REVIEW PAPER

Exploring the innovation landscape of bamboo fiber technologies from global patent data perspective

Sun Minghan [iD] · **Zhu Xiuzhu** [iD] · **Jiang Man** [iD]

Abstract With the global popularity of the concept of green and sustainable development, bamboo fiber technology has made great advances and found its way into several important materials applications. This study attempts to analyze the bamboo fiber technology from a patent perspective, hoping to help enterprises and R&D personnels better grasp the technology development trend and evolution path. Because the current patent analysis methods can not achieve the above objectives well, this paper proposes a new method of clustering and identifying sub-clusters by constructing bamboo fiber patent citation network and patent-international patent classification two mode network. Moreover, this paper uses natural language processing and main path analysis to perform subject word analysis and key technology identification on these technological sub-clusters, respectively. The analysis process and method in this study also have implications for patent analysis in technological fields such as graphene or carbon fiber.

Introduction

With the global popularity of the concept of green and sustainable development, people are gradually realizing that the currently used petrochemical-based fibers and textiles will bring huge burdens on resources and the environment. Therefore, biomass or lignocellulose, as the oldest source of natural polymers and the most abundant renewable resources on Earth, have started re-gain popularity. Bamboo fiber is one of the important classes of natural fibers. Thanks to the promotion of technological innovation and green development concepts, bamboo fiber technology has seen great development and found many important applications.

With the rapid development of bamboo fiber technology, enterprises and R&D personnels in this field are facing the following questions :

- Which countries or regions are the innovation of bamboo fiber technology mainly distributed from global patent data perspective?
- What sub-technologies can bamboo fiber technology innovation be divided into? And what are the "research hot-spots" of each sub-technology?

S. Minghan · Z. Xiuzhu · J. Man (✉)
School of Management, Huazhong University of Science and Technology, Wuhan 430074, China
e-mail: jiangman_@hust.edu.cn

S. Minghan · Z. Xiuzhu · J. Man
Sino-European Institute for Intellectual Property, Huazhong University of Science and Technology, Wuhan 430074, China

- What are the current global innovation trends of this bamboo fiber sub-technologies?

However, the current patent analysis method cannot answer the above questions well. Therefore, this study using the latest patent metrology methods (patent family citation network, clustering algorithm, natural semantic processing and main path analysis algorithm), to optimize patent information processing and visualization, which can help us systematically answer the above questions.

This paper will be developed according to the following sections. The second section describes the research status of bamboo fiber and patent analysis. The third section introduces the research framework, methods and tools of this paper. The fourth section deals with patent data and builds a citation network. The fifth and final section is the analysis and display of the data results. The sixth section summarizes the article and puts forward some suggestions.

Research background

Bamboo fiber

China is rich in bamboo resources and has a long history of cultivation and utilization. Bamboo fiber is the fifth largest natural fiber after cotton, hemp, wool and silk. It is a cellulose fiber extracted from naturally growing bamboo. In the modern bamboo industry, bamboo fiber has become the darling of the low-carbon economy era. Generally speaking, bamboo fiber can be divided into four categories:

I.   Natural Bamboo Fiber. It is directly separated from bamboo. It only removes impurities (lignin, polypentose, bamboo powder, pectin, etc.) inside and outside the cellulose bundle, and retains the natural bamboo cellulose morphology, molecular structure, and aggregate structure (Abe and Yano 2009). Natural bamboo fiber can be used in the process of pure spinning and blending (Chen et al. 2016). It is a new raw material often selected by enterprises such as cotton spinning, wool spinning, hemp spinning, silk spinning and so on Jawaid and Abdul Khalil (2011).

II. Bamboo Pulp Fiber. It could be easily prepared via viscose spinning process or Lyocell spinning process with bamboo (Wang et al. 2019). The manufacturing process is basically similar to other viscose fibers. However, during the processing, the natural characteristics of bamboo were destroyed, and the fiber's deodorizing, antibacterial, and UV protection functions were significantly reduced.

III. Bamboo Charcoal Fiber. It is made by using nanotechnology to micronize bamboo charcoal, and then the bamboo charcoal sub-nano-level fine powder is evenly incorporated into the chemical fiber through the melt spinning process, which is made by drawing with biochemical technology (Wang et al. 2019; Su et al. 2011). Bamboo charcoal fiber has certain effects such as moisture absorption, heat preservation, and deodorization.

IV. Bamboo Fiber Reinforcement Composites (BFRC). It is a new material made of natural bamboo fiber and thermoplastic resin (Faruk et al. 2012) or thermosetting resin matrix (Muhammad et al. 2018). Bamboo fiber of Bambusa or Phyllostachys is used as the reinforcing material of the bamboo fiber reinforced resin composite material. Compared with glass fiber reinforced composites, natural bamboo fiber composites have the advantages of low density, good sound insulation, high specific performance, recyclability, low price, good human affinity, and complete biodegradability (Joshi et al. 2004). With the increase of people's awareness of environmental protection, BFRC as "green products" will have great development opportunity (Liu et al. 2012).

Patent analysis

The metrological analysis of patent documents helps researchers observe different aspects of patent activity and easily understand the development of subject technology. The rapid development of science and technology and the increasingly fierce competition in the industry require intellectual property researchers to continuously update analysis indicators to meet the needs of enterprises to obtain competitive intelligence

and the government to formulate scientific and technological development strategies. Early patent analysis methods mainly compared changes in the number of patents of different entities (such as countries, affiliates, inventors, and technological fields) over time. However, simple quantitative statistical analysis and patent citation analysis methods cannot obtain comprehensive, objective, and accurate technological information.

In recent years, social network analysis (SNA) has been introduced into information science due to its unique perspective. SNA has gradually been used in patent intelligence analysis, and becoming a research hotspot. Social network analysis methods provide a very effective means for patent information mining (Sternitzke 2009). The current research on patent citation networks is mainly focused on two aspects. One is the topology and visual analysis of the patent citation (Choe et al. 2016), which can intuitively display information about the overall structure of the network, enabling researchers to intuitively understand overview of group patents (Ji et al. 2019). The another is the node analysis of the patent citation network, which can identify high-value and important patent nodes (Choe et al. 2013).

Patent citation network analysis is often used to identify patent clusters and discover technological topics. It has been proved that the application of appropriate clustering algorithms can detect and predict emerging technology trends (Bruck et al. 2016). Chen et al. (2012) used the U.S. Patent Classification Number technology subgroup network to identify technology evolution at the macro-national level. Érdi et al. (2012) constructed patent citation network to predict emerging technology clusters by analyzing the evolution of the structure. Kim et al. (2013) constructed a citation network between technical modules of printed electronics technologies and found that control technology has played a huge role in the integration of technology between modules. Xu et al. (2014) analyzed the development trend of various drugs for treating Alzheimer's Disease (AD) through patent citation cluster analysis. Nakamura et al. (2015) identifies technology subgroups in the drivetrain domain by clustering patent citation networks. Recently, some scholars explored the technological connections and development trends of antibiotics Zhang et al. (2016), Hepatitis B Drugs Huang et al. (2016) and anti-Parkinson drugs Qu et al.

(2019) through patent citation network analysis and clustering methods. Yoon and Park (2004) applied the concept of network analysis to patent analysis, and proposes co-occurrence network analysis on patented technical topics. Chang et al. (2010) explored carbon nanotube field technological trends using patent subject-word association networks. Gui et al. (2018) divided the technical stages of patents by subject terms and builds a patent citation tree to reveal the development of bogie technology in the high-speed rail industry.

Main path analysis (MPA) based on patent citation network is one of the most appealing ways to identify the critical developing paths to discover citation trajectories. Many researchers have contributed to the main path analysis. In 1989, Hummon and Doreian combined the Main Path Analysis method with bibliometrics for the first time, and pioneered the evolutionary analysis of scientifically dominated ideas with citation networks Hummon and Dereian (1989).Furthermore, Batagelj realized the identification of the main path of the network by computer software. Batagelj (2003) also proposed a new method of Search Path Count (SPC). von Wartburg et al. (2005) proposed that the importance of individual nodes should be combined with the overall connection structure of the network to determine whether a node is the main node. The main path analysis method is mainly divided into two types in the practice of citation network analysis, one is a citation network for scientific papers, and the other is a patent citation network. Mina et al. (2007) used literature citation data and patent citation data to reveal developments and transfers in the field of coronary heart disease treatment. Calero-Medina and Noyons (2008) pointed out that the literature citation network main path analysis method can better understand the scientific progress of research in the Absorptive Capacity (AC) field.Other scholars have used the literature's main path analysis method to reveal the technology development trajectory and development trend of fullerene and carbon nanotubes (Lucio-Arias and Leydesdorff 2008), Resource-Based Theory (RBT) Liu and Lu (2012), Hershey index Lu and Liu (2012), Data Envelopment Analysis (DEA) Liu et al. (2013), fuel cells Ho et al. (2014), lithium iron phosphate batteries and data quality (Xiao et al. 2014). Verspagen (2007) used patent citation data to identify the path of fuel cell technology. Fontana et al. (2009) used patent citation

network for the evolution and visualization of the technology track of the Ethernet Ethernet data standard. Huang et al. (2017) traced 3D printing technology evolution pathways by constructing a patent family citation network. Kim and Shin (2018) used clustering and main path analysis methods to identify the main path and extended technical trajectory of HVDC transmission. Liu et al. (2019) put forward some considerations in the main path analysis of patent citations that are different from literature citations.

Research framework, methodologies and tools

With the large-scale construction of patent databases, patent data is becoming more and more accessible. However, due to the rapid development of science and technology, the number of patents has increased dramatically in recent years, which has caused difficulties in patent analysis. The patent citation network analysis method combines the network analysis method and the citation analysis method to discover the global relationship and potential information between patents. Therefore, this study uses the patent citation network analysis method to mine patent information. Specifically, the application of network analysis in patent citation relationship mining is divided into three main categories: patent citation network visualization, patent citation network cluster analysis, and patent citation network node analysis.

This section focuses on the construction and analysis of the bamboo fiber patent citation network. It is divided into four parts (Fig. 1). The first part is how to build a patent family citation network. The second part introduces the clustering process of patent citation network in this paper. The third part will introduce how to analyze the keywords of each cluse. And the fourth part will show how to discover core patents.

Construct a patent citation network (PCN) by data cleaning

Patent Family Frietsch and Schmoch (2009) is often used internationally to name a group of patent applications. These applications are used to protect the same invention content in different countries Sternitzke (2009). Patent family Martínez (2010) are

often used in cross-country patent statistics to avoid double counting of the same invention. In the definition of patent family, the most commonly used is the definition based on the earliest priority of the same patent. Priority filing uses the earliest patent application for each invention in a patent family, regardless of patent grant. Therefore, it can accurately indicate when and where the invention first occurred. Therefore, priority filing (de Rassenfosse et al. 2013) can be used to obtain and compare the complete picture of patent activity (Nakamura et al. 2015) in several inventing countries (Shubbak 2019). Therefore, in this research we uses the patent family based on priority.

Figure 2 shows several cases where patent citations differ from literature citations. Patent A1, Patent A2, and Patent A3 in patent family A may be patents for the same invention in different countries, or they may be the publication number, license number and modified license number of the same patent for the same invention in the same country. Therefore, the patent family patents are numbered in chronological order according to the earliest priority time sequence. In the patent citation information processing, patents of the same patent family are replaced by a unified number to obtain patent family citation information. Patent family citation information is used to construct a patent family citation network, in which each edge of the citation network is assigned a value of 1, and network nodes are traversed from small serial number to large serial number to ensure acyclic traversal. In the above analysis process, Excel VBA language was used to extract, replace, and remove deduplicate patent citation information. Software Pajek was used to construct patent family citation network.

Find sub-clusters of PCN by community detection method (CDM)

With the deepening of people's research on complex networks, more and more properties of complex networks have been discovered. In 2002, Girvan and Newman in "Structure in social and biological networks" Girvan and Newman (2002) pointed out that clustering is common in complex networks. They named each class as a community, and made a discovery algorithms of these societies. Since then, a lot of research has been done on community discovery in complex networks, and many algorithms have been proposed. Among them, the classical and common are
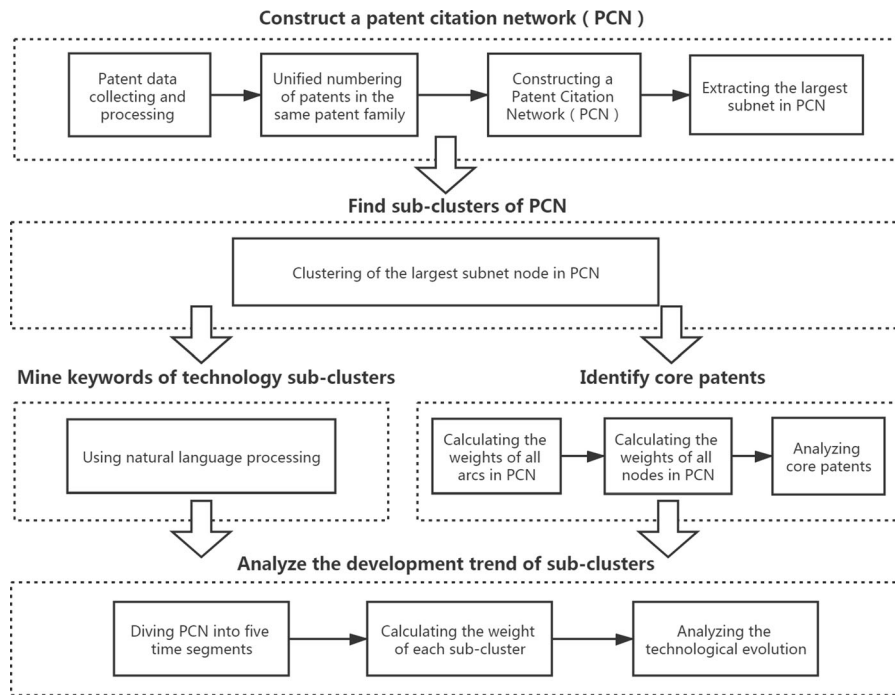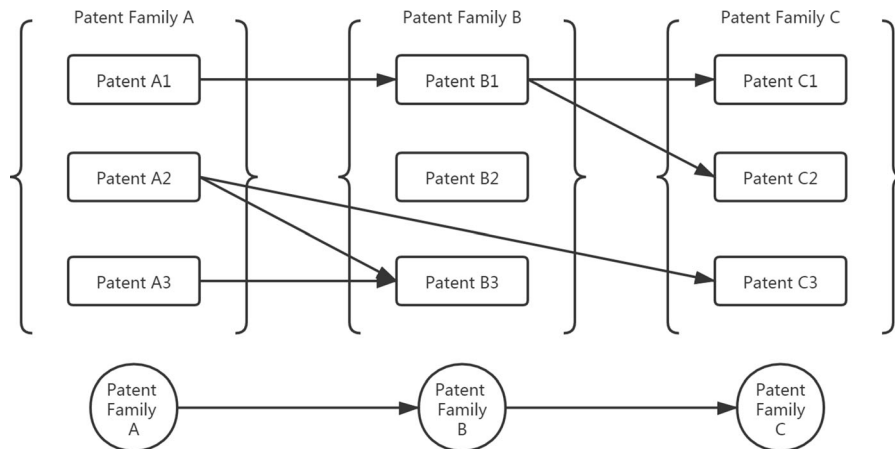
Fig. 1 Research framework

Fig. 2 Construction of patent family citation network

K-means iterative calculation method, Louvain method, and Modularity class method Newman (2003). Although the clustering algorithms of social networks have been greatly developed, it is still a huge challenge to directly use clustering algorithms to identify technical subgroups in the patent citation network, especially in the case of bamboo fiber technology, which contains several interconnected

Sub-technologies. So the IPC number is used to assist the patent citation network clustering in this paper.

IPC uses a classification principle mainly based on functionality and auxiliary by application. In the form of grades, the technical content is indicated: Section-Class-Subclass-Group-Subgroup, and a complete classification system is formed by classification Sampaio et al. (2018). The IPC represents the general category of a certain technology, such as D for textlies. D03 for

weaving. D03D for woven fabrics; methods of weaving; looms. D03D-015 for woven fabrics characterised by the material or construction of the yarn or other warp or weft elements used. D03D-015/02 for the warp or weft elements being of stiff material. A patent could have multiple IPC numbers. On the one hand, a patent represents the intersection of the technical fields represented by IPC Numbers. On the other hand, patents with multiple IPC numbers also indicate that technical convergence is taking place in the technical field represented by the IPC number of the patent. This paper uses the analysis of the class at the group level of the IPC. Specifically, we uses programming to intercept groups in one or more IPC numbers of each patent. After that, we will remove duplicates with each patent's IPC classification numbers.

Figure 3 vividly illustrates the process of identifying sub-clusters in patent citation networks. The left of Fig. 3 is the patent-IPC two mode network, and the right of Fig. 3 is the patent citation network. This paper uses the Modularity class method Blondel et al. (2008) to cluster the patent-IPC two mode network, and then maps the clustering results to the patent citation network to achieve the technological sub-cluster division in the citation network. Because the Modularity Class method is packaged in the software Gephi, this paper uses Gephi software for patent citation network clustering and visualization in the above analysis process.
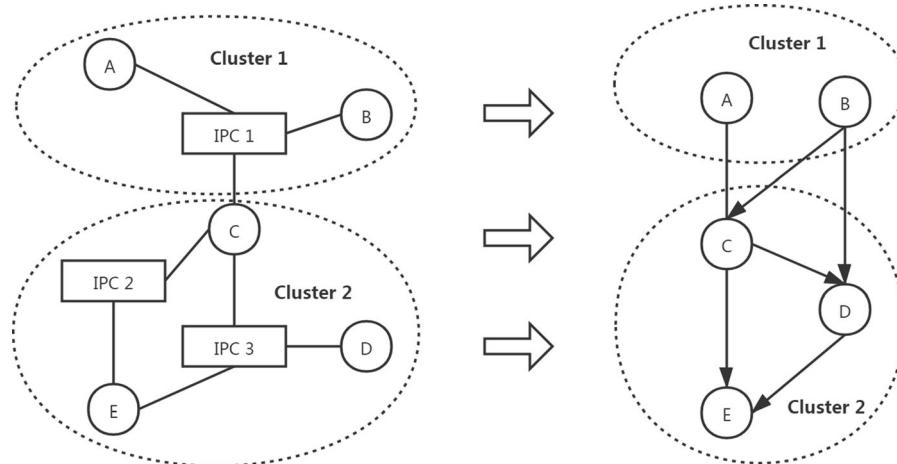
Mine keywords of technological sub-clusters by natural language processing (NLP)

The process of mining technological topics for each subgroup can be divided into 4 steps: 1 obtaining the title information of the patents in the subgroup; 2 accessing the remote natural language service provider interface to perform word segmentation operations on the patent title; 3 Lemmatizing the words in the phrase; 4 according to the order of the words in the phrase, build the topic word cloud network and visualization (Fig. 4).

In the above analysis process, this study uses Power BI Query to remotely access Microsoft's natural language processing platform to perform word segmentation on patent titles, and uses Python natural language packages to lemmatize the words in the phrase, such as plural nouns, verbs in different tenses, and adjectives in comparative forms. Then use the social network analysis software Pajek and Gephi to construct the topic word network.

Identify core patents of technological sub-clusters by main path analysis (MPA)

In a complex patent citation network, how to calculate the weights of each citation link is a core issue. Node Pair Projection Count, Search Path Link Count, Search Path Node Pair and Search Path Count were the most widespread algorithms. In this paper, we used the SPC suggested by Batagelj (2003). In the SPC algorithms, the number of reachable node pairs through a specific

Fig. 3 Identify sub-clusters in patent citation network

Stage 1: Method for manufacturing bamboo fiber clothes, involves pre-processing raw bamboo fiber, preparing raw bamboo fiber and performing bamboo fiber post treatment process and knitting process

Stage 2: manufacturing bamboo fiber clothes , raw bamboo fiber, bamboo fiber post treatment process, knitting process

Stage 3: manufacture bamboo fiber clothe , raw bamboo fiber, bamboo fiber post treatment process, knit process

Stage 4:

manufacture → bamboo → fiber → colthe
raw ↗ bamboo   fiber ↘ post → treatment ↗ process ← knit

Fig. 4 Identify technological topics for sub-clusters of patent citation network

link from all source nodes to all sink nodes is calculated, and then, weights are allocated to all arcs in the patent citation network.

In the citation network, a source node means that it is cited, but it never references other nodes; a sink node means that it references other nodes, but it is never cited. In other words, the source node is the origin of knowledge, and the sink node is the end point of knowledge diffusion in this network. As is shown in Fig. 5, the original value of all the arcs is 1, there are two source nodes A, B, and four sink nodes E, G, H, I. When an exhaustive search is performed for each path from the source node to the sink node, the SPC value of each arc is the number of times all paths have passed this arc. For example, the SPC value of edge A-C is 4, because there are four arcs A–C–D–E, A–C–D–F–G, A–C–D–F–H, and A–C–D–F–I from the source node to the sink node. The larger the SPC value, the more

important this arc is in knowledge transfer. After the traversal calculation is completed,for convenient statistics, the values of the arcs are normalized, that is, the current value is divided by the value of the largest arc. For patent analysis, we pay more attention to discovering core patents. The identification principle adopted in this paper is that the more patent nodes with more path weights controlled in the citation network, the more important they are.

As shown in Fig. 5, the values of the source nodes A and B are 0.50. The values of the sink nodes E, G, H, and I are 0.25. C, D, and F are intermediate nodes in the network, and their node values are 1 ,1, 0.75, so C and D are the core nodes in the network. In the above analysis process, because the SPC is packaged in the software Pajek, this paper uses Pajek software for main path analyses of patent citation network, and
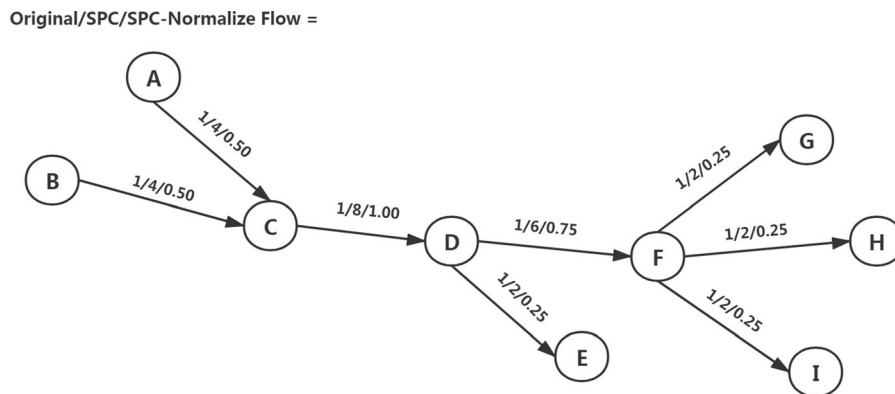
Original/SPC/SPC-Normalize Flow =

A
B 1/4/0.50
1/4/0.50
C 1/8/1.00 D 1/6/0.75 F
1/2/0.25 E
1/2/0.25 G
1/2/0.25 H
1/2/0.25 I

Fig. 5 An example of SPC algorithm

uses Software Cytoscape to lay out and visualize the key paths of technological evolution and core patents.

Data collection and citation network construction

In the following, we used the Derwent Innovations Index (DII) as the target patent database to collect patent information of patent families and patent citations. Since the DII is a global patent dataset that contains patent families from 47 patent authorities. Furthermore, in order to enable technicians to fully understand the technological content of patents, DII invited experts in related fields to uniformly rewrite patent texts in more than 30 languages into English abstracts of 250–500 words. The DII abstracts are all described in plain language, which mainly includes the specific core technological information describing the patent novelty, main use, and technological advantage of the patents. The search query we used is "Title = (Bamboo Fiber*)", which was directed to search the title. Besides, in consideration of the time lag for when patents are filed, we refined the publication period to 1978 through 2018, while we performed the search on May 20, 2019. Ultimately, we received 9488 records. Patent search results show that the first patent for bamboo fiber began to appear in 1996.

Figure 6 depicts the global growth trend of bamboo fiber patent. The abscissa is the earliest priority year of the patent family. The ordinate is the total number of patent applications (Total application) and the total number of patent family applications (Local application). From Fig. 6, we can find that although the patent of bamboo fiber has only a history of more than 20 years, the growth rate is very fast. The period from 1996 to 2008 was the germination period of bamboo fiber technology, which was relatively slow to develop but some important technology accumulation was underway. 2008–2018 was in the period of rapid development of technology, and the growth was exponentially distributed. At present, the bamboo fiber technology is still in the high-speed development period, and the development momentum is still strong. We predicted that there is still a lot of room for development in the future.

The number of patent applications in a country or region is equal to the sum of the number of local applications and the number of foreign applications. It can be seen from Table 1 that the patents of bamboo fiber technology in various countries and regions are mainly local applications. Although multinational patents have higher value, but their number were relatively few. After analyzing the main countries and regions of bamboo fiber patent sources and distribution in Table 1, we can find that the bamboo fiber

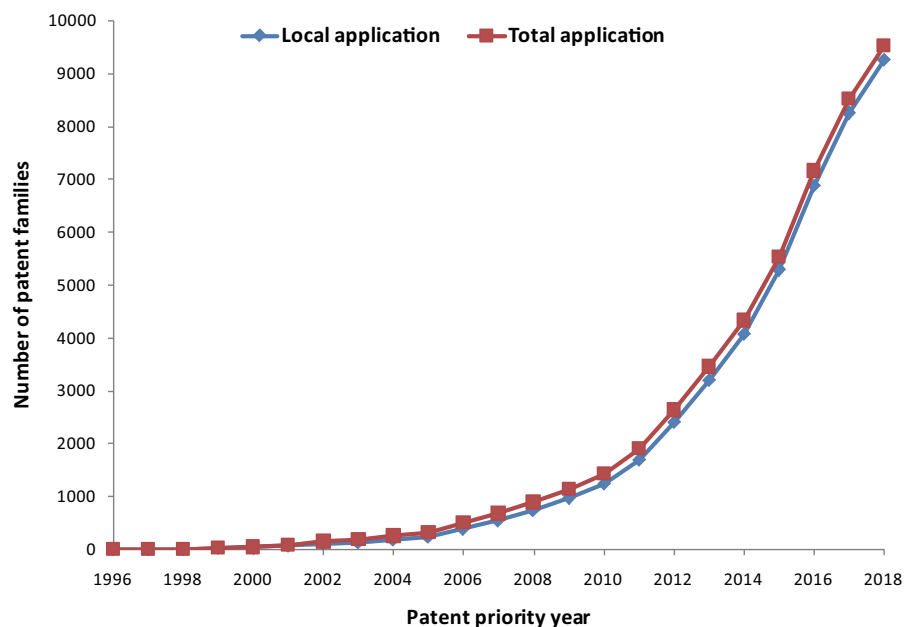**Fig. 6** Global bamboo fiber patent growth trend

Table 1 National or regional distribution of patent applications for bamboo fiber technology

Country or Region	CN	JP	US	WO	KR	EP	DE	TW	IN	AU	BR	FR
Foreign application	64	18	80	103	21	68	6	9	9	16	10	1
Local application	9676	388	44	0	74	10	50	35	15	6	10	14
Total application	9740	406	124	103	95	78	56	44	24	22	20	15

patent source is closely related to the global distribution of bamboo, mainly in the subtropical zone. The sources of bamboo fiber patented technology innovation are mainly in the East Asia, Europe, and America. The East Asia is the center of bamboo distribution in the world and the center of bamboo fiber technology innovation. China Mainland (CN) has a considerable number of patents on bamboo fiber, which has provided important technical support for Chinese green development and industrial upgrading and transformation. The bamboo industry in Japan (JP) and South Korea (KR) has a long history as China, but it mainly develops high-tech bamboo industry. China Taiwan (TW) is also an important region for bamboo fiber innovation with many bamboo fiber patents distributed. Although India (IN), Myanmar, Thailand, Vietnam, Indonesia and the Philippines have a large number of bamboo cultivation, their bamboo industry is relatively primitive and traditional, so the number of patent applications is very few. In the past hundred years, the United States (US) and European countries have introduced a large number of bamboo varieties from some bamboo-producing countries in Asia, and combined their advanced technological advantages to develop high-tech bamboo industries. US, Germany (DE), France (FR), United Kingdom (BR) and Italy have some bamboo fiber patent distribution.

In Fig. 7, each node represents a patent family. Statistical analysis of the bamboo fiber patent family citation network shows that the largest subnet in the network has 1974 nodes, accounting for 89.66% of the citation network nodes. Other network subnets are relatively small and contain a few number of patent families. The number of nodes is less than 6. It can be found that in the bamboo fiber technology, the connection between the technologies is very close. The patent node occupying an important position in the largest subnet (also the core subnet) is also a core important technology in the entire technological field. Patents in scattered small groups are often on the edge

of technology. Therefore, we use the largest subnet as the analysis object to study the technological branches and technological evolution of its sub-clusers.

Result and analysis

Based on the methods in "Research framework, methodologies and tools" section and the data processing in "Data collection and citation network construction" section, patent analysis of bamboo fiber technology is analyzed in this section, including sub-cluster analysis, core technology analysis and development trend analysis. Using multiple analysis tools to deeply mine patent information, identify the technological topics of the technology cluster sub-clusters, and discover the connections between the technology sub-clusters and core patents, which is helpful to bring practical conclusions to researchers. Furthermore, these methods and tools are also useful for patent analysis in other fields, such as analysis in graphene materials, nanomaterials or other fields.

Sub-cluster analysis of the patent citation network (PCN)

Figure 8b is obtained by mapping the clustering results in Fig.e 8a to the patent citation network. Figure 8b is actually the largest subnet in Fig. 7. After clustering, it was divided into four sub-clusters, and there is technological convergence among these four sub-clusters. We can also discover the relationship and proportion of each sub-cluster. These four groups accounted for 63.3%, 17.2%, 9.8%, and 9.0%, respectively. Cluster 1 (the purple) accounts for the highest proportion, with 1227 patents; Cluster 2 (the green) accounts for the second, with 339 patents; Cluster 3 (the blue) accounts for the third, with 193 patents. Cluster 1 and Cluster 2 are far apart, and Cluster 3 is the bridge between Cluster 1 and Cluster 2. Cluster 4
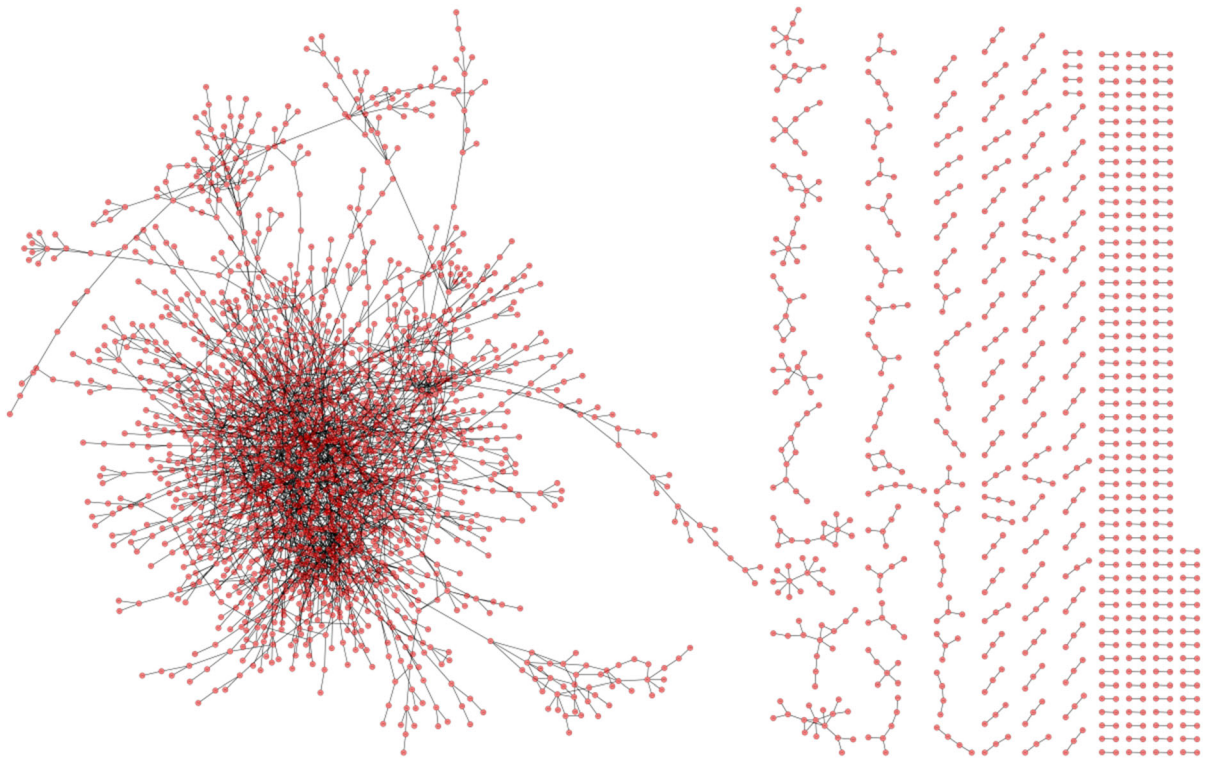
Fig. 7 Patent family citation network for bamboo fiber technology

(the black) has the smallest technology, with 178 patents. Cluster 4 is included in Cluster 1. It can be concluded that Cluster 4 is a relatively independent technology in Cluster 1, but at the same time, it has many common technologies with Cluster 1.

Table 2 is the IPC table of bamboo fiber technology clustering, and Fig. 9 is a visualization of technical topics in the bamboo fiber field. In this stage, we use the combined method of IPC classification numbers and technological subject terms to mine the technological fields and subjects of each sub-cluser, so as to understand the patent content in depth. we first analysis the IPC group of all targeted patents to understand the distribution of technology fields. Then use text analysis methods to mine and visualize the topic words. The clustering results in this paper are consistent with the technological classification of bamboo fiber in the existing literature, which verifies the scientificity and correctness of the method in this paper. Through the interpretation of the meaning of the IPC classification number and the mining of technological keywords, we identified four technical groups. It can be understood that Cluster 1 belongs to

the application of bamboo fiber in the textile field, including the application of bamboo fiber and bamboo charcoal fiber; Cluster 2 is the manufacture and application of natural bamboo fiber reinforced composite materials; Cluster 3 is the preparation of bamboo raw fiber raw materials; Cluster 4 is the preparation of bamboo charcoal fiber viscose.

Among the four technological sub-clusters mentioned above, the technologies involved in cluster 1 and Cluster 2 are diverse, while the technologies in Cluster 3 and cluster 4 are relatively single. We find that Cluster 4 provides new materials for the technological development of Cluster 1, and Cluster 1 is the main application direction of Cluster 4. To gain more insight, next we analyze the sub-clusters one by one.

In the Cluster 1, D02G-003 (threadscrimping or curling fibers, filaments, yarns, or threads) is mentioned in 544 patents. The result is followed by D03D (woven fabrics; methods of weaving; looms), which include D03D-015 (woven fabrics characterised by the material or construction of the yarn or other warp or weft elements used) and D03D-013 (woven fabrics featured by the special disposition of

Fig. 8 Identify sub-clusters in the patent citation network of bamboo fiber technology
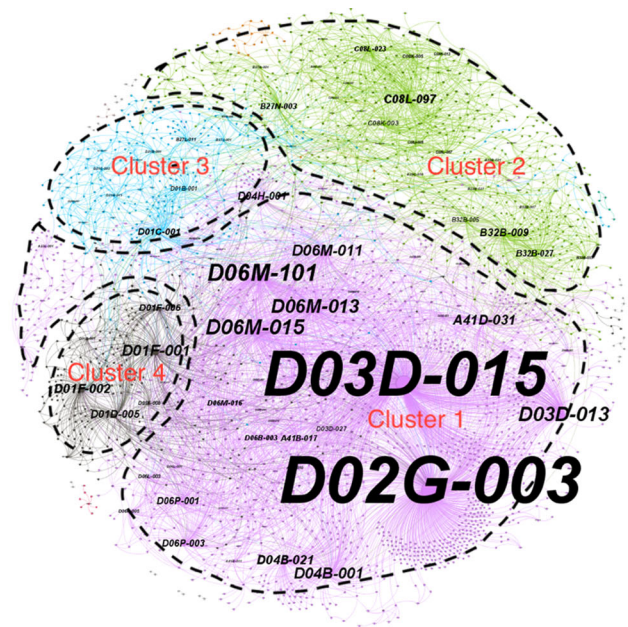
(a) Clustering of patent-IPC two mode network
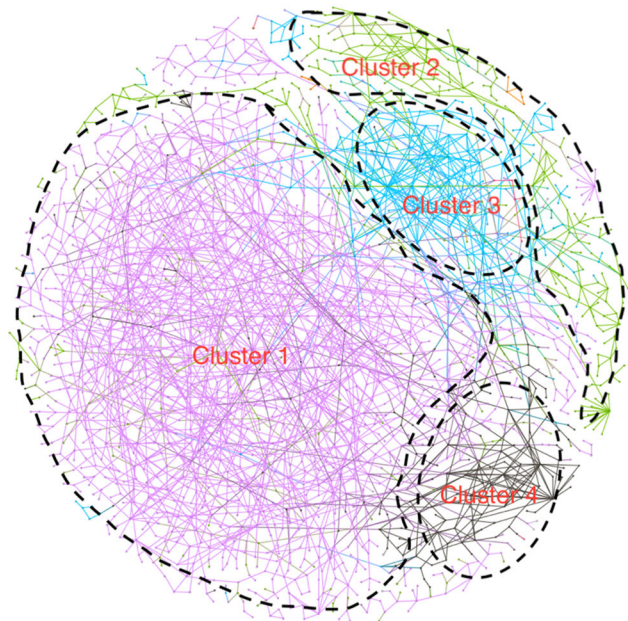
(b) Clustering of patent citation network

the warp or weft threads). D06M (treatment of fibers, threads, yarns, fabrics, feathers of fibrous goods made from such materials) and D04B (knitting) take up the next highest proportion. Bamboo fiber in Cluster 1 is used to mix with cotton fiber, milk protein, hemp, flex, terylene, silk, wool, polypropylene, nano-silver to form yarn or fabric. It has the characteristics of multi functional, anti bacteria, friendly environment, and health care. The technological proportions, components and manufacturing methods are hot-spots for innovation. In addition, there are also a small number of patents on the application of pulp and viscose. In the

Table 2 The table of bamboo fiber technology clustering

Rank	Cluster 1	Number	Cluster 2	Number	Cluster 3	Number	Cluster 4	Number
1	D02G-003	544	C08L-097	95	D01C-001	75	D01F-001	131
2	D03D-015	523	B32B-009	91	D01B-001	46	D01F-002	101
3	D06M-101	194	B32B-027	71	B27L-011	37	D01D-005	89
4	D06M-015	172	B27N-003	65	D21B-001	26	D01F-006	76
5	D03D-013	163	C08L-023	57	D21H-011	25	D01F-008	41
6	D06M-013	158	C08K-003	51	B27J-001	25	D01D-001	26
7	D06M-011	124	B32B-005	47	D21C-003	24	D01D-013	15
8	D04B-001	123	C08K-005	38	B27K-009	20	D01F-009	6
9	A41D-031	113	B32B-033	32	D21H-017	18	C08G-063	6
10	D04B-021	103	C08K-013	30	B27K-005	14	B01J-020	6
11	D04H-001	88	C08L-067	29	D21C-005	13	C08B-009	5
12	D06P-003	82	C08J-005	28	D21H-021	12	D01F-011	4
13	D06P-001	80	B32B-007	26	D21C-001	12	D02J-001	3
14	A41B-017	65	B27N-001	26	D21H-027	11	D01D-010	3
15	D06M-016	57	B32B-037	24	D21C-009	10	C02F-001	3

Cluster 2, C08L (compositions of macromolecular compounds) has the highest proportion, which include C08L-097 (compositions of lignin containing materials), C08L-023 (compositions of homopolymers or copolymers) and C08L-067 (compositions of polyesters; compositions of derivatives of such polymers). The result is followed by B32B (layered products), which include B32B-027 (layered products essentially comprising synthetic resin), B32B-033 (layered products characterised by particular properties or particular surface features). Bamboo fiber in Cluster 2 is mainly used as the raw material of bamboo fiber reinforced composite materials. Resin, glass, plastic, rubber, polyester, etc. are mixed with bamboo fiber to make a composite board or pipe. The comprehensive properties of bamboo fiber reinforced composites can meet various needs, and they are often used as automotive interiors, wind turbine blades, enclosures for sound boxes and electronic equipment, high-performance medical equipment, pipes, and comprehensive urban corridors. The result of Cluster 3 indicate that D01C-001 (chemical or biological treatment of natural filament or fibrous raw materials in order to produce spinnable filaments or fibers) is mentioned in 72 patents. The result is followed by D01B-001 (mechanical separation of fibers from plant materials),and B27L-011 (Manufacture of wood shavings, chips, powder) take up the next highest proportion. Sub-cluster 3 is mainly about patents for some methods and processes for preparing bamboo fibers from raw bamboo. It includes processes for preparing cellulose such as slicing, high-temperature and high-pressure cooking, degumming, bleaching, and drying, as well as a method for preparing a small amount of bamboo fiber slurry and viscose fibers. The smallest sub-cluster is Cluster 4, and the main technology man-made charcoal fibers, which include D01F-001 (general methods for the manufacture of man-made filaments or the like) and D01D-001 (treatment of filament-forming or like material). Cluster 4 is mainly about the preparation of bamboo charcoal viscose fiber, which has the characteristics of small particles of bamboo charcoal fiber powder, reaching nanometer level and high adsorption.

Core technology analysis of each sub-cluster

The main path analysis focuses more on the connections between nodes in the network than on the nodes themselves. Including local main path, global main path, critical main path, multi-start main path, main path components, etc. This article first extracts important nodes and important paths in each sub-cluster citation network, and then performs visualization. In the process of visualization, the layout of the hierarchical network is adopted, and the weight of the
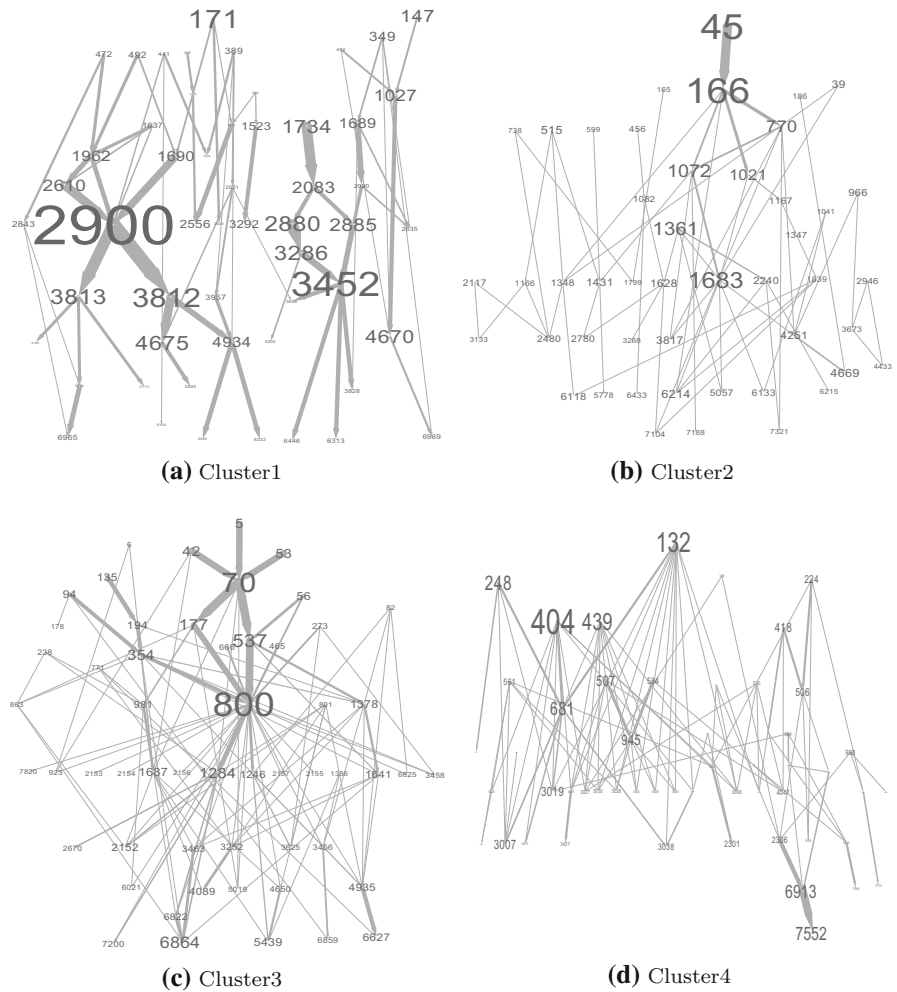
Fig. 9 Visualizing the technological topics in the bamboo fiber field

(a) Cluster 1

(b) Cluster 2

(c) Cluster 3

(d) Cluster 4

edges is represented by the thickness of the edges, and the size of the node labels is represented by the size of the nodes. In order to clearly show the core patents and important paths, edges with a line value less than 0.01 and discrete points are ignored (Fig. 10).

The main content of Cluster 1 is the application of bamboo fiber in the textile field. The patents in Cluster 1 are mainly distributed in China. From adding bamboo fibers to fiber fabrics to improve fabric performance, adding antibacterial agents to bamboo fiber fabrics in different ways, and then producing bamboo fiber underwear and socks with antibacterial functions, the technological development path is relatively clear. The field of innovation is also diverse. The most patents are mainly distributed in the function, combination and application fields of bamboo fiber composite fabrics (Table 3).

The main content of Cluster 2 is the manufacture and application of bamboo fiber reinforced composite materials. The patents in Cluster 2 are mainly distributed in China. The distribution of technological innovation in this field is diverse. Its technological development path is also relatively clear, mainly from the raw material ratio of bamboo fiber reinforced composite materials (resin, glass, plastic, rubber, polyester), the molding process of bamboo fiber reinforced composite materials (including injection molding, hollow molding, extruding blanks) and application fields of bamboo fiber reinforced composite materials (packaging materials, automotive interiors, decoration materials, electrical appliances, etc.) (Table 4).

The main content of the Cluster 3 is the production process of bamboo fiber raw materials. The technological development path in this field is relatively

Fig. 10 Main path analysis of sub-clusters

(a) Cluster1

(b) Cluster2

(c) Cluster3

(d) Cluster4

Table 3 Core patents list of Cluster 1

No.	Value	Patent number	Year	Content
171	0.036	CN100406629-C	2004	Bamboo fiber knitting fabric has the excellent performance of bamboo, including moisture absorption, permeation, health care and antibiotic property and has improved costume performance and size stability
2900	0.066	CN103498273-B	2013	Fabric comprises bamboo fiber and terylene blended fiber, prepared by immersing bamboo fiber and terylene blended fiber in antibacterial agent
3452	0.045	CN104018273-A	2014	Antibacterial wicking textile fabrics comprises milk protein fiber and bamboo fiber blended with antibacterial agent
3812	0.037	CN104432590-B	2014	Antimicrobial underwear contains microfine polyester fiber, bamboo fiber, milk fiber and spandex fiber blended woven fabric having natural antibacterial agent coating
4675	0.030	CN105011391-B	2015	Natural antibacterial bamboo fiber sock used for promoting blood circulation comprises bamboo fiber, lilion fiber, Asparagus fiber, milk fiber, and alginate fiber
4670	0.028	CN105002630-B	2015	Anti-deformation bamboo fiber bath towel, comprises bamboo fiber, combed cotton and superfine fiber that are mixed with raw material of untwisted yarn of bamboo fiber, ultra-fine fiber, combed cotton, milk fiber, modal fiber and fiber tea

Table 4 Core patents list of Cluster 2

No.	Value	Patent Number	Year	Content
45	0.164	JP2002322365-A	2001	Natural raw-material composite material for compacts, contains specific amount of thermoplastic synthetic resin composition and bamboo-type raw-material having preset average particle diameter or fiber length
166	0.164	WO2005121253-A1; KR2005117192-A; KR607405-B1; CN1965032-B; IN248000-B	2004	Sheet composition for e.g. interior sheet for car, comprises specific amount of bamboo fiber, and thermoplastic resin, e.g. polypropylene, polyethylene, acrylonitrile butadiene styrene, polystyrene, or polyvinylchloride
770	0.061	CN101747645-B	2009	Preparing bamboo-plastic composite material comprises mixing modified bamboo fiber, carrier resin, mixed auxiliary agent and putting mixture into double screw extruder for extruding to obtain product
1072	0.069	CN101880423-A	2010	Bamboo fiber/polypropylene composite material used for producing structural, decorative and package products comprises polypropylene, bamboo fiber, compatibilizer and plasticizer
1361	0.073	CN102229749-B	2011	Bamboo-plastic composite material comprises specified amount of polypropylene, bamboo powder or bamboo fiber, compatibilizer, toughening agent, coupling agent, lubricating agent, nuclear and auxiliary agent
1683	0.095	CN102558679-A	2011	Composite material used for e.g. extruded sheets, contains homopolymer polypropylene, bamboo fiber, coupling agent, maleic anhydride-grafted polypropylene, antioxidant, lubricant and molecular weight regulator.

vague. The key patents are mainly related to the crushing or slicing of bamboo fibers, followed by softening, rinsing, bleaching, drying and other bamboo fiber preparation processes. The patent distribution in this field is international, and its technology has the highest value. It is the foundation and core patent of the bamboo fiber industry. Automatic production equipment and environmentally friendly degumming softeners have become important research and development directions in this field (Table 5).

The main content of the Cluster 4 is the preparation of bamboo charcoal viscose fiber. The patents in Cluster 4 are mainly distributed in China. The technological development path in this field is also relatively vague. The key patents mainly relate to the preparation of nano-sized bamboo charcoal fiber particles and the preparation process of bamboo charcoal viscose fibers. This technology is an emerging technology sub-cluster with broad development prospects. But the field of innovation is relatively single, and the number of patents is still small. The preparation of nano-sized bamboo charcoal particles and the preparation of bamboo charcoal viscose fibers

have become important R&D directions in this field (Table 6).

The development trend of each sub-cluster

In order to trace the development trend of each sub-cluster in the technical field of bamboo fiber, we divide the citation network (Fig. 8b) into five time segments in chronological order. And then we analyze the importance of each sub-cluster in the technological evolution by using PageRank algorithm to calculate their weight in each time period.

As shown in Fig. 11. Cluster 1 is bamboo fiber used in the textile field. The technical proportions in the five time periods are 36–30–32–43–39%, ranking first or second in each time period. Therefore, this technology occupies an important position and its development trend is relatively stable. Cluster 2 is the manufacture and application of bamboo fiber reinforced composite materials. The proportion of technology in the five time periods is 4–30–34–23–20%, and the technology development shows an inverted "U" shape trend, which peaked during 2010-2012, and then the

Table 5 Core patents list of Cluster 3

| No.	Value	Patent Number	Year	Content
70	0.354	WO2003089699-A1; AU2003236085-A1; CN1208505-C; US2007267159-A1	2002	Producing method of bamboo fiber, involves pretreating bamboo fiber, decomposing bamboo fiber, forming bamboo and subjecting to after treatment
354	0.139	KR754315-B1; WO2008063014-A1; US2010294443-A1	2006	Method for manufacturing a bamboo chip to produce a natural fiber and a method for manufacturing a bamboo fiber using the same.
800	0.453	CN101538744-B	2009	Making bamboo fiber, comprises sawing, sectioning, splitting, scouring, cleaning, drying, and enzyme treating.
537	0.204	CN101210350-B	2007	Organic processing of bamboo fiber, involves separating bamboo material into yellow and green bamboo, softening, rinsing, bleaching, washing and drying bleached bamboo fiber, airing washed fiber, and carding aired bamboo fiber.
1284	0.141	WO2012126168-A1; VN36233-A; IN201307030-P4; CN102959142-B; US9630337-B2	2011	YMethod for producing e.g. weave composite bamboo fiber, involves slicing, flattening, softening, dividing, debonding, rinsing, immersing, drying and opening natural bamboo fiber, and cutting natural bamboo fiber to certain length
6864	0.169	WO2018119834-A1	2016	Clean production of bamboo fibers involves dividing fresh bamboo materials into bamboo strips, removing e.g. bamboo leaves, cutting into pieces, dividing into shreds, twisting into rope-shaped bamboo filaments, refining and drying

Table 6 Core patents list of Cluster 4

No.	Value	Patent Number	Year	Content
132	0.097	CN1293243-C	2003	Bamboo charcoal viscose fiber and method for making same.
404	0.120	CN100558952-C	2007	Bamboo carbon viscose fiber and its manufacturing method.
681	0.069	CN101724932-B	2008	Composite functional bamboo pulp fiber contains specified range of absolute dry fiber content and remainder of water and micro-impurity in final product.
6913	0.069	CN106835324-A	2017	Preparing polypropylene nano bamboo carbon short fiber by drying bamboo, carbonizing, calcining and cooling, physical or chemical processing, surface treating and dispersing with spinning grade homopoly propylene powder and hot melt spinning.
7552	0.069	CN107268102-A	2017	Fine-denier polypropylene staple fiber manufacturing involves preparing raw materials including polypropylene chips and additives, placing in mixer to obtain raw material, where additive comprises bamboo carbon particles as raw material.

proportion gradually becomes smaller. This shows that the technology is slowly maturing. Cluster 3 is the extraction process of bamboo fiber from bamboo raw materials. The proportion of technology in the five sectors has decreased year by year, being 40–30–14–12–11%. During 1998-2006, Cluster 3 was the

Fig. 11 The development trend of each technological sub-cluster
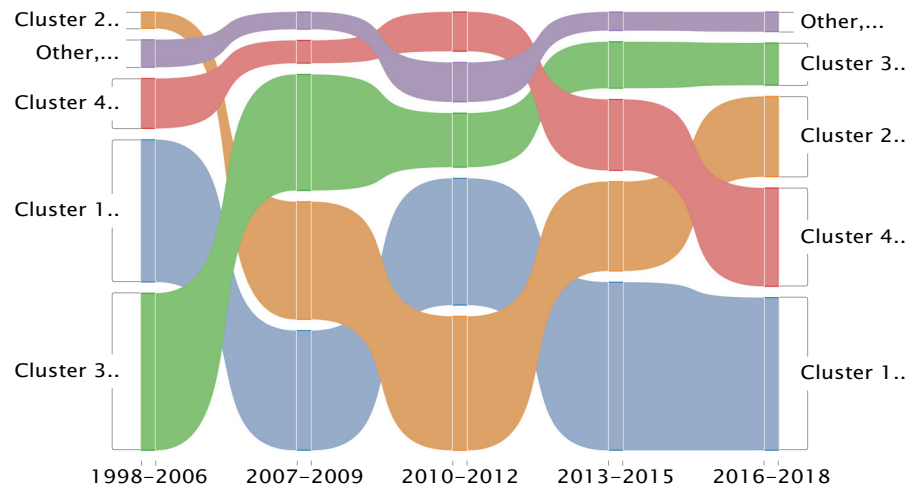
mainstream technology, and the proportion of technology gradually decreased with the growth of the year. The technical importance was replaced by other technical clusters, indicating that the technology for extracting bamboo fibers from bamboo is very mature. Cluster 4 is the preparation of bamboo charcoal fiber viscose. The proportion of technologies in the five time segments is 13–6–10–18–25%. It is worth noting that since 2012, the growth rate of this technology has increased year by year and reached its maximum in 2016-2018, indicating that the technology has the potential for continuous development and is an important development trend in the future, which deserves more research.

Conclusions and suggestions

In this paper, the detailed analysis of the bamboo fiber technology from the patent perspective lead us to conclude the following three conclusions and suggestions:

1. The patent distribution of bamboo fiber technology lead us to conclude that the innovation of bamboo fiber technology is very dependent on the origin of the raw materials, therefore forming two major innovaton regions: the East Asia region and Europe-America region. East Asia has the largest number of patents and technology development potential. And in this area, China Mainland, Japan, South Korea, and China Taiwan have leading positions in technology. For countries with abundant bamboo resources, such as India, Myanmar, Thailand, Vietnam, Indonesia, and Philippines, but relatively lacking in technology, they have great technology transfer potential. Licensing or transfer of patented technology can help the development and upgrading of the local bamboo industry. In Europe and the U.S., the distribution of patents is more balanced and the market development is more mature.

2. In the bamboo fiber patent citation network, the largest subnet was divided into four sub-clusters. And we identified the themes and core technologies of these four technical sub-clusters. Cluster 1 is the application of bamboo fiber in the textile field. The main R&D direction of cluster 1 is the functionality (antibacterial, adsorption, etc.), combination (spinning or cloth with a variety of fibers) and application areas (underwear, socks, etc.) of bamboo fiber composite fabrics. Cluster 2 is the manufacture and application of bamboo fiber reinforced composite materials. The main R&D direction of cluster 2 is mainly in the raw material combination ratio, molding process and application fields of bamboo fiber reinforced composite materials (packaging materials, automotive interiors, decoration materials, electrical appliances, etc.). Cluster 3 is the extraction process of bamboo fiber from bamboo raw materials. The important R&D directions of Cluster 3 are automated production equipment and environmentally friendly degumming softeners. And Cluster 4 is the preparation of bamboo charcoal

fiber viscose. The important R&D directions of cluster 4 are the preparation of nano-scale bamboo charcoal particles and the preparation process of bamboo charcoal viscose fibers.

3. The application of bamboo fiber in the textile field is still the focus of the technical innovation. As to the technology of extracting bamboo fiber from bamboo raw materials, it has entered the mature stage of innovation. And the technology of manufacture and application of bamboo fiber reinforced composites is beginning to enter the mature stage of innovation. On the contrary, the technology of bamboo charcoal fiber is in the period of repid development of innovation, which deserves more research in the future.

Limitations and prospects

It should be pointed out that the purpose of this study is to analyze the innovation prospect and hot-spots of bamboo fiber technology, rather than the entire bamboo fiber industry. For example, An important application of bamboo fiber technology is used in papermaking. However, in the analysis of this article, this technology has not appeared a large-scale patent cluster. This result means that the technology may not be a current innovation hotspot. The reason may be that the technology has a long history of development, the technical process is relatively simple and the innovation prospect is limited. Since we only used patent data in this article, in future research, we should pay more attention to the literature in this field. Through the joint analysis of literature and patent data, we hope we can identify more green technologies with innovative potential, and providing information support for governments in policy formulation, technology transfer and promotion, thereby accelerating the innovation and development of green technologies.

Compliance with ethical standards

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