Analysis of technology evolution in 3D printing industry segmentation based on dynamic patent network

Shugang Li¹, Lingling Zheng*¹
¹School of Management, Shanghai University, Shanghai, 200444, PR China
* Corresponding author’s e-mail: 15751003489@163.com

Abstract. Technological evolution analysis is an important way to analyse the development of industry and the trend of technological change, which has important guiding significance for the government and enterprises to make the technological strategies. The patent network method can effectively identify the key technology of the industry, but it has some shortcomings in judging the technology group and other details. Therefore, this study proposes an identification model of the technology theme clustering based on IPC, which is helpful to fully reveal the evolution characteristics of the industry. This study further introduces the time dimension to build a patent network with multiple attribute nodes based on the patent of the 3D printing industry.

1. Introduction
Technology is playing an important role in maintaining the country's central position on the world political stage. In order to consolidate its core position and improve the competition strength, the enterprise must rely on the technology with development potential and economic benefits. The core of the technology is innovation, which is the key point of strategy plan. Based on the technology monitoring analysis, the development path of technology can be effectively analysed and predicted the development trend of technology, so as to obtain technological innovation.

Technology monitoring predicts and evaluates technologies through analysing the current and historical data of technologies. Technology monitoring plays an important role in the process of technology strategic planning. Enterprises need to use technology observation and practical evaluation to identify opportunities and challenges in the market. Technology monitoring is an important method for providing the development environment insight and technology evaluation to the enterprise.

Technology monitoring has been deriving a variety of methods since the 1970s. For example, literature clustering method, subject consensus method, but there are some limitations among different methods. The prerequisite of literature clustering is numerous objective data, which will reduce the accuracy of results due to the limitation of information. Some scholars put forward the consensus method, such as the Delphi method, which relies on the experts' knowledge and experience judgment and lacks data support, so, will result in overly subjective and narrow results. Therefore, this study proposes a new technology monitoring method, which is based on the patent data and combined with the patent theme clustering and technology network analysis for comprehensively and dynamic analysis each technology group of the 3D printing industry.

The structure of this paper is as follows. Section 2 makes a comprehensive analysis of the existing patent monitoring methods. Section 3 introduces the technology monitoring method proposed in this study. Section 4 verifies the validity of the method by the 3D printing patent from the Derwent Innovation Index. The final section makes a summary of this study.
2. Literature review

2.1 Technology monitoring

The research methods of technology monitoring include biological evolution, technical life cycle, citation analysis and so on. Some scholars analyse technology from micro perspective based on the quantitative data dimension. For example, Ganguly analysed the whole process of technology development from the indicators of market maturity, technology adoption rate and expected utility of enterprises based on the literature data [6]. Buchanan analysed the technology based on patent data to summarized and sorted out the innovation features of existing technologies [7]. Momeni carried out the clustering analysis on the patent literature and identify the technical track and core technologies [8].

Husig analysed the characteristics of technological evolution through questionnaires, thus establishing an evaluation standard of technological change [9]. Sainio and Puumalainen analysed the evolution process of technology from four dimensions: practical value, market value, technical value and innovation value [10]. Hang established an analysis model by sorting and analysing the drive of existing technology innovation [11].

To sum up, the study of technology evolution method is still in the initial stage, the vast majority of literature mainly focus on the technical perspective of external factors, and less from the technique internal features. So, this study subdivides the technology to get the features of technology industry change characteristics.

2.2 Technology network

The patent network is a visual method of technology strategic plan, which will analyse the relationship among product, source and market can be clearly defined [12].

Kostoff made the patent network based on the opinions of experts to identify key components of technology and corresponding useful scenarios [13]. Wartburg analysed the U.S. patents from 1963 to 2002 and the results showed that citations and patents increased quickly over time [14].

Carley developed the method of social network analysis, integrating knowledge management, behavioral research and social network technology, and proposed the method of Dynamic network analysis (DNA) [15]. Dynamic networks represent organizations as collections that connect people, knowledge, resources, tasks, and connections to change. Dynamic network analysis can simulate large organizational networks, evaluate the current status of the organization and predict the impact of network changes on the organization. Bommarito applied distance measure and hierarchical clustering algorithm to analyse the dynamic citation network for U.S. patents [16] Dynamic evolution analysis of patent network will be the key point of future development. Barbera conducted research on technology evolution based on patent citation network [17]. Lee concluded collaborative evolution based on the patent data in ICT [18]. Kegler studied the evolution of institutional cooperation network by patent network [19].

The existing methods do not introduce time dimension to construct multi-mode dynamic network for analysing the whole process of industry development. Therefore, in order to make up for the existing deficiencies and improve the accuracy and efficiency of industrial analysis, this study introduces the time dimension to build the patent dynamic network in the subdivided technology groups to analyse the technological evolution characteristics of 3D printing industry from multiple perspectives.

3. The dynamic key entity evolution network of technology groups

Based on the text mining method theory, this study subdivides the technology group based on the patent IPC and proposed the dynamic key entity evolution network of subdivision technology groups (DENS), so as to carry on the patent citation and in-depth analysis of the subject field.
3.1 The framework of DENS

![Diagram of DENS framework]

As shown in the Figure 1, the DENS consists of four parts: time dimension, patent subject clustering, patent network, and the final technology visual evolution module.

3.2 Time dimension

Based on the number of patents in the 3D printing industry, the industry life cycle is analysed through a grey prediction model. The grey system theory was proposed and developed by Professor Deng in 1982[20]. This study analyses and predicts the life cycle stage of 3D printing industry through the grey prediction model, the number and size of patents in the field are used as a symbol of the stage of the industry life cycle. To predict the development of future patents based on the number of patents for each year from 1994 to 2018 in the 3D printing industry.

\[ x^{(1)}(t) = \sum_{t}^{T} x^{(0)}(t) \]  

\( x^{(1)}(t) \) is a cumulative sequence, \( x^{(0)}(k) \) is the original sequence, that is, the number of sequences in the \( t \) year.

3.3 Patent cluster

Since the content of this study is the evolution path of patent networks in the technical field, the patented IPC classification number is used as the basic data for patent similarity calculation.

The international patent classification (IPC) is a high-level summary of the patent technology knowledge field and is an effective way to understand the hot spots of technology. As shown in Figure 2, this study proposes a clustering method based on the IPC.

![Diagram of patent cluster process]

Figure 2. The process of patent cluster.
\[ \text{sim}(i, j) = \frac{\sum_{k=1}^{\text{ipc}} ic_{ki} \times ic_{kj}}{\sqrt{\sum_{k=1}^{\text{ipc}} ic_{ki}^2} \times \sqrt{\sum_{k=1}^{\text{ipc}} ic_{kj}^2}} \] (2)

\text{ ipc indicates the number of IPC included in all patents under this time dimension, \textit{ic}_{ki} corresponds to the number of IPCs in the \textit{kth} patent subclass of patent \textit{i}. The power is the result of the clustering result of the patent subject. The similarity mean is used as the threshold \( \lambda \) for determining the patent category. When the \text{sim}(i, j) between the two patents is greater than the threshold, it is judged to be the same category. For patents, when the patents belong to the same subject, the edges of the two are connected.}

3.4 Patent network

3.4.1 Key entities.
By using the information in the patent information and the correspondence between the patents can construct various patent networks. In Table. 2., we use multiple patented networks in each patent cluster that is, by dynamic network analysis to build key entity evaluation index systems and analyse the evolution of key entities in related patent clusters.

Key-Inventor: The key inventors refer to individuals who have a wide range of contacts with other members.

Key-Assignee: When an assignee has more backward citations, it indicates to a certain extent the technical status of the patent, that is, the institution also belongs to the leader in the field.

Key-State: The more patented technology the area contains, the easier it is to produce better quality technology and thus demonstrate its leadership.

3.4.2 Patent citation

As shown in Figure 3., the patent citation relationship under each event dimension from the database and convert the period into the structured data of the patent number and the citation relationship.

\[ PN_t(i) = \sum_{j=1, j \neq i}^{j} PN_t[i, j] \] (3)

\( PN_t \) indicates the patent citation relationship matrix within the time period of \( t \), \( PN_t[i, j] \) represents the citation relationship between the \( i \) patent and the \( j \) patent; when there is no citation relationship between the two patents, when it is recorded as 0, when there is a reference relationship, it is recorded as 1. At the same time, we add the number of citations of the \( i \) patent and all other patents as another measure of the key patent technology.

4. Experiments and results
In this study, with the “theme = 3D printing”, the time dimension is more than 8,000 patents in the Derwent Innovation Index.
4.1 The results of industry life cycle division
As shown in the Figure 4, combined with the analysis results of the grey prediction model, this study divides the period from 1994 to 2013 into the introduction stage of the 3D printing industry, from 2014 to 2015 as the growth stage, and from 2016 to 2018 as the maturity stage. As the number of patents is abundant in the maturity stage, for specifically analyse the evolution we further subdivide the maturity stage into three independent time dimensions. With the industry life cycle division will more comprehensively and meticulously to analyse the evolution of the 3D printing industry.

4.2 The results of patent cluster
As shown in the Figure 5, the technology groups classification within the industry is more dispersed. Because the topic clustering results are scattered, which is not conducive to the development of technology and retrograde system analysis, this study only selects the number of patents more than 100 patents in a single category. As shown in Table 1, as the increase of the development stage, the number of patent in all categories is increasing, and the technology is different and diversified.

![Figure 4. The predicted results of the life cycle of 3D printing industry](image)
![Figure 5. The classification results of patent cluster in introduction stage.](image)

Table 1. The count of patent cluster in different time dimension.

| Year       | 1994-2013 | 2014-2015 | 2016 | 2017 | 2018 |
|------------|-----------|-----------|------|------|------|
| Count of groups | 3         | 11        | 15   | 17   | 20   |

4.3 Evolution of key entities
As shown in Table 2, in the introduction stage of the industry life cycle, the influence of the inventor in the industry is relatively high compared with the development period. In the growth stage, the inventor's influence in the whole industry is gradually reduced, and the influence in its specific patent cluster is constantly improving. Due to the rapid increase in the number of patents in the growth stage, the patent clusters are also diversified and differentiated, and the inventors focus on a specific technical field, and the influence on other fields will be reduced, from the key leaders of the industry to the development of leaders in the technical field.

Table 2. The influence of industry and patent cluster of Key-Inventor in different time dimension.

| Year       | Author     | Citation of industry | Citation of cluster |
|------------|------------|----------------------|---------------------|
| 1994-2013  | Gbureck U  | 0.013                | 0.032               |
|            | Seitz H    | 0.011                | 0.040               |
| 2014-2015  | Chua CK    | 0.012                | 0.012               |
|            | Cho DW     | 0.012                | 0.022               |
| 2016       | Yeong WY   | 0.012                | 0.036               |
|            | Chen Y     | 0.011                | 0.033               |
Figure 6. The evolution of Key-Assignee in introduction stage, 2017, 2018.

As shown in Figure 6, the assignees have not changed much during the introduction and development of industrial development. With the development of the industry, the number of patents of each assignee has gradually increased and expanded. With the development of the industry, the influence of assignees basically shows a growing trend.

Table 3. The influence of Key-State in different time dimension.

| State            | 1994-2013 | 2014-2015 | 2016 | 2017 | 2018 |
|------------------|-----------|-----------|------|------|------|
| USA              | 0.026     | 0.038     | 0.319| 0.333| 0.299|
| Peoples R China  | 0.065     | 0.050     | 0.151| 0.166| 0.194|
| UK               | 0.034     | 0.042     | 0.078| 0.082| 0.074|
| Germany          | 0.023     | 0.057     | 0.061| 0.066| 0.066|
| South Korea      | 0.054     | 0.047     | 0.045| 0.054| 0.053|

It can be seen from the Table 3 that the influence of countries is basically maintained at a certain level. China's influence in the development stage has been greatly improved, that is, activities in the 3D printing industry are becoming more and more active.

In summary, the centrality of the key entity of patent cluster will gradually improve, while weaken within the industry. That is, the influence of key entities is characterized by the domain of patent clusters, which gradually weakens the leadership of the industry. Patents gradually aggregate similar patented technologies by focusing on the key patents, thus forming a new patent cluster.

5. Conclusions

Based on the patents of the 3D printing industry, this paper constructs a patent network under the subject clustering and analyses the dynamic evolution path of the industry by analysing the changes of key entities. By identifying Key-Inventor, Key-Assignee and Key-State networks to identify and analyse important entities in the 3D printing industry from different dimensions, it is helpful to fully understand the technological transformation path and characteristics of the 3D printing industry, and to develop technical strategies for enterprises. The plan provides a theoretical basis and time guidance.

Since each industry sector often has multiple sub-technical groups, which have different technical backgrounds and knowledge bases. Therefore, this paper adopts the IPC number as the clustering foundation of the sub-technology groups, which provides an effective way to further understand the hot spots and evolution direction of industrial technology. Through the IPC topic clustering method, the clustering results of the technology group can be visualized by visualized clustering results.

References

[1] Taşkin H, Adali M R, Ersin e. (2004) Technological intelligence and competitive strategies: Journal of Intelligent Manufacturing, 15(4): 417-429.
[2] Choi C, Park y. (2009) Monitoring the organic structure of technology based on the patent
development paths. Technological Forecasting and Social Change, 76(6): 754-768.

[3] Nosella A, Petroni G. (2008) Technological change and technology monitoring process: Evidence from four Italian case studies. Journal of Engineering and Technology Management, 25(4): 321-337.

[4] Lichtenthaler e. (2003) Third generation management of technology intelligence processes. R&D management, 33(4): 361-375.

[5] Ansoff h. (1975) Managing strategic surprise by response to weak signals. California management review, 18(2): 21-33.

[6] Ganguly A, Nilchiani R, Farr J v. (2010) Defining A set of metrics to evaluate the potential disruptiveness of A technology. Engineering Management Journal, 22(1): 34-44

[7] Buchanan, B. (2010) Armitage toolkit for the systematic analysis of patent data to assess a potentially disruptive technology. United Kingdom, London n: Intellectual Property Office, 2-16.

[8] Momeni A, Rost k. (2016) Identification and monitoring of possible disruptive technologies by patents-development paths and topic modeling. Technological Forecasting and Social Change, 104:16-29.

[9] Hüsig S. (2005) Christiane Hipp, Michael Dowling. Analysing disruptive potential: the case of wireless local area network and mobile communications network companies. R&D Management, 35(1).

[10] Liisa M. S, Kaisu P. (2007) Evaluating technology disruptiveness in a strategic corporate context: a case study. Journal of Technological Forecasting & Social Change, nominal (8)

[11] Hang, C C, Chen, Jin, Yu. (2011) An assessment framework for disruptive innovation. Foresight: the Journal of Futures Studies, Strategic Thinking and Policy, 13(5).

[12] Robert Phaal, Clare J.P. Farrukh, David r. (2004) Probert. Technology roadmapping -- A planning framework for evolution and revolution. Technological Forecasting & Social Change, 71(1).

[13] Ronald N. Kostoff, R, Boylan R. Simons. (2004) Disruptive technology roadmaps. Technological Forecasting & Social Change, 71(1).

[14] Von Wartburg I, Teichert T, Rost k. (2005) invention-progress measured by multi-stage patent citation analysis. Research Policy, 34(10): 1591-1607.

[15] Carley k. (2003) Dynamic network analysis.

[16] Bommarito II M J, Katz D M, Zelner J L, et al. (2010) Distance measures for dynamic citation networks. Physica A: Statistical Mechanics and its Applications, 389(19): 4201-4208.

[17] Barberá-Tomás D, Jiménez-Sáez F, Castelló-Molina I. (2011) Mapping the importance of the real world: The validity of connectivity analysis of patent citations networks. Research Policy, 40(3): 473-486.

[18] Lee S, Kim M S, Park y. (2009) ICT co-evolution and Korean ICT strategy -- An analysis based on patent data. Telecommunications Policy, 33(5-6): 253-271.

[19] Kegler M. (2010) Using network analysis to assess the evolution of organizational collaboration in response to a major environmental health threat. Health education research, 25(3): 413-424.

[20] Deng J L. (2005) The primary methods of grey system theory. Huazhong University of Science and Technology Press, Wuhan.