Technology Foresight of Remote Sensing Based on Patent Analysis

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***Abstract*—In this paper, we propose a new method of patent analysis for technology foresight by using patent co-citation clustering, technology life cycle theory, and Logistic model and apply it in the field of remote sensing. Firstly, the co-citation clustering method is used to analyze patents about remote sensing, which can visually show the distribution of patents and select the core patents groups with strong co-citation relationship that represents the technical groups in this field. Through the analysis of the clusters, 8 main technical directions are obtained. Then, we search patents again for the main technical directions, and use the technology life cycle theory and Logistic model to analyze and forecast the future development trend of technology. According to the analysis, the remote sensing technologies are found that have passed through a long period of germination. Among them, "remote sensing image processing technology in later period" is in the growing stage, which is being developed rapidly. The technologies related to "remote sensing imaging equipment" and "remote sensing image initial processing" are becoming mature. Based on these analyses, some suggestions on the future development, application direction and industrial prospects of remote sensing technologies are advocated.**

Keywords—Remote sensing; Patent co-citation analysis; Technology life cycle; Logistic model; Technology Foresight.

I. INTRODUCTION

Remote sensing technology is a comprehensive detecting technology, which uses modern optics and electronics detection apparatus to detect and record the characteristics of the electromagnetic wave of the remote target without contacting. By analyzing and interpreting the characteristics, properties and changing pattern of the target are revealed. The basic principle is that the characteristics of electromagnetic wave of different objects are different, and by detecting the reflection of electromagnetic wave and the electromagnetic wave emitted by the object, the information of the object is extracted, which can help to identify the remote objects [1].

Remote sensing technology has the characteristics of large detection range, high speed of data acquisition, short cycle and is rarely subject to ground conditions, which can be widely used in military and civilian areas, such as military reconnaissance, military mapping, marine monitoring, meteorological observation, vegetation classification, land utilization planning, etc. The application of remote sensing technology to a certain field can improve the information decision support ability and the competitiveness to get more benefits [2]. At present, with the rapid development of aviation, space and unmanned aerial vehicle (UAV) technology, remote sensing technology has entered the commercial application stage, and has great potentials for development and application. Therefore, it is very important to carry out the remote sensing technology foresight to make clear the technology development trend. It will be helpful to realize the new breakthrough of remote sensing technology, and gradually take the advantageous position in the development of industrial technology. It will have a profound impact on improving the level of social information, promoting sustainable economic development, improving people's living quality, and enhancing public safety and national defense [3].

The importance of technology foresight is gradually realized, but it's a very difficult work because that technological development is a complicated process, which is influenced by many factors, such as science, economy, society and so on. Technology foresight requires a comprehensive set of methods. At present, the activities of technology foresight around the world mainly adopts the methods based on experts' opinions such as Delphi and workshops. Some other methods are Scenario analysis and Technology Roadmap. The objective and quantitative research methods for technology foresight are quite few. In some studies, the literature bibliometrics is introduced, which is a quantitative tool of technology foresight [4]. In this paper, we propose a method of patent analysis to make technology foresight of remote sensing. This method is based on the patent data and can use them for efficient clustering and intuitive display. It can be used as a new quantitative tool in the specific aspects of technology foresight. It can play the role of reference, support and verification in technology foresight, and improve the scientificalness and objectivity of the research.

In this paper, a study on the patents of remote sensing field is carried out, in which the main technical directions and the patent life cycle in the remote sensing field are analyzed by the method of co-citation clustering and Logistic

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model. In Section 2, we present the research methods in the study, including patent co-citation analysis, LinLog visualization clustering method, and S-curve Technology Life Cycle Forecasting method, and introduce the database we use. In the Section 3, we carry out an empirical study in the field of remote sensing, which prove the validity of the method. In the Section 4, we draw some conclusions and look forward to the future works.

II. RESEARCH METHODS & DATA SOURCE

A. Patent Co-citation Clustering Analysis

Co-citation is that two or more patents are all cited by the same patent. Generally, patents with co-citation relationship have certain correlation in content. The more frequently patents are co-cited; the more similar they are [5]. However, it is not comprehensive to measure the related strength only with the total number of co-citations. When basic patents both have large number of citations, they are more likely to be co-cited, which can't mean they're more similar. In this paper, (1) is adopted[6] to express the related strength of patent I and patent J—Cij:

$$Cij = \frac{Nij}{\sqrt{Ni} \cdot \sqrt{Nj}} . \quad (1)$$

In (1), N_{ij} represents the number of co-citations of patent I and patent J; N_i and N_j respectively represent the number of citations of patent I and patent J.

After the calculation of the relationship between patents, we cluster patents according to their related strength. Some scholars have taken some research on document co-citation clustering. Reference [7] introduced the citation contexts in document clustering, which can increase the effectiveness of the bag-of-words representation. Reference [8] used co-citation cluster analysis to propose a knowledge-transfer analysis model. Reference [9] used Girvan-Newman algorithm in the patent co-citation clustering to identify the main technologies of Apple Corp.

This paper uses the LinLog visualization clustering method to cluster the patents, and explore the main technical directions of the remote sensing field. LinLog model, which is proposed by Noack Andreas in 2007, is a kind of force-directed algorithm based on the energy function, which can show a good clustering effect to a large number of nodes [10]. This algorithm applies the idea of mechanics to the layout of the graph, which assumes that a repulsion force exists between any two nodes, and a pulling force exists between the nodes which are related. The starting positions of nodes are random, and then each node can adjust its position according to the repulsion force and pulling force from the other nodes, until the pulling force and the repulsion force reach equilibrium [11]. Obviously, any two nodes will not overlap due to the existing repulsion forces, and the related nodes will be close to each other under the pulling force. Each cluster represents a group of patents with strong co-citation relationships, which have strong correlation and represent a technical direction in this field.

B. S-curve Technology Forecasting and Logistic Model

Verhulst proposed the growth model in 1938[12]. According to this model(Figure1), the growth process of the technology is similar to that of human, and it can be experienced in the germination stage, growing stage, mature stage and decline stage. In the germination stage, the growth is slow; the growing stage is a period of rapid growth; after growing stage, it enters the mature stage, in which the development is slow; finally reaches the limit and enters the decline stage. The fitting curve of the process is called the growth curve, and because of its S shape, it is called S-curve [13].

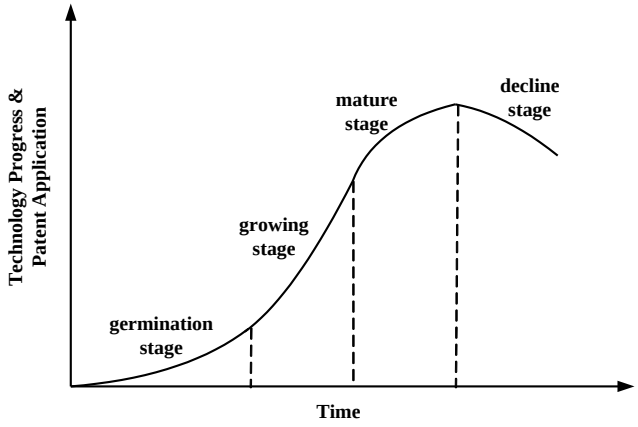

Figure 1. Technology Growth S-curve

The equation of the S curve is the Logistic model [14], as the Eq. (2) shows:

$$y = \frac{l}{1 + \alpha e^{-\beta T}} . \quad (2)$$

In the equation, y is the number of patent accumulation; α is the slope of the S curve, which is the growth rate of the S curve; β is the time point of the turning point (midpoint) in the growth curve; l is the saturation level of growth, that is, the saturation point (saturation); [l×10%, l×90%] is the time required for the growth and maturity.

The meaning of three parameters are as follows: (1)*saturation*: the maximum utility value generated by using a technique, that is, the highest value of the number of patent accumulation; (2)*growth time*: the time needed for producing the 10%~90% of the maximum utility value of a technology, i.e., the time needed for the period of growth and maturity; (3)*midpoint*: anti curve point of S-curve, that is, the 0 value point for two differential. These three parameters can be automatically calculated by the system. It is necessary to point out that the S curve model is a theoretical model of technology development, which does not take into account the influence of external factors that may bring changes to technological development. If there are some new emerging disruptive technologies or other changing factors, using S-curve to estimate the technology life cycle may cause some

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errors. In this paper, we only roughly estimate the technology life cycle, and the results also need to be corrected by the experts in technical field.

C. Data Source

In this study, the number of patent accumulation in the field of remote sensing around the world represents the development level of technology. The patents about remote sensing are retrieved by the patent retrieval tool—TI (Thomson innovation), which has the world's largest patent database, including patents from the United States, European countries, Japan, South Korea and so on, also containing the DOCdb (INPADOC) database and the Derwent World Patents Index (DWPI) database [15]. We use all the patents about remote sensing which were published before October 15, 2015 as the data source to research the technology development status of remote sensing industry.

III. TECHNOLOGY FORESIGHT OF REMOTE SENSING

Based on about 5027 patents related to remote sensing technology, we use the patent co-citation clustering method to cluster the patents, and get the current main technical directions of remote sensing. Then, we retrieve patents for the selected technical directions again, use the Logistic model to carry out the technology life cycle analysis and forecast the development trend of the remote sensing technology in the future.

A. Main Technical Directions of remote sensing

Get the first 30% of the highest cited patents in each year for co-citation clustering and visualization. Figure 2 is the patent co-citation clustering map. In this map, each cluster of nodes represents a patents group in which every patent is related to each other. It can represent a certain technical direction or a theme in the field. The number of nodes in a cluster represents the number of core patents contained in the technical direction. Also, it can represent people's attention to the technical direction in some way. Node's size represents patent's cited frequency; the greater the node is the higher the cited frequency is. Some different clusters may have similar topics, so we need to understand each cluster by manual analysis and summarize the main technical directions. Through the analysis of patents in the all clusters, we can draw the technical direction of each patents group (marked in the picture).

According to the patent co-citation clustering, in this paper 8 main technical directions in the remote sensing field from the perspective of patent application are summarized as follows: (1) "Fusion method of remote sensing image"; (2) "registration and correlation method of remote sensing

Figure 2. Patent Co-citation Clustering Map in the Field of Remote Sensing.

image"; (3) "object recognition and feature extraction method of remote sensing image"; (4) "changes detection method of remote sensing image"; (5) "remote sensing temperature measurement, inversion method"; (6) "imaging spectrometer & spectral imaging devices"; (7) "synthetic aperture radar/SAR"; (8) "Microwave remote sensor".

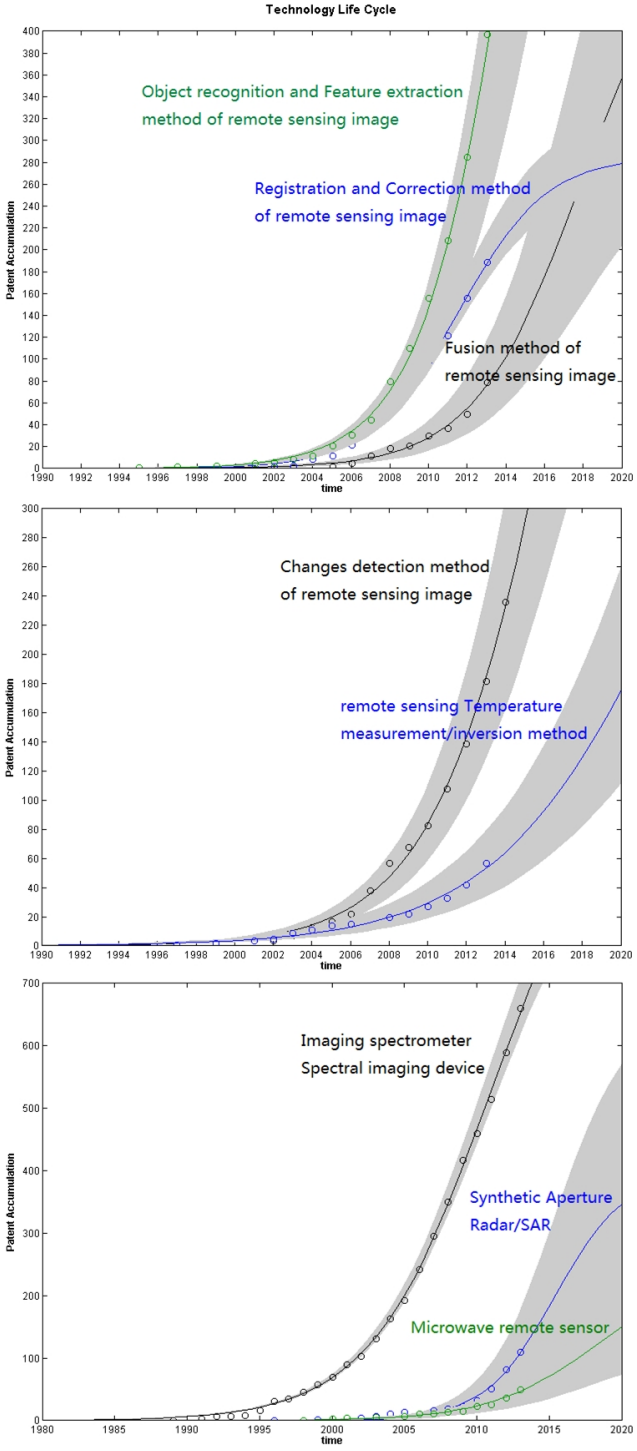

Figure 3. Logistic model of each technical direction.

B. *Results of Technical Life Cycle Analysis*

According to the Logistic model, we analyze the number of patent applications in the field of remote sensing. The growth curves of 8 technical directions are shown in Figure 3, which are fitted out by Loglet Lab2 [16]. The relevant parameters of Logistic Model are shown in Table I.

Taking "Fusion method of remote sensing image" as an example, the S curve and its implication are analyzed. From the beginning of 2003, there have been patents applications about remote sensing image fusion method. The system estimates that the growing stage needs 12 years, and the turning point will occur in 2018. Patent applications continued to grow until 2012, this period is the germination stage; then the technology goes into the growing stage until 2018, this period presents a trend of accelerated growth; from 2019 to 2025, patents about remote sensing image fusion show slow growth trend, but the total amount is still increasing, this period is mature stage; after this, patent growth will fall into recession, and the number of patents shows a decreasing trend.

TABLE I. PARAMETERS OF LOGISTIC MODEL

Code of Tech. Direction	Saturation	Midpoint	Growth Time
1	527.142	2017.933	12.135
2	285.587	2011.539	9.992
3	1388.207	2015.499	11.31
4	885.418	2017.381	14.346
5	541.418	2023.469	20.721
6	1036.318	2010.829	17.966
7	400.924	2015.443	10.743
8	248.668	2018.451	16.41

According to the method above, the S-curves of the 8 main technical directions are analyzed, and the distribution of their technical life cycle is obtained, as shown in Table Ⅱ. As can be seen in Table 1, from the perspective of patent, the 8 main technical directions in remote sensing have been through the germination stage. Among them, the technical directions in the growing stage are: (1) "Fusion method of remote sensing image"; (3) "object recognition and feature extraction method of remote sensing image"; (4) "changes detection method of remote sensing image"; (5) "remote sensing temperature measurement, inversion method"; (8) "Microwave remote sensor"; the technical directions in the mature stage are: (2) "registration and correlation method of remote sensing image"; (6) "imaging spectrometer & spectral imaging devices"; (7) "synthetic aperture radar/SAR".

It can be seen from the above data that remote sensing technologies have passed the stage of basic research, and most of the key technologies are in the stage of rapid growth. Technologies about "remote sensing imaging equipment" and "remote sensing image initial processing" are becoming mature. At present and in the near future, the key point of remote sensing technology development is the object-oriented, the demand-oriented, the high speed, efficient and automatic remote sensing image processing technology in later perid.

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TABLE II. ESTIMATED TIME OF TECHNOLOGY LIFE CYCLE

Code of Tech. Direction	Germination stage	Growing stage	Mature stage	Decline stage
1	2003-2011	2012-2018	2019-2025	2026-
2	2001-2006	2007-2012	2013-2018	2019-
3	1995-2009	2010-2016	2017-2023	2023-
4	2002-2009	2010-2017	2018-2025	2026-
5	1997-2012	2013-2023	2024-2034	2035-
6	1989-2001	2002-2011	2012-2021	2022-
7	1996-2009	2010-2015	2016-2021	2022-
8	1998-2009	2010-2018	2019-2027	2028-

IV. CONCLUSION AND FUTURE WORK.

A. Conclusions

In this paper, we cluster more than 5000 patents related to remote sensing with the patent co-citation clustering method, and summary 8 main technical directions in this field as follows: (1) "Fusion method of remote sensing image"; (2) "registration and correlation method of remote sensing image"; (3) "object recognition and feature extraction method of remote sensing image"; (4) "changes detection method of remote sensing image"; (5) "remote sensing temperature measurement, inversion method"; (6) "imaging spectrometer & spectral imaging devices"; (7) "synthetic aperture radar/SAR"; (8) "Microwave remote sensor". Then, we retrieve patents for the selected technical directions again and use the Logistic model to carry out the technology life cycle analysis. Based on the analysis result, the distribution of their technical life cycle is obtained. It is cleared that 3 technical directions related to "remote sensing imaging equipment" and "remote sensing image initial processing" are becoming mature and other 5 directions related to “remote sensing image processing technology in later period” are in the stage of rapid growth.

With the results of technology life cycle analysis, we analyze the patents’ contents of each group deeply and make the following conclusions:

(1) Remote sensing technologies have passed the stage of basic research. Technologies related to "remote sensing imaging equipment" and "remote sensing image initial processing" are becoming mature. At present and in the near future, the key point of remote sensing technology development is the object-oriented, the demand-oriented, the high speed, efficient and automatic remote sensing image processing technology in later period.

(2) In early times, remote sensing technology was applied to the static object recognition, such as forest vegetation cover, coastline, airports, roads, bridges and so on. With the remote sensing technology being developed to “high temporal resolution”, “high spatial resolution”, and “wide scale”, the application of remote sensing is going towards disaster monitoring, sea state monitoring, ship target detecting, digital city, and so on.

(3) Patent applications related to remote sensing are in a rapid growth trend. The main technical directions of remote sensing are also in the growing stage, and nearly half of them are tending to be mature. Remote sensing patent applicants from the early military and scientific research institutions gradually extended to individuals and business organizations. The application range of remote sensing is from the early military, government to civilian, commercial. This shows that it is a good opportunity for the business development of remote sensing technology and the promotion of its industrialization. Remote sensing technology will have broad prospects for industrial development.

B. Future Works

(1) Extending data sources of technology foresight

In this paper, patent database is used as the data source of the technology foresight, which can include most of the research results from practical technical inventions around the world. However, there may be some time lags because it usually needs 2-3 years for a patent from the application to the general public. And if the patent search strategy is not complete, it will cause the research results to be not comprehensive. In addition to patents, there are also other kinds of technical information that are valuable and significant to the study on the future development trend of science and technology, such as literatures, business news, reports from the authoritative research institutions. In the future, we can make technology foresight using the combination of multi-source data, such as combining patents and scientific literature. Then we can use data mining to find the similarities and differences in the path of development from different perspectives, and search for the future potential technology opportunities.

(2) Combining the clustering analysis and text mining

This paper uses LinLog algorithm to realize the patent co-citation clustering analysis and visualization, but the analysis of clusters’ contents is hand finished, resulting in a larger workload. In the future, the text mining method can be introduced in the analysis of the clustering results, which can automatically show the technical direction of each cluster.

(3) Combining patent analysis and experts’ opinions

In most of the current technology foresight activities, patent analysis and experts’ opinions can not effectively combine. In the future works, we can carry out some expert investigations before the patent analysis, so that we are able to conduct a patent analysis or other quantitative analysis on issues that the experts are more concerned about. On the other hand, due to the development of science and technology involves many other issues, such as issues about economy and society, it is very complicated. The conclusions from patent analysis also need to be submitted to the experts for further analysis and study, in order to play the better role for technology foresight.

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