent document clustering, technology forecasting, and technology life cycle analysis to analyze the content of patent abstracts. Fig. 3 depicts the patent content analysis process.

2.1. Patent map analysis

Patents archived in most patent databases contain a variety of information such as the publication and application date, the applicants, the inventors, and the international classification number. Patent map analysis uses this information to create general summaries. One such summary is the patent count which can be expressed as a cumulative patent count or as yearly patent count. Cumulative patent counts reflect the technology life cycle which in turn can be used to determine the development stage of the technology. If analysts know the development stage of the technology, it is possible to forecast future trends and predict market saturation levels. Knowledge about the maturity and future market growth of technology innovations helps researchers decide whether to continue investing resources or switch research directions.

Patent analysis can also be used to compare the strategic industry positioning between nations. By analyzing patent counts or the number of applicants from different countries, researchers can quickly determine which countries are taking the lead in different areas of a technology. Inventor profiling is used to identify inventors with the most patents, to analyze the contributions of a specific inventor, and to link the inventors to the companies that share in the ownership and application of the invention.

2.2. Technology and patent document clustering

Clustering is widely used for text mining, pattern recognition, webpage analysis, and marketing analysis [19,20]. Clustering is used to separate a heterogeneous population into a number of homogeneous subgroups without predefined classes [21]. The purpose of clustering is to select elements that are as similar as possible within groups but as different as possible between groups. Groups are clustered based on entities' similarity according to specified variables and the meanings of clusters depend on the context of the analysis. In this research, the clustering technique proposed by Hsu [22] has been used to extract clusters from China RFID patent documents. The process includes data preprocessing

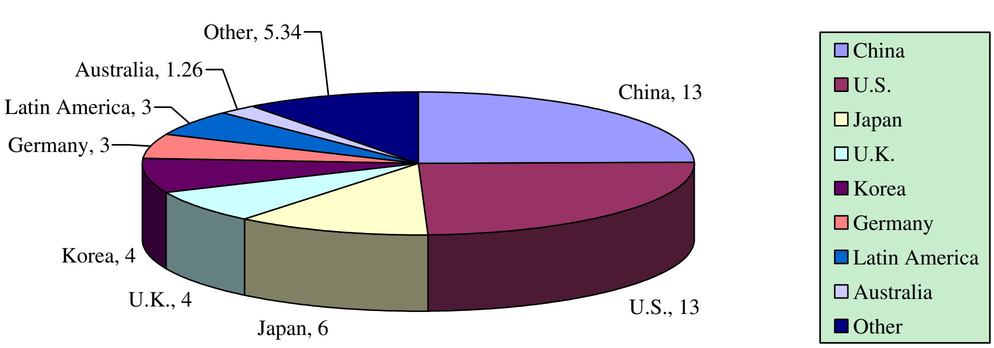

Fig. 1. RFID global market distribution in 2008 (by country, billion US dollars).

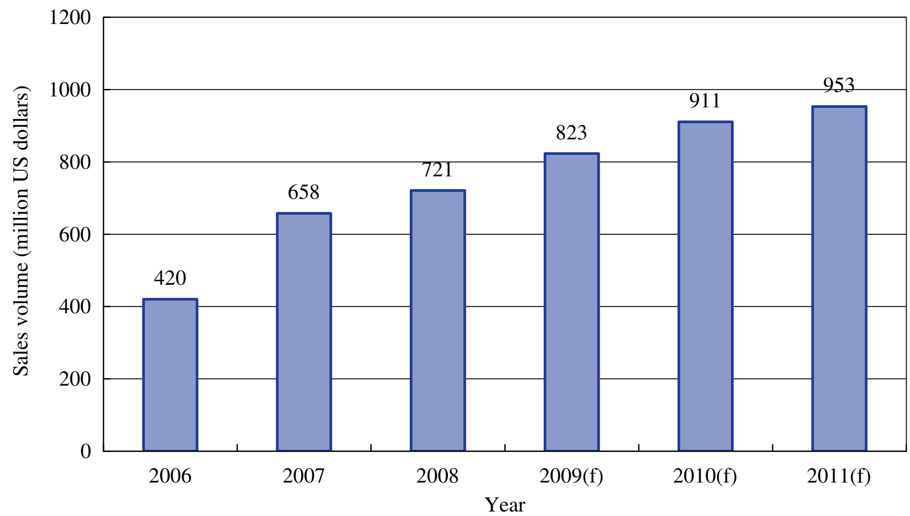

Fig. 2. Scale of China's RFID market (2006–2011). Data source: ICT Country Report, MIC, July 2008.

and key phrase extraction, key phrase correlation measure, patent technology clustering and patent document clustering. Since Hsu used English patent documents, some of the processes are modified to accommodate Chinese language patent analysis.

2.2.1. Data preprocessing and key phrase extraction

Patent document key phrase extraction requires preprocessing the patent documents into a standard format. The standard format is created by removing the spaces between words and phrases. Then, word processing software is used to count the frequencies of words and phrases. An ontology serves as the specification of related concepts used to extract meaningful words and phrases from the patent document. Since the ontology is domain specific, experts must define the keywords and phrases related to the patent concepts. Then, the concept related keywords and phrases of the patent document are extracted for analysis. The frequency of these keywords and phrases are used as input for patent technology clustering.

The RFID ontology tree for this research is a modification of the tree originally defined by Pitzek [23]. Since the RFID patent documents downloaded from SIPO use simplified Chinese characters, the 46 English phrases of the original ontology were translated into Chinese. Fig. 4 shows the ontology and the simplified Chinese character translation for the Chinese language RFID ontology tree.

2.2.2. Key phrase correlation measures

The key phrase extraction generates a list of important phrases from each patent document which is then used to form logical link between ideas and methodologies. Hsu et al.'s [24] algorithm uses four stages for key phrases analysis. First, the patent document is transformed into a key phrases vector by analyzing the frequency of the keywords and phrases. Second, by eliminating redundant phrases, the key phrase frequency vector is derived. Third, the correlation values between key phrases are computed as shown in Formula (1). Finally, the number of different key phrases occurring in the document is used to derive the correlation coefficients as shown in Table 1.

$$R_{ij} = \frac{\sum_{l=1}^{N_D} X_{i,l}X_{j,l} - N_D\bar{X}_i\bar{X}_j}{\sqrt{\left(\sum_{l=1}^{N_D} X_{i,l}^2 - N_D\bar{X}_i^2\right)\left(\sum_{l=1}^{N_D} X_{j,l}^2 - N_D\bar{X}_j^2\right)}}, \tag{1}$$

where N_D is the total number of documents and $X_{i,l}$ is the number of key phrase I occurring in document D_l.

2.2.3. Patent technology clustering

Once the key phrase correlation matrix is derived, it is used for patent technology clustering. The key phrase correlation matrix is the input for the clustering algorithm and represents the technology contained in the patent documents. By applying the key phrases correlation matrix as input, the K-means algorithm generates patent technology clusters. Patent technology clusters provide insight into the relationships between patents.

2.2.4. Patent document clustering

Patent document clustering, unlike technology clustering which clusters technology represented by key phrases, splits many documents into groups according to the similarity between documents. Using the K-means algorithm, the technology clusters which are generated from the correlation matrices are then used as the key variables to cluster patent documents. As shown in Table 2, the matrix is constructed as an input for patent document clustering. There are two major patent classification systems; the International Patent Classification (IPC) and the United States Patent Classification (USPC) system. However, patents with the same classification code may be entirely different. To solve this problem, patent document clustering derives the internal relationship based on the key aspects of the technologies and groups patents that are within the same technology field. In addition to generating the characteristic of each patent document cluster, the frequency of each key phrase (KP) appearing in each patent cluster is calculated as shown in Table 3. KP_n is a representative phrase of the patent cluster TC_M if the F_{nm} is the largest frequency among TC_1–TC_M. For example, if F_{12} is the largest frequency among TC_1–TC_M, then KP_1 is a representative phrase of TC_2; if F_{32} is also the largest frequency among TC_1–TC_M, then KP_3 is also the representative phrase of TC_2. Thus, TC_2 may have several representative phrases, such as KP_1, KP_3, KP_{18}, KP_{23}, and KP_{41}. Thus, the characteristics of cluster TC2 are defined using these KPs.

2.3. Patent technology forecasting

Patents are important indicators that can be used to explore technological trends and development [25–27]. Ernest [26] states that patent applications are easily retrieved and can measure the

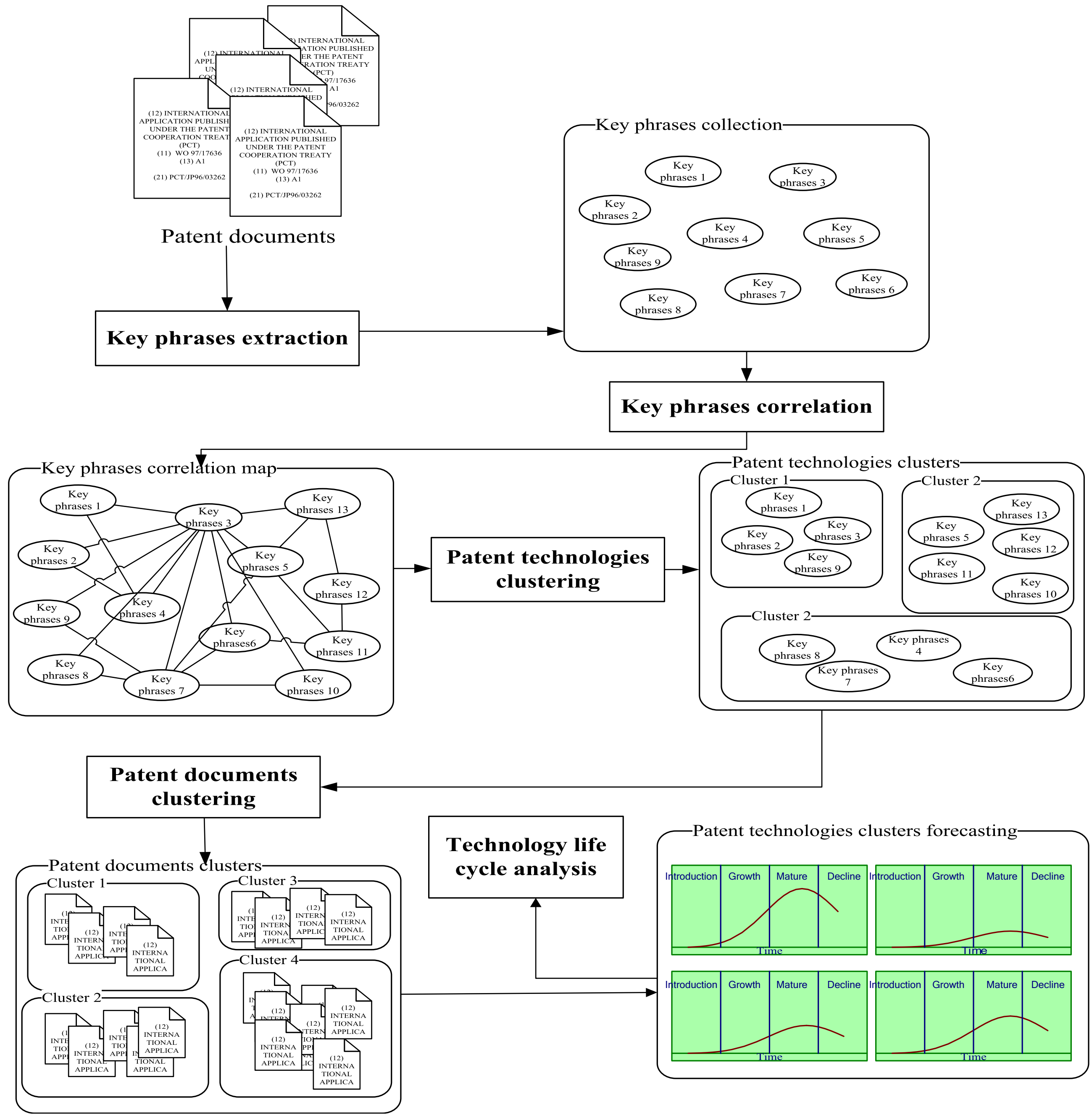

Fig. 3. Patent content analysis process.

impact of R&D activities. Andersen [27] suggests that the accumulations of patents are useful for measuring technology trends and reflect the diffusion of the technology. Therefore, in this research, cumulative patent applications are used for forecasting future RFID technology development trends. Patent application volume reveals the maturity of a new technology and can be viewed as shared knowledge. If the volume of patent applications is growing, then there are many resources creating the technology and the innovation. In such cases the technology may soon reach its peak. On the other hand, if the volume of applications is declining, then the technology may be is in the processes of being substituted by a new technology and thus entering the decline stage of the technology life cycle.

Growth curves are widely used in technology forecasting [28–31]. The most common is the S-curve which is used to model product life cycles. The simple logistic model is a widely used S-curve forecasting model [32–35]. The most important characteristic of the simple logistic model is its symmetry about the point of inflection. Therefore, if the point of inflection of an S-curve has occurred, then it is easy to forecast the remaining trend. In this research, cumulative patent application volume is modeled as an S-curve with a point of inflection. The model for the simple logistic curve is controlled by three coefficients, a, b, and L is expressed as

$$y_t = \frac{L}{1 + ae^{-bt}} \tag{2}$$

where y_t represents the cumulative patent applications at time T, L is the maximum value of y_t, a describes the location of the curve, and b controls the shape of the curve. L, a, and b are computed using a nonlinear least squared estimation method provided by a statistic

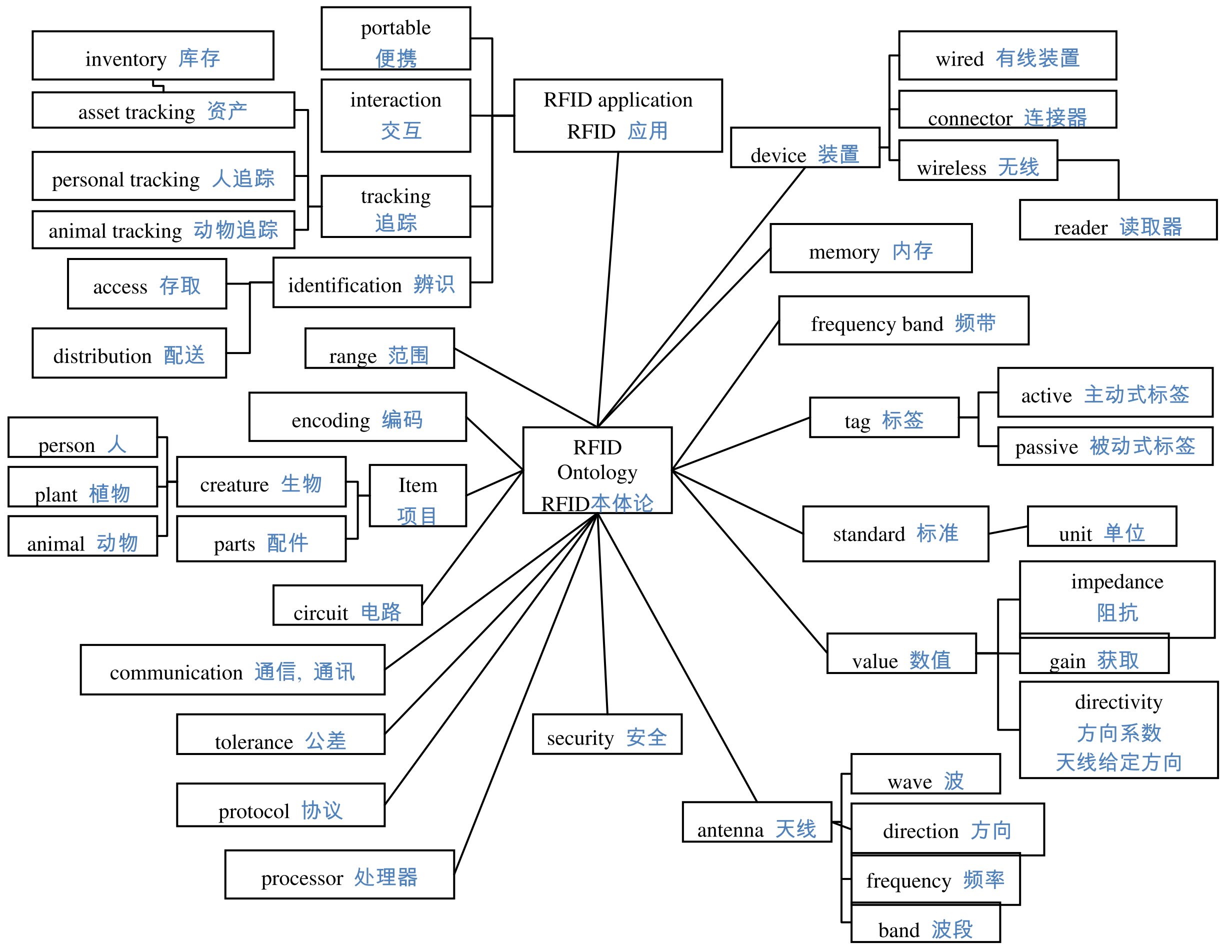

Fig. 4. Pritzek's RFID technology ontology tree with corresponding simplified Chinese characters.

Table 1
Key phrases correlation matrix.

	KP_1	KP_2	KP_3	...	KP_n
KP_1	$R_{1,1}$	$R_{1,2}$	$R_{1,3}$	...	...
KP_2	$R_{2,1}$	$R_{2,2}$	...	...	...
KP_3	$R_{3,1}$	...	...	...	...
...	...	...	...	...	...
...	...	...	...	...	...
KP_n	...	...	...	...	...

Table 2
The matrix of patent documents with M patent clusters.

	$Patent_1$	$Patent_2$	$Patent_3$	...	$Patent_N$
TC_1	N_{11}	N_{12}	N_{13}	...	N_{1N}
TC_2	N_{21}	N_{22}	N_{23}	...	N_{2N}
TC_3	N_{31}	N_{32}	N_{33}	...	N_{3N}
⋮	⋮	⋮	⋮	...	⋮
⋮	⋮	⋮	⋮	...	⋮
TC_M	N_{M1}	N_{M2}	N_{M3}	...	N_{MN}

Notation: $N_{ij} = \sum_{m=1}^{N(KP_i)} KPF_m$, where $N(KP_i)$ is the number of key phrases (belonging to technology cluster i) that are included in patent j and KPF_m is the frequency of the key phrase m (belonging to technology cluster i) of the document j. TC_M, total patent $cluster_M$.

Table 3
The frequency of key phrase in M patent clusters.

	TC_1	TC_2	TC_3	...	TC_M
KP_1	F_{11}	F_{12}	F_{13}	...	F_{1M}
KP_2	F_{21}	F_{22}	F_{23}	...	F_{2M}
KP_3	F_{31}	F_{32}	F_{33}	...	F_{3M}
⋮	⋮	⋮	⋮	...	⋮
⋮	⋮	⋮	⋮	...	⋮
KP_n	F_{n1}	F_{n2}	F_{n3}	...	F_{nM}

software package like SYSTAT. Using this model, one can forecast how many patent applications will be submitted in the future. Once the possible ceiling value of cumulative applications (L) is determined, the stage of the technology life cycle is estimated and time when the saturation of the technology will occur is computed.

2.4. Technology life cycle analysis

Patent activities can be used to interpret the technological stage of an industry. Ernst [26] suggests that the cumulative patent applications for a particular technology over time can be plotted as S-shape curve to represent its technology life cycle. The technology life cycle has four stages including introduction, growth, maturity and saturation [26]. During the introduction stage, there is little growth in the number of patent applications. The growth stage, on the other hand, is characterized by exponential growth. As the patent application rate declines, the mature stage is entered. The saturation stage indicates limited growth with few patent applications.

Andersen [27] used simple logistic models to plot the technology lifecycle and uses different cyclical points to calculate the duration of the four stages of the life cycle. After the upper limit L is estimated using the forecasting model, and then the technology's life cycle stage is determined.

For the simple logistic model, Meyer and Ausubel [31] propose that the range from 10% to 90% of the limit L represents the growth stage. Additionally, Ernest [26] defines the maturity stage beginning from the inflection point, or 50% of the upper limit, for a simple logistic curve. In this paper the 10%, 50%, and 90% of the limit L are used to define the three cyclical points for classifying the four stages of the technology life cycle. Thus, if $y(T)$ represents the cumulative patent applications at time T, L is the maximum value of $y(T)$. Then, $y(T)/L < 10\%$, $10\% \leqq y(T)/L < 50\%$, $50\% \leqq y(T)/L < 90\%$, and $90\% \leqq y(T)/L$, mark the range for technology in introduction, growth, maturity, and saturation stages, respectively.

The early period of each stage may have characteristics similar to the previous stage. Moreover, the growth and maturity stages are important stages with long durations. Thus, the growth stage is partitioned into the early growth stage and the growth stage that together reach 30% of the upper limit; the mature stage is also partitioned with the early maturity and the mature stage reaching 50% of the upper limit.

Liu [36] notes that strategic planning for patent management should account for the technology life cycle. When technology is in the introduction stage, companies should develop and apply related patent technology as a means to strengthen their position in the industry. If the technology is in its growth stage, the plan should include means to modify the core technology and search for new applications. During the maturity stage, technology developers should be clear on the boundaries of intellectual property and evaluate the advantages of forming strategic alliances to trade IP. Finally, if the technology is in the decline stage, new technology will be created to replace the old and signal new opportunities for research and development.

3. China RFID patent analysis

In order to understand the development of RFID technology in China, the patent database maintained by the SIPO [37] was used. The SIPO database covers all patent information filed in China since September, 1985. The SIPO database does not provide a function to search for key phrases among full text patent documents. Patents can only be searched using attributes set by the SIPO database. The search attributes are limited to the patent title, abstract, the application number, the application date, publication number, publication date, international classification, name of the applicant(s), inventor's name, priority, patent cooperation treaty (PCT), grant publication date, attorney and agent, and the address of the applicant. Since the database does not allow a key phrase search among the full text of the Chinese document, the search and analysis is limited to the electronic text contained in the abstract. Thus, the patents abstracts from 1995 to 2008 with either the key phrases of "RFID" or "Radio Frequency Identification" were downloaded and archived for analysis.

3.1. Patent map analysis

A patent map analysis is used to synthesize patent information including patent counts, patent contribution by nation, and inventor analysis. Fig. 5 shows the patent counts and cumulative number of RFID patent applications generated from the SIPO patent database from the earliest filings until the year 2008. As seen in Fig. 5, the trends for RFID related patents have increased sharply since 1995, with a peak in the number of applications reached in

Table 4
The 10 largest corporate RFID patent applications in China.

Applicant(s) name	Country	Number of patent application
IBM	US	42
Fujitsu Ltd.	Japan	36
3 M	US	32
Avery Dennison Corporation	US	27
Sensortronics, Inc.	US	26
Samsung Electronics Co., Ltd.	Korea	25
Hitachi, Ltd.	Japan	25
Beijing Chengyi Chuangke Software Development Co., Ltd.	China	19
ZTE Corporation	China	18
Nokia	Finland	17

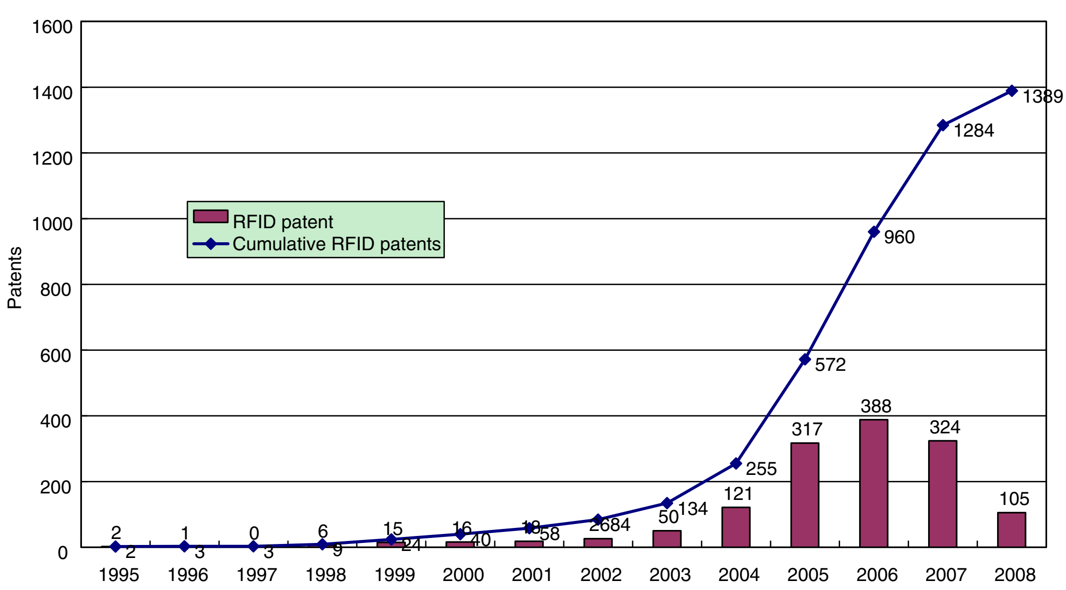

Fig. 5. Number of RFID patent applications per year in SIPO database.

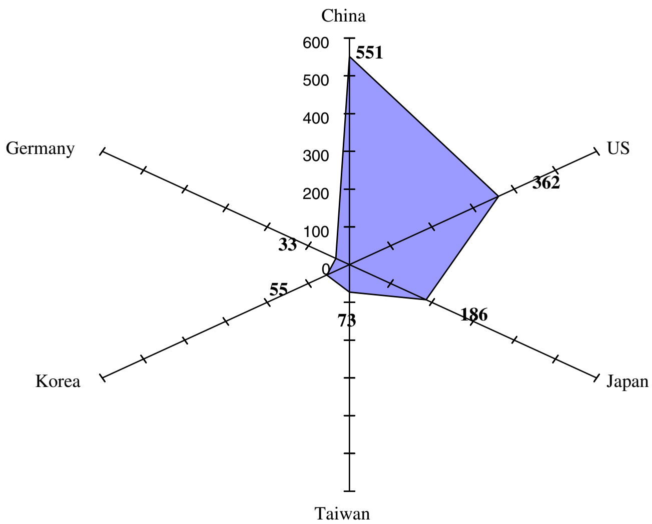

Fig. 6. The six largest applicant's county of origin.

2006. From the year 1995 to the year 2008, a total of 1389 RFID patent applications were added to the SIPO database.

Table 4 shows the top 10 applicants who applied for RFID related patents in China. As shown in Table 4, the applicants include some well known companies like IBM, Fujitsu, 3 M, and Samsung Electronics. Companies that applied for the most patents were from the US and Japan, with only two Chinese companies on the list. However, as shown in Fig. 6, China holds the largest number with 551 RFID patent applications in the SIPO database. Applicants from the US are the second largest group with a total of 362 RFID patents. Applicants from Japan, Taiwan, and Korea are the third, fourth, and fifth largest holders of RFID patent applications and in total hold 186, 73, and 55 entries.

3.2. China RFID patent content clustering

Patent documents downloaded from SIPO with RFID or Radio Frequency Identification appearing in the abstract from 1995 to 2008 were used for patent content clustering. The patent abstracts are written in simplified Chinese so a modified ontology tree with 46 translated key phrases was used to extract keywords and phrases. Since the Chinese translation of five key phrases; wired device (无线装置), passive tag (被动式标签), directivity (方向系数), personal tracking (个人跟踪), and animal tracking (动物追踪) do not appear in any patent abstracts, only 41 key phrases are used for our analysis. After key phrases extraction, the correlation matrix was derived as shown in Table 5.

To better understand how phrase extraction and counting are used to derive the correlation matrix shown in Table 5, one must look at how patent applications are filed. Inventors apply for patents for a single new invention; for example, if a new function for enhancing the capacity of tag is invented, then a patent application can be filed in which the keyword "tag" may appear many times while the keyword "reader" may not appear at all, even though tag and reader cannot work without each other. The key phrase extraction used in this research builds on an earlier research conducted on the RFID patent applications filed with the US Patent and Trademark Office and [43]. The methodology starts with key phrase extraction and then proceeds to counting the frequency of key phrase in the patent document to derive the key phrase correlation matrix.

The key phrase correlation matrix is used for patent technology clustering. In this step, patent technology clusters are computed using the K-means clustering method. The 41 key phrases are clustered into six technology clusters. Fig. 7 presents the six clusters and the key phrases of each cluster.

Patent document clustering is a method that classifies patents based on the similarity of the technologies. Patents with similar technologies fall into the same clusters which enables researchers to readily analyze the characteristics or features of the patent documents within the cluster. By comparing the frequency of each key phrase appearing in the patent document cluster, the representative phrases of each document clusters can be generated. Different clusters are named based on each clusters' representative phrases to give the audience a general idea about the cluster. However, when discussing the development of a cluster, each element in the cluster should be clearly analyzed individually. As shown in Table 6, six clusters are classified from the patent documents and the representative phrases of each cluster are shown in Table 6.

The meaning of key phrases in Fig. 7 is different from that of in Table 6. The key phrases in Fig. 7 are clustered from the correlation matrix and are the results of the technology cluster. The key phrases in the same technology cluster have close relationships and are of similar concepts. The representative phrases in Table 6 are used to explore the characteristics and features of the document clusters by comparing the frequency of the phrases.

3.3. Technology forecasting and technology life cycle analysis

The clustering results are then used to forecast the future trends of the clusters. The growth curves of the six clusters are depicted in Fig. 8. Using the simple logistic model, the trajectory of the Chinese RFID patents and the maximum cumulative RFID patent applications (upper limit) are estimated as shown in Appendix 1. The data are then used to determine the stage of cluster's technology life cycle as shown in Table 7.

3.4. China RFID patent document clustering results

Using the clustering technique described earlier, the data was further analyzed. The first cluster, RFID concepts and applications, contains the fundamental RFID technologies, including the concepts of developing a tag and the interaction system. Some basic functions of RFID, such as security and distribution are also

Table 5
Key phrase correlation matrix (partial).

	Device	Connector	Wireless	Reader	Memory	Tag	Active	Standard
Device	1.0000	−0.0125	0.0175	−0.0172	0.0284	−0.0465	−0.0161	−0.0104
Connector	−0.0125	1.0000	−0.0093	0.0202	−0.0053	0.0136	−0.0021	−0.0083
Wireless	0.0175	−0.0093	1.0000	0.0036	−0.0080	−0.0058	0.0049	0.0037
Reader	−0.0172	0.0202	0.0036	1.0000	−0.0237	0.1384	0.0066	0.0141
Memory	0.0284	−0.0053	−0.0080	−0.0237	1.0000	0.0273	−0.0033	0.0074
Tag	−0.0465	0.0136	−0.0058	0.1384	0.0273	1.0000	0.0764	−0.0255
Active	−0.0161	−0.0021	0.0049	0.0066	−0.0033	0.0764	1.0000	−0.0053
Standard	−0.0104	−0.0083	0.0037	0.0141	0.0074	−0.0255	−0.0053	1.0000

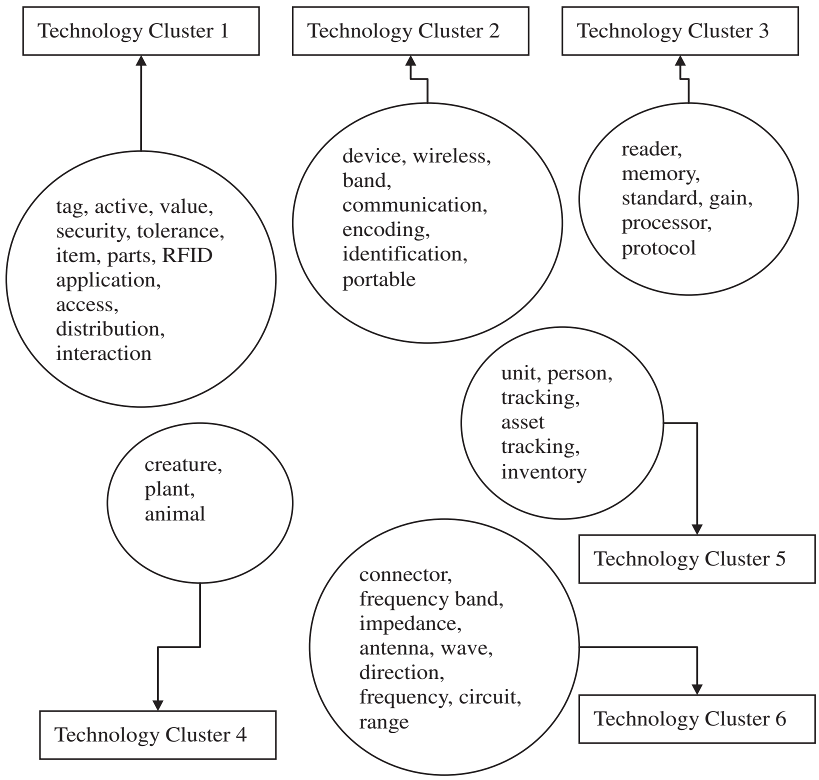

Fig. 7. Technology clusters for RFID.

Table 6
The patent document clustering result.

Clusters number	Cluster features	Representative phrases	The number of patents in the cluster
1	RFID concepts and application	Tag, security, interaction, item, distribution, active, value, access, tolerance	217
2	Wireless communication device	Device, wireless, communication, identification, portable, band, parts	134
3	RFID architecture	Reader, protocol, processor, standard	73
4	Frequency band and wave	Frequency band, wave	54
5	RFID tracking implementation	RFID application, tracking, asset tracking, inventory, creature, person, animal, memory, unit, gain, encoding, plant	686
6	RFID transmission apparatus	Antenna, circuit, connector, direction, frequency, impedance, range	225

included in this cluster. The patents in this cluster provide innovations for providing improvements such as the modification to RFID tags and security system to increase the safety in using RFID tags. The analysis of the applicants' original country shows that the most patent applicants in this cluster are from China (98), the second largest country is the US (61) and the third is Japan (22) (See Appendix 2). One purpose of this research is to determine if there are RFID technology gaps that can be exploited for further R&D. From the technology life cycle analysis (Table 7), the first cluster appears to be in the maturity stage and the number of patent applications is forecasted to reach its upper limit (279) in 2018.

The second cluster, wireless communication devices, introduces techniques for tag identification and includes RFID wireless transmission technologies. Communication devices are the main focus of this cluster and many patents describe the wireless signal transmission technologies, and the communication of different kinds of messages. For example, there is a patent in this cluster which utilizes an RFID tag in an IC card to automatically send messages to other electronic devices. The dominant applicant countries in the second cluster are from China (50), Taiwan (24), and Japan (19). The US holds fourth place with only 18 patents. The life cycle analysis shows the second cluster to be in the saturation stage with a predicted 90% share of upper limit to be reached in the year 2013. This cluster is the only cluster in the saturation stage.

Cluster number 3, RFID architecture, contains key phrases like "reader", "protocol", "processor" and "standard" and these terms describe the essential architecture of RFID. The patents in this cluster focus on how to improve the functions of RFID readers or protocols and increase the efficiency of RFID operations. For example, a patent in this cluster describes a method and protocol to communicate between different RFID readers and simultaneously transmit data. The ability to strengthen the processors for RFID readers is also mentioned in this cluster. The largest group of applicant is from China (24) followed by groups of applicants from the US (22) and Japan (6). As shown in Table 7, the current share of RFID patent applications is at 78%, which means this cluster has entered the mature stage and will reach an upper limit (90 applications) in 2016.

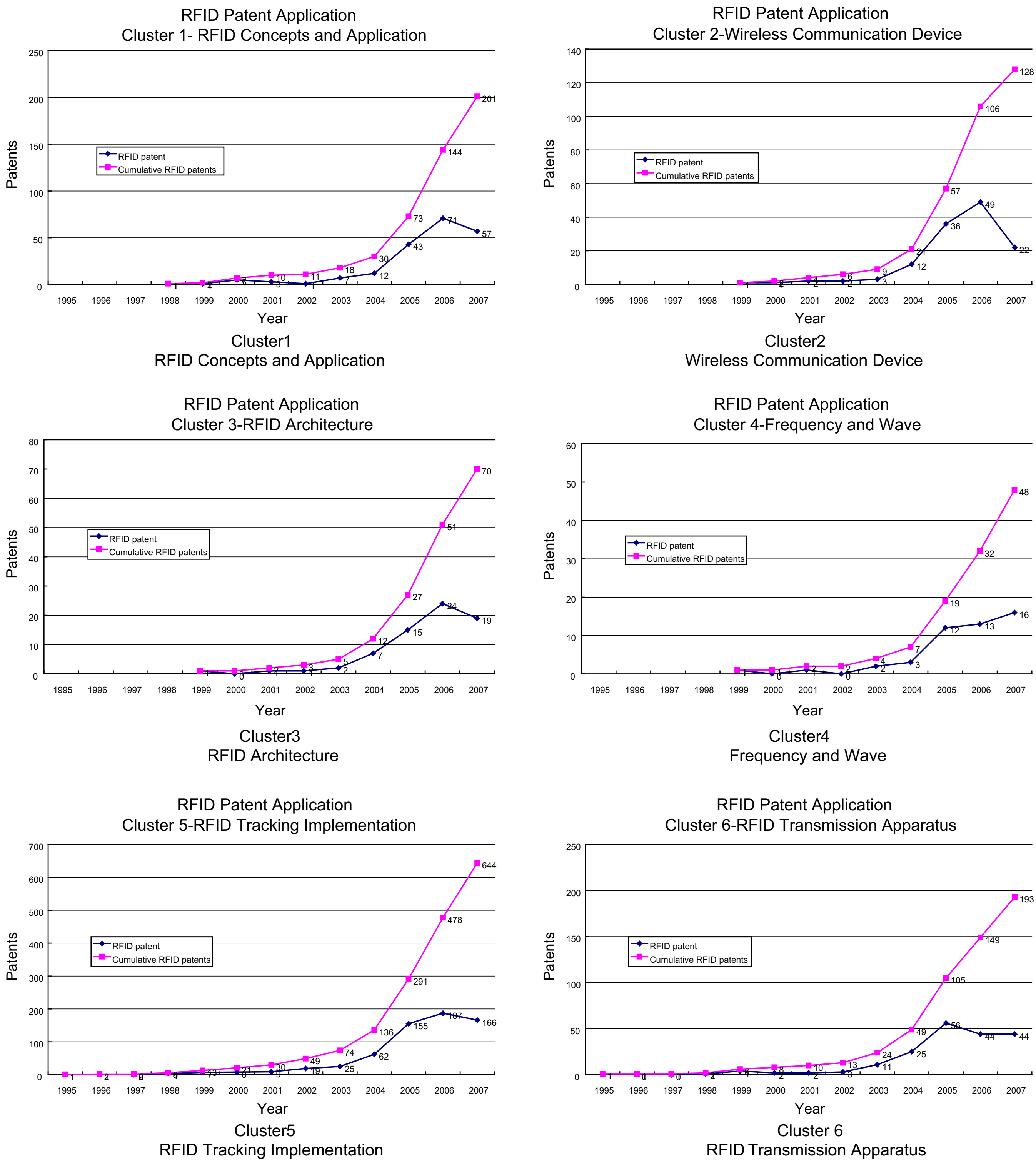

Fig. 8. China RFID patents application and cumulative patent number.

The fourth cluster contains patents relating to frequency bands and waves. Frequency bands and waves are the means by which RFID systems transmit data. Different waveforms use different transmission methods and carry different amounts of data with different efficiencies. Therefore, methods to improve wave patterns are a crucial R&D direction. Noting that this cluster has the fewest patent applications and a continuing growth rate shown in Fig. 8, there is good potential for the development of related technology. As shown in Table 7, this cluster has only reached 66% of its upper limit and the life cycle is in the early part of the mature stage. Therefore, inventors and investors should analyze potential opportunities in this cluster. The largest group of patent holders in this cluster are from China (25), followed by the US (13), and Japan (12).

The fifth cluster represents the implementation and applications of RFID related technologies used for tracking. There are more

Table 7
The forecasting results.

	Patent applications (1995–2007)[a]	Estimated maximum patent applications	Year of upper limit	Share of upper limit (%)	Stage of technology life cycle
Cluster 1	201	279	2018	72.04	Mature
Cluster 2	128	142	2013	90.14	Saturated
Cluster 3	70	90	2016	77.78	Mature
Cluster 4	48	73	2018	65.75	Early maturity
Cluster 5	644	927	2021	69.47	Mature
Cluster 6	193	240	2018	80.42	Mature
Total	1284	1734	2020	74.05	Mature

* Since SIPO only published the patent applications applied before August, 31, 2008 when retrieving; only applications from 1995 to 2007 are used for forecasting.

patents in this cluster (686) than any other cluster. The technologies developed within this cluster contain technologies needed in monitoring and tracking of inventories, people, and animal. The patented technologies in this cluster define how RFID technology can be implemented in the public transportation system, mobile phones, community security systems, and animal tracking systems. This cluster includes patents from the earliest application period (i.e. 1995), is in the mature stage, and is forecasted to reach its upper limit in 2021 (Table 7). Applicants from China have submitted the most patent to this cluster (289), followed by the US with 192 applications.

Finally, cluster number 6, RFID transmission apparatus, defines the framework and architecture for RFID transmission apparatus and systems. Most patents in this cluster are related to the antenna, circuits and connectors which improve the functions of RFID. Some device innovations for data transmission and the activation range are introduced in this cluster. As shown in Table 7, the sixth cluster has entered the mature stage of the technology life cycle with 80% share of its upper limit. This cluster is predicted to reach saturation in the year 2018. Once again the group of patent holders from China is the largest with 551 applications, the US with 362 applications, and Japan with 186 patent applications.

4. Discussion

There are many research papers and reports that analyze patents to discuss the development of RFID industry [38–43] and most conclude that there is still more opportunities for technology development. However, the research does not describe the specific areas that have the greatest R&D potential. There are many different subareas and technologies within an industry. For example, the RFID industry can be classified as RFID architectures, RFID devices, RFID applications, and different subareas fall into different developmental stages. If researchers analyze patent data from a macro level and view the information by using descriptive statistical analysis such as patent counts, patent analysis by nations or inventor analysis, the subareas that should be targeted for development cannot be determined. In this research, the Chinese RFID patent applications are analyzed using the K-means algorithm to cluster patent documents. Six clusters are derived and each cluster is studied using a forecasting model to determine developmental stage and trends.

Based on the forecasting model used in this research and given the rate of applications filed in China, it appears that the China RFID patent applications will reach an upper limit of 1734 in the year 2020. Although there will likely be another 10 years of growth and innovation, each subarea does not have the same potential for development.

This research, along with previous research [36], suggests that analyzing patent data could reveal the technology life cycle which then can be used to direct a patent management strategy. For the RFID technology, the analysis of patents suggests that, for manufacturers in RFID frequency and waves subarea, the most promising area of development is in modifying the core technology and searching for more applications. The manufacturers in RFID wireless communication devices subarea should start to reduce any further investment in this area and start licensing or selling their old patents while shifting their R&D focus toward creating new technologies which will in time replace the old technology. As for the RFID manufacturers in other four subareas, since they are in the maturity stage, patent applicants should avoid invading other's patent intellectual property and innovators should seek the cooperation of the other applicants (i.e. formation of alliances).

The results of this study show that RFID wireless communication devices have entered the saturation stage and the technology in this cluster is mature with little room for development. Four clusters: RFID concepts and applications, RFID architecture, RFID tracking implementation, and RFID transmission apparatus, have also entered the maturity stage. One clusters, RFID frequency and waves is still in the early growth stage with the most potential for further development. The RFID operating frequencies are generally organized into four main frequency bands including low frequency (LF), high frequency (HF), ultra high frequency (UHF), and microwave [44]. Higher frequencies cover longer ranges and have higher data transfer rates and offer better security. RFID can be further applied in tracking and managing living things (e.g., medical care) and there is a growing need for RFID systems that can better utilize high frequency bands for communication.

5. Conclusions

The R&D and innovation strategies for different technology life cycle are different. In mature stage, the basic characteristic is a peak growth and the competition is fiercer and the development of the technologies is mature, therefore, a customer-orientated R&D strategy would focus on either improving or designing a RFID product, application or technology which can attract more or new customers. For instance, researchers can use customer-centric market research method like quality function deployment (QFD) to innovate for desirable new applications. Alternatively, the manufacturers focus can shift toward standardizing their products by improving their production process to create robust designs which will improve product reliability. In maturity stage, the existing manufacturers own many patents related to the products, thus a patent search is strongly recommended before any new functions or designs are added to the products or technology.

As for saturation stage, its characteristic is that the growth begins to slow down and decline. The market is stable and strong brands appear. Some new products or technologies will replace the existing ones, so the marketing objective for the companies in the subarea of wireless communication device is to reduce expenditure to remain profitable. To reduce expenditure, companies need to start phasing out the unprofitable products to lower the operation cost. At this stage, a price-orientated R&D strategy is appropriate. Since there will be new substitutions for this product or technology, the leading manufacturers need to sell their stock items with lower price. For those producers with no strong brand, they can only provide additional functions with much lower price to survive in the market place. Thus, the function combinations or alternative materials or technologies are useful innovations strategy in maturity stage.

This research introduce a methodology which combine patent content clustering and technology life cycle forecasting to find a niche space of an industry. Since China is currently one of the world's largest manufacturers and consumers of RFID applications, the study focus was RFID development in China. The results suggest that the most promising niche into invest in for firms in China appears to be in the improvement of the RFID frequencies and waves which will yield more reliable RFID systems and applications. The future research can apply the same methodology to study different patent databases, such databases in United States Patent and Trademark Office (USPTO) and World Intellectual Property Organization (WIPO) to analyze the RFID industry more completely.

Appendix 1. Estimated parameters using the simple logistic model

Cluster features	L	a	b	R^2
RFID concepts and applications	278.58	6533.71	0.98	0.997
Wireless communication devices	141.51	17466.49	1.35	0.998
RFID architecture	90.36	3119.98	1.03	0.999
Frequency bands and waves	72.61	1548.90	0.89	0.997
RFID tracking and implementation	926.88	17703.89	0.82	0.998
RFID transmission apparatus	240.40	21560.08	0.88	0.997
Total RFID industry	1734.04	37566.03	0.89	0.998

Appendix 2. Patent counts of applicants' country of origin and application percentage

Country	Patent	Application percentage
Cluster 1		
China	98	45.16
US	61	28.11
Japan	22	10.14
Korea	16	7.37
Taiwan	5	2.30
Cluster 2		
China	50	37.31
Taiwan	24	17.91
Japan	19	14.18
US	18	13.43
Finland	6	4.48
Cluster 3		
China	24	32.88
US	22	30.14
Japan	6	8.22
Korea	6	8.22
Finland	4	5.48

Appendix 2 (*continued*)

Country	Patent	Application percentage
Cluster 4		
China	25	46.30
US	13	24.07
Japan	12	22.22
Taiwan	1	1.85
Finland	1	1.85
Cluster 5		
China	289	42.13
US	192	27.99
Japan	53	7.73
Taiwan	35	5.10
Germany	25	3.64
Cluster 6		
Japan	74	32.89
China	65	28.89
US	56	24.89
Taiwan	5	2.22
Korea	5	2.22

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