Analyzing Technological Knowledge Diffusion among Technological Fields Using Patent Data: The Example of Microfluidics

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***Abstract*--Study of technological knowledge diffusion can provide a basis for R&D planners to invest new R&D projects with a proper direction. In this paper, we introduce a modified method to analyze the diffusion degree of technological knowledge among different technological fields using patent data at the technology patent class level. This method first generates a patent citation network related to a specific research area and then establishes a technological field diffusion matrix according to the concordance between the patent document and the corresponding patent class. After that indicators are set up to measure the diffusion degree of technological field from two aspects of diffusion depth and breadth and then we discern the diffusion types of typical fields. Finally, we conduct microfluidic technology as a case study to prove the feasibility of the method.**

I. INTRODUCTION

With the ever faster pace of technology innovation, new technological knowledge keeps emerging and diffusing all the time[1]. Technological knowledge not only flows in the same technological field which is called internal diffusion, but it also spreads between different technological fields. Technological knowledge diffusion has brought about an advance in generation of new technology. Muti-technology fusion and technology re-innovation occur in the process of technological knowledge diffusion, which leads to the development and evolution of technology itself. Meanwhile, technology application in different fields along with technological knowledge diffusion has also changed the structure and pattern of related fields. Studies have shown that the boundaries of technology are gradually becoming blurred, outstanding inventions no longer appear in a single technological field but often appear between technological fields[2-3]. It reflects that technological knowledge diffusion among different technological fields has become a common diffusion phenomenon. Previous literature of technological knowledge diffusion has mainly focused on the relationship between knowledge diffusion and economic factors[4-5], a few studies have investigated the structure of international technological knowledge diffusion at the macro level[6-7]. But they rarely go deep into the technological field level to analyze the degree of the technological knowledge diffusion. For government and enterprises, R &D investment has a high risk since the uncertainty of innovation and diffusion. It is difficult to make the choice whether they should strengthen the investment to an existing technology domain or to an emerging technology field[8-9]. Therefore, study of technological knowledge diffusion among different technological fields can provide a basis for R&D planners to invest new R&D projects with a proper direction[10]. Identification of diffusion degree of technological fields can be meaningful for R&D planners to analyze the role of each technology field and distinguish the mature field and emerging field, which has the vital significance for exploiting the R&D opportunities and reducing the risk of R&D investment.

This paper introduces a modified method to analyze the diffusion degree of technological knowledge among different technological fields using patent data at the technology patent class level. This method first generates a patent citation network related to a specific research area and then establishes a technological field diffusion matrix according to the concordance between the patent document and the corresponding patent class. Because the patent class and the patent document do not have an one-to-one correspondence relationship, some patents belong to multiple technological fields. Each technological field has a certain practical significance and represents the scope of the technology patent. So we set different weights to each patent classification rather than selecting primary patent classification only. After that indicators are set up to measure the diffusion degree of technological field from two aspects of diffusion depth and breadth. Then we discern the diffusion type of typical fields. Finally, microfluidic technology is conduct as a case study to prove the feasibility of the method.

II. RELATED WORKS

A. technological knowledge diffusion

A few studies have investigated the relationship between economic factors and technological knowledge diffusion[4-5]. Some scholars focused on the structure of international technological knowledge diffusion at the macro level[6-7]. Patent collaboration used to measure international technological knowledge diffusion and mathematical models have been established to explain international technological knowledge diffusion phenomenon [11-15]. Some other scholars tend to study technological knowledge diffusion from the perspective of industry, they use patent networks and input-output analysis to measure knowledge flows[16-18]. The distribution curve of technological knowledge diffusion is another research topic. Some other scholars explore if the distribution of technological knowledge diffusion can follow a classic S-curve distribution and make predictions of trend of diffusion[19-20].Most relevant to our work here is technological knowledge diffusion at the level of technological fields[18,21,22,23]. Researchers concentrated on identification of knowledge intermediaries in one technological field and classified patent class according to technological knowledge fusion[22-23]. It is still required to develop measurement of technological knowledge diffusion degree from different aspects. In this regard, we introduce a modified method to analyze the diffusion degree of technological knowledge among technological fields from two aspects of diffusion depth and breadth.

B. patent citation analysis

Patent data contains the information of technical characteristics in detail that can be widely used to measure inventive activity[24]. Patent citation information can be used as different measurements. Some studies use the number of citations to measure the value of patents that more frequently cited patents have higher value[24-26]. A few studies use patent citation information to explore similarities between technologies and present a new classification method to cluster patents[27]. However, studies above rarely notice the implication of characteristic of directivity in patent citation information. Patent citations not only establish relationships among different patents[28], but they also reflect the diffusion direction which is from the cited patent to the citing patent. We can identify the links between innovations and their technological 'antecedents' and 'descendants' by tracing forward patent citations and backward patent citations[21]. Moreover, citation information of patents provide us effective information resources for mining linkages among inventors, firms, countries, etc.[21]. In this regard, we use patent citation information to depict technological knowledge diffusion across various technological fields and extend the patent citation network to a weighted directional network of technology fields.

III. METHOD

This section presents a procedural framework for analyzing technological knowledge diffusion among technological fields. It consists of 3 steps below:

1. Generating the patent citation network related to a specific research area by extracting forward patent citations and backward patent citations.
2. Establishing the technological knowledge diffusion matrix among technological fields.
3. Setting up indicators to measure the diffusion degree of technological fields.

Each step of the procedural method will be explained in detail as follows.

A. Generating the patent citation network

Citation relationships between patents reflect the links between innovations and technological 'antecedents' and 'descendants'. If a patent cites many other patents, we can assume that this patent absorb much knowledge from the cited patents. Similarly, a patent which is cited by other later patents can be considered to diffuse its technological knowledge to other later patents. The direction of technological knowledge diffusion is from the cited patents to citing patents. The expansion of technological knowledge is accompanied by the absorption and diffusion of technological knowledge.

In this step, we generate the patent citation network related to a specific area, which is helpful for processing data of the second step. Firstly, we should select suitable patent database and collect patent data. The collection of patent data may be a more complex problem due to the choice of various patent databases. We can choose the secondary databases like the NEBR database or collect patent data manually from the patent office websites. It is simple and easy to get patent citation data from the secondary databases, but the secondary databases may not provide the latest information as well as all of the patents from the NEBR database are only U.S. patents. Patent data from the NEBR database and U.S. Patent and Trademark Office (USPTO) database are both U.S. patents, which may not reflect the state of global technology. Therefore, we collect patent data from the Derwent Innovations Index which covers more than 100 countries and 40 patent office[29]. The difference between our research and previous studies is that our research object is limited to a specific technology. We just consider the technological knowledge diffusion in the relevant specific area. Therefore, we get rid of the cited patents and the citing patents which are not included in this technology area in order to ensure that each patent in the patent citation network is closely related to this related specific area. Our own JAVA-based mining program helps us to complete the data processing[30].

B. Establishing the technological knowledge diffusion matrix among technological fields

In this step, we establish the technological knowledge diffusion matrix among technological fields from the patent citation network in the previous step. Firstly, each patent citation pair is extracted from the patent citation network. The reason why we choose to get each patent citation pair from the patent citation network instead of getting it directly from the patent database is that the patent citation network excluding irrelevant patent can make data processing more easily. We refer to each citation from patent i to a previous patent as a citation pair. A patent citation pair shows that the technological knowledge diffusion direction is from the cited patent to the citing patent. Each patent is assigned to one or more classifications and we assume that the classification of the patent represents that patent's technological fields. So we convert technological knowledge diffusion between patents into ones between technological fields on the basis of the correspondence of the patent document and the patent class. In order to clarify the involved technological field in detail, patent applicants would tend to list classification code according to the patent subject. We have noticed that some patents are classified into multiple IPC codes which may not be an individual phenomenon. Previous studies consider the first classification code as the primary classification code and use only primary classification to identify technological knowledge flows[18].However, we consider that each IPC code of a patent is of great significance, for it reflects the information of the technological fields comprehensively. Patent applicants not only list the primary classification, but they also list other classifications since both the primary classification and non-primary classifications are related to the patent document. The very non-primary classification which is often overlooked may imply the important information. In contrast to previous research, we consider each IPC codes instead of the only primary IPC codes for each patent citation pair. The procedure is shown in Fig.1.

TABLE 1. TECHNOLOGICAL KNOWLEDGE DIFFUSION MATRIX AMONG TECHNOLOGICAL FIELDS

	IPCa	IPCb	IPCc	IPCd
IPCa	---	∑KDa,b	∑KDa,c	∑KDa,d
IPCb	∑KDb,a	---	∑KDb,c	∑KDb,d
IPCc	∑KDc,a	∑KDc,b	---	∑KDc,d
IPCd	∑KDd,a	∑KDd,b	∑KDd,c	---

∑KDa,b means the knowledge diffusion from class a to class b by adding the knowledge diffusion from class a to class b in each patent citation pair

In Fig.1, we show the procedure for generating the technological knowledge diffusion matrix among technological fields. More specifically, we assume that patent 1 is cited by Patent 2 and Patent 1 is classified into IPCa and IPCb while Patent B is classified into IPCa, IPCc and IPCd. The number of classifications of patent 1 is n and the number of classifications of patent 2 is m. In this context, the diffusion pair from patent 1 to patent 2 is converted to 6 (n×m)technological field diffusion pairs that are pairs from IPCa to IPCa, from IPCa to IPCc, from IPCa to IPCd, from IPCb to IPCa, from IPCb to IPCc, and from IPCb to IPCd. The first pair from IPCa to IPCa is equivalent to the self-citation pair. We calculate that the weight of each diffusion pair between IPC codes is the reciprocal of product of the numbers of patent 1 and patent 2. Using the above method, we organize the technological knowledge diffusion matrix among technological fields by aggregating the weight of each diffusion pair between IPC codes.

C. Setting up indicators to measure the diffusion depth and breadth of technological fields

This step describes several indicators to measure the diffusion depth and breadth of technological fields and then presents a method to analyze the diffusion types of typical technological fields using a knowledge diffusion map.

1. Diffusion Depth of technological fields

Diffusion Depth(DD) of technological fields focusing on the citation frequency reflects diffusion capability and demanded quantity of the technological field. The more frequently one technological field diffuse its knowledge to other fields, the depth of this technological field diffusion is deeper. We notice that each technological field would bring in some other fields' knowledge and also send out its knowledge. We define Diffusion Depth inside (DDin) as the amount of knowledge that the corresponding technological field brings in from others which belong to different fields. DDin can be measured by summing the weight of the inward arcs. We also define Diffusion Depth outside(DDout) as the amount of knowledge that the corresponding technological field send out to other technological fields. DDout can be measured by adding the weight of the outward arcs. The calculation method is as follows.

$$DDin(i)=\sum_{class(i)\neq class(j)} KDD_{j,i} \quad (1)$$

$$DDout(i)=\sum_{class(i)\neq class(j)} KDD_{i,j} \quad (2)$$

where KDDi,j means the knowledge diffusion from class i to class j from the point of diffusion depth by adding the citation frequency from class a to class b in each patent citation pair.

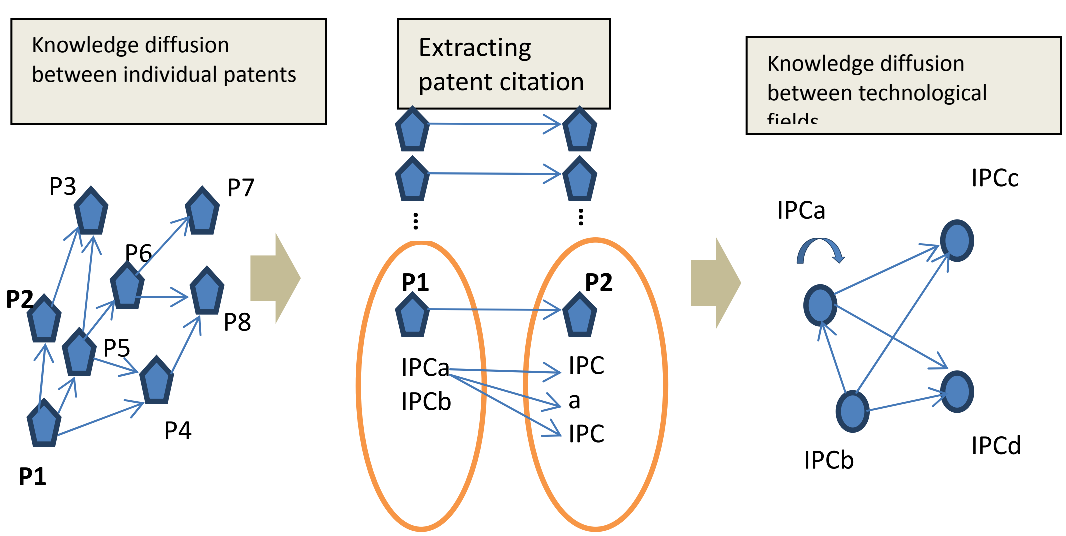

Fig.1. Procedure for generating the technological knowledge diffusion matrix among technological fields

We establish coordinates for identification of technological diffusion depth state for each technological field in Fig.2.

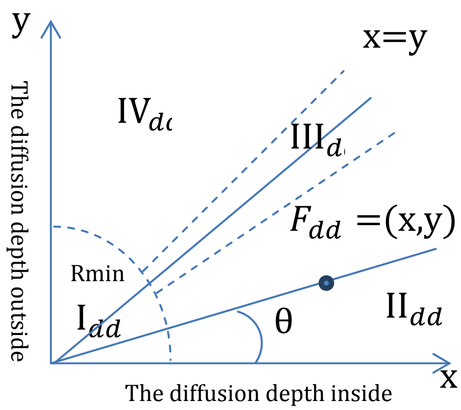

Fig.2. Technological diffusion depth state map

$$R=\sqrt{X^2+Y^2}; \tag{3}$$
$$\theta=\arctan(Y/X) \tag{4}$$

F_{dd} (x,y) describes the diffusion depth state of each technological field. We set the value of X as DDin and set the value of y as DDout. R reflects the comprehensive ability of diffusion depth inside (DDin) and diffusion depth outside (DDout). We set a minimum value of R as a threshold. Θ reflects the tendency of diffusion depth inside (DDin) or diffusion depth outside(DDout). $\Theta_0 = 45°$, we define 2Δ as the mature bandwidth. We divide the technological diffusion depth state map into four part that is I_{dd}, II_{dd}, III_{dd} and IV_{dd} according to the value of Θ and R as follows:

When R≤Rmin, the interaction of the technological field and other fields is not obvious. The technological field belongs to I_{dd}.

When $\Theta<\Theta_0-\Delta$ and R>Rmin, the technological field brings in large amount of other fields' knowledge but relatively sends less knowledge out. The technological field belongs to II_{dd}.

When $\Theta\in(\Theta_0-\Delta,\Theta_0+\Delta)$ and R>Rmin, the technological field is in an equilibrium diffusion state which means the amount of the knowledge that it brings in is equal to the amount of the knowledge that the field sends out. The technological field belongs to III_{dd}.

When $\Theta>\Theta_0+\Delta$ and R>Rmin, the technological field sends its knowledge out in abundance but brings in less knowledge from other fields. The technological field belongs to IV_{dd}.

2. Diffusion Breadth of technological fields

Diffusion breadth of technological fields focusing on the field diversity reflects diffusion scope and coverage of the technological field. Some technological fields may diffuse knowledge more frequently but not variously while some technological fields may send less knowledge out but the number of technological fields outside is large, which shows that it is not enough to measure diffusion of technological knowledge from only the view of diffusion depth. We should consider the variety of technological fields from the view of diffusion breadth. As well, we define Diffusion Breadth inside (DBin) as the variety of knowledge that the corresponding technological field brings in from others. DBin can be measured by adding the number of fields which the weight of inward arcs is nonzero. We also define Diffusion Breadth outside (DBout) as the diversity of knowledge that the corresponding technological field send out to other technological fields. DBout can be measured by summing the number of fields which the weight of outward arcs is nonzero. The calculation method is as follows.

$$\mathrm{DBin(i)} = \sum_{\mathrm{KDD_{j,i}} \neq 0} \mathrm{Ni} \;; \tag{5}$$
$$\mathrm{DBout(i)} = \sum_{\mathrm{KDD_{i,j}} \neq 0} \mathrm{Ni} \tag{6}$$

where $\mathrm{KDD_{j,i}} \neq 0$ or $\mathrm{KDD_{i,j}} \neq 0$ reflects the relative inside or outside fields, ∑Ni means the number of inside fields or outside fields.

We establish coordinates for each technological field for identification of technological diffusion breadth state in Fig.3.

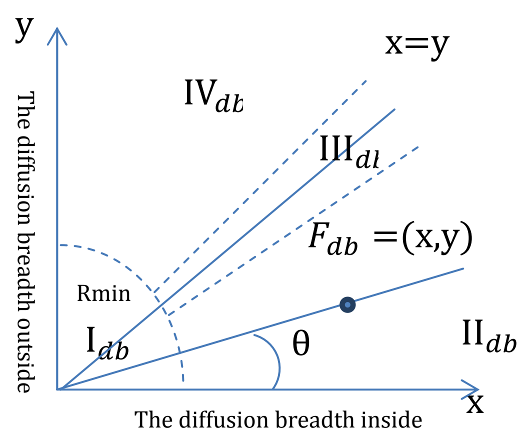

Fig.3. Technological diffusion breadth state map

$$R'=\sqrt{X^2+Y^2}; \tag{7}$$
$$\theta'=\arctan(Y/X) \tag{8}$$

F_{db} (x,y) describes the diffusion breadth state of each technological field. We set the value of X as DBin and set the value of y as DBout. R' reflects the comprehensive ability of diffusion breadth inside (DBin) and diffusion breadth outside (DBout). We set a minimum value of R as a threshold. Θ' reflects the tendency of diffusion breadth inside (DBin) or diffusion breadth outside (DBout). $\Theta'_0 = 45°$, we define 2Δ as the mature bandwidth. We divide the technological diffusion breadth state map into four part that is I_{db}, II_{db}, III_{db} and IV_{db} according to the value of Θ' and R as follows:

When R'≤R'min, the interaction of the technological field and other fields is not obvious. The technological field belongs to I_{db}.

When $\Theta' < \Theta'_0 - \Delta$ and $R' > Rmin$, the technological field brings various fields' knowledge but relatively sends single fields' knowledge out. The technological field belongs to II_{db}.

When $\Theta' \in (\Theta'_0 - \Delta, \Theta'_0 + \Delta)$ and $R' > Rmin$, the technological field is in an equilibrium diffusion state which means the types of fields that it brings in is equal to the types of fields that it sends out. The technological field belongs to III_{db}.

When $\Theta' > \Theta'_0 + \Delta$ and $R' > Rmin$, the technological field sends various fields' knowledge out but brings in single fields' knowledge from other fields. The technological field belongs to IV_{db}.

3. Diffusion types of technological fields

We consider both diffusion depth and diffusion breadth of each technological field and classify technological knowledge diffusion patterns into a four categories of taxonomy at the technological field level:

(i) the consistent diffusion depth and diffusion breadth. The part of technological diffusion depth state map which the technological field falls in stays the same as (or very approximate to) the corresponding part in the technological diffusion breadth state map, such as it belongs to (I_{dd},I_{db}), (II_{dd},II_{db}), (III_{dd},III_{db}) or (IV_{dd},IV_{db}). The strong consistency of the two kinds of state illustrate the strong diffusion property of in this respect. We can continue to subdivide the category (i) into consistently scarce (I_{dd},I_{db}), consistently converging (II_{dd},II_{db}), consistently balanced(III_{dd},III_{db}) and consistently diverging(IV_{dd},IV_{db}). (I_{dd},I_{db}) and (II_{dd},II_{db}) can be the situations of emerging fields while (III_{dd},III_{db}) and (IV_{dd},IV_{db}) can be the situations of mature fields.

(ii) the limited diffusion depth or diffusion breadth. The part of technological diffusion depth state map which the technological field falls in is different from (or even appears an opposite tendency to) the corresponding part in technological diffusion breadth state map, such as it belongs to (I_{dd},IV_{db}), (IV_{dd},II_{db}), (III_{dd},II_{db}) or (II_{dd},IV_{db}) and so on.

IV EMPIRICAL STUDY: THE CASE OF MICROFLUIDICS

A. Data collection

This paper conducts an empirical study to prove the feasibility of the method using patent data related to the microfluidics. Based on analytical chemistry, bio-analytical chemistry and micro electro mechanical Systems（MEMS） techniques, microfluidic chip is characterized by its complex micro-channel networks and the integration of all the functions in a laboratory such as sampling, attenuation, adding reagent, reaction, separation, detection and so on. Since a microfluidic chip could be used for many times and costs very little regent, it has an extensive applicability and is regarded as the focus of the fast developing micro total analysis system. To prepare patent data for our analysis, we collect international patents related to the microfluidics from the Derwent Innovations Index. After eliminating irrelevant patents, we finally acquire3474 main patents which are closely related to the microfluidics. The patents were filed between 1989 and 2013. We use our own JAVA-based mining program to complete the data processing and generate the patent citation network of microfluidics. In the data processing, we eliminated the cited patents and the citing patents which are not included in this technology area in order to ensure each patent in the patent citation network is closely related to this related specific area. After generating the patent citation network, we extract 9317 patent citation pairs from the patent citation network. We convert patent citation pairs into technological field diffusion pairs based on of correspondence method we have proposed. The amount of technological fields of cited patents is 188 while the number of technological fields of citing patents is 165. Then we organize the technological knowledge diffusion matrix among technological fields by aggregating the weight of each diffusion pair between IPC codes. We use front three IPC codes as technology class representing the technological field. Technological knowledge diffusion matrix among technological fields is a 197*197 matrix which covers the technological fields of cited patents and citing patents. The diffusion of technological knowledge between all pair of technology classes is visualized in Fig.4.

	A01K	A01N	A21C	A41D	A43B	A45D	A46B	A47J	A61B	A61D
A01K	0	0	0	0	0	0	0	0	0	0
A01N	0	0	0	0	0	0	0	0	0	0
A21C	0	0	0	0	0	0	0	0	0	0
A41D	0	0	0	0	0	0	0	0	0	0
A43B	0	0	0	0	0	0	0	0	0	0
A45D	0	0	0	0	0	0	0	0	0	0
A46B	0	0	0	0	0	2/3	0	0	0	0
A47J	1/84	0	0	0	0	0	0	0	1/28	1/42

Fig.4.Technological knowledge diffusion matrix among technological fields

B. Results and technological implications

We firstly establish coordinates reflecting technological diffusion depth state for each technological field in Fig.5-1 and Fig.5-2.From the map, we can identify the diffusion capability of the technological field.

In technological knowledge diffusion depth state map with large scale axis, we can see that B01L(chemical or physical laboratory apparatus for general use), C12M(Apparatus for enzymology or microbiology), G01N(investigating or analyzing materials by determining their chemical or physical properties) belong to III_{dd}. Microfluidic chip is a kind of physical and chemical device that integrates several specific function (like detecting, separating, analyzing, cell culturing and so on) on a single chip based on some specific physical and chemical mechanism or technique. It is also known as 'Lab-on-a-chip' or 'μTAS'(Micro Total Analysis Systems"). This indicated that microfluidic chip itself could be defined as 'a chemical or physical laboratory apparatus'. That's to say B01L is a fundamental classification in patents of microfluidic chip. Thus, it's not difficult to understand why the coordinate of B01L appears a strong diffusion depth inside state and a strong diffusion depth outside state as well. Besides, we all know that one of the most basic and hottest applications of microfluidic chip is using in Bio-Analysis. So enzymology and microbiology problems are also important subjects of study by using microfluidic chips. Therefore, C12M is a key technological fields related to microfluidic technology. Study on the technology for analyzing enzymology or microbiology problems in a microfluidic chip are tightly focused by scholars of many areas. Thus, C12M bringing in much knowledge from other technological fields is observed, for the scholars should using specific technique from other fields. Meanwhile, their results may enlighten some other scholars for developing microfluidic techniques. This situation could result in a huge value of diffusion. As to the result of G01N, we all know that analyzing a specified chemical or physical property of a target is fundamental application of a microfluidic chip. So this situation could be well explained as that of B01L. The results of this two technique areas in the chart is also of a great similarity, for they all fall in III_{dd}. Thus, the technological fields which fall in III_{dd} could be regarded as a fundamental technology or a fundamental application based on the explanation above.

In order to show the map clearly we draw technological knowledge diffusion depth state map with small scale axis based on the same data. We can see that B01F(mixing, e.g. dissolving, emulsifying, dispersing), C12P (fermentation or enzyme-using processes to synthesis a desired chemical compound or composition or to or to separate optical isomers from a racemic mixture), B32B (layered products, i.e. products built-up of strata of flat or non-flat, e.g. cellular or honeycomb), F15C(fluid-circuit elements predominantly used for computing or control purposes), C12Q(measuring or testing processes involving enzymes or micro-organisms) are the typical fields which belong to II_{dd}, B01D (separation), B81B (micro-structural devices or system, e.g. micro-mechanical devices), B01J (chemical or physical processes, e.g. catalysis, colloid chemistry; their relevant apparatus), F16K (valves; taps; cocks; actuating-floats; devices for venting or aerating), C12N (micro-organisms or enzymes) are typical fields which belong to IV_{dd} and H05B (electric heating; electric lighting not otherwise provided for) is the typical field which belongs to I_{dd}. The technological knowledge in B01F related to the research of microfluidics has mainly focused on mixture of different solvents or a mixture of gas and liquid. It is a relatively new research hotspot that has a strong application demand. For there are some technical difficulties in B01F, the technological knowledge in this field is still in the preliminary research

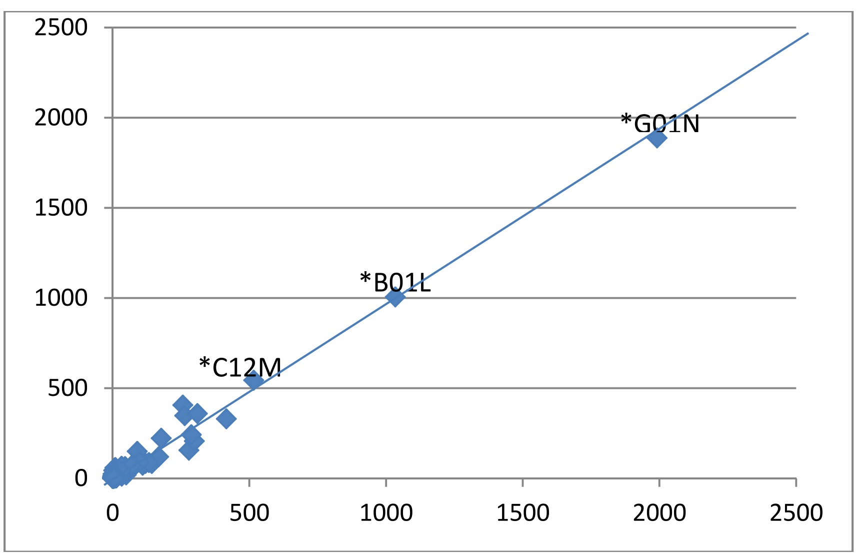

Fig.5-1.technological knowledge diffusion depth state map with large scale axis

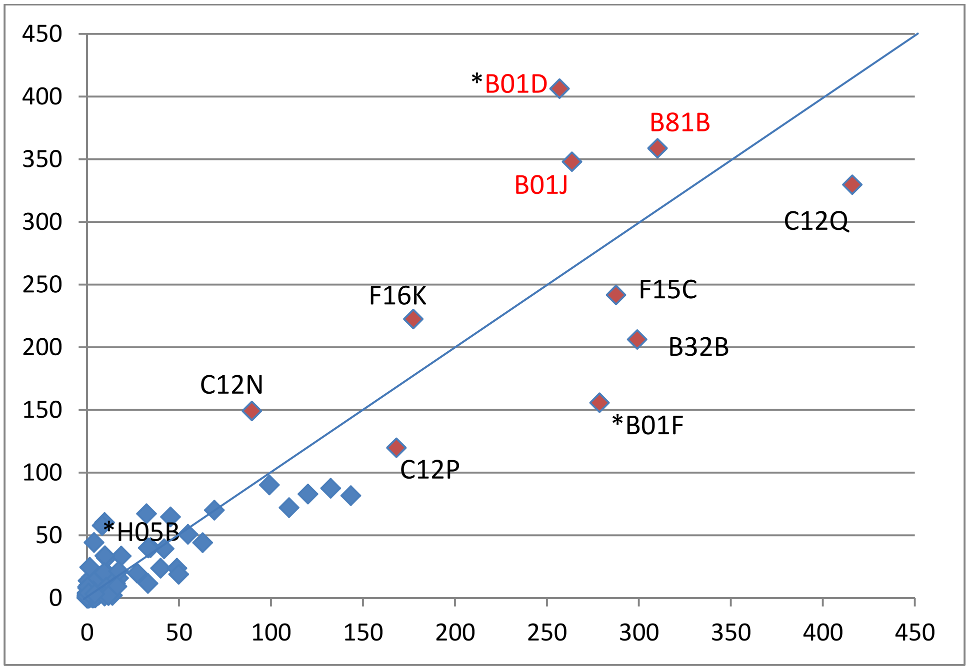

Fig.5-2.technological knowledge diffusion depth state map

stage. Thus, B01F requires bringing in technological knowledge from other fields to improve itself. That is to say, the capability of diffusion depth inside of B01F is strong. However, the technological knowledge of this field is still in its developing stage and not mature, it presents a less diffusion depth outside situation. Similarity, B32B shows the same diffusion depth state with B01F. B32B is about microfluidic chip bonding with multilayer chip material and micro-channel is spatial reticulated structure which may be related to cellular. Multilayered structure of microfluidic chip is in the process of growing and therefore B32B need other fields' knowledge to improve itself. As to the result of B01D, it falls into the opposite part compared with B01F. B01F is a mature technological knowledge field related to microfluidic technology. Study on B01F related to the microfluidic technology is primary separating the required cell, tissue or specific structure with the reagent by making specific structure which is similar to molecular sieve type or other special ways so as to achieve the purpose of separation. The technological knowledge in B01F is more widely adopted. Thus, it's not difficult to understand why the coordinate of B01F appears a strong diffusing depth outside state as well. H05B is an optical technological field in the research area of microfluidics which contains the liquid driven technological knowledge and temperature control technological knowledge. It is a limited technological field for the R of coordinates is less than the minimum R value although the diffusion depth inside and diffusion depth outside of the field exists at the same time. It illustrates that the field H05B is not a main stream related to microfluidics. There are many other fields falling in the part of I_{dd},II_{dd}, III_{dd}, IV_{dd} and we explain the representative fields to prove the feasibility and consistency of the method.

We then establish coordinates reflecting technological diffusion breadth state for each technological field in Fig.6 according to the steps proposed in 3.3.2. From the map, we can identify the diffusion scope of the technological field. More fields falling into part II_{db} than in Part IV_{db} in the map means the fields related to microfluidics intend to absorb more various fields' knowledge than sending out its knowledge to comprehensive fields. It reflects the microfluidics is an intercrossing technology which needs to integrate various fields' knowledge to achieve development and technological knowledge of microfluidics is used in specific and limited areas. The fields which have strong diffusion breadth inside and diffusion breadth outside mostly fall into II_{db}. We see G01N sending its knowledge to 173 fields and bringing in 147 fields which shows that G01N related with microfluidics is a fundamental and an applicable knowledge field as well.

We take diffusion depth and diffusion breadth into consideration and compare the difference between the typical fields in Table2.We identify that C12Q, F15C, B32B, B01F, C12P, H05B accord with the consistent diffusion depth and diffusion breadth state, which illustrates that these fields in microfluidics are in the development process with quantity increasing and field expanding.

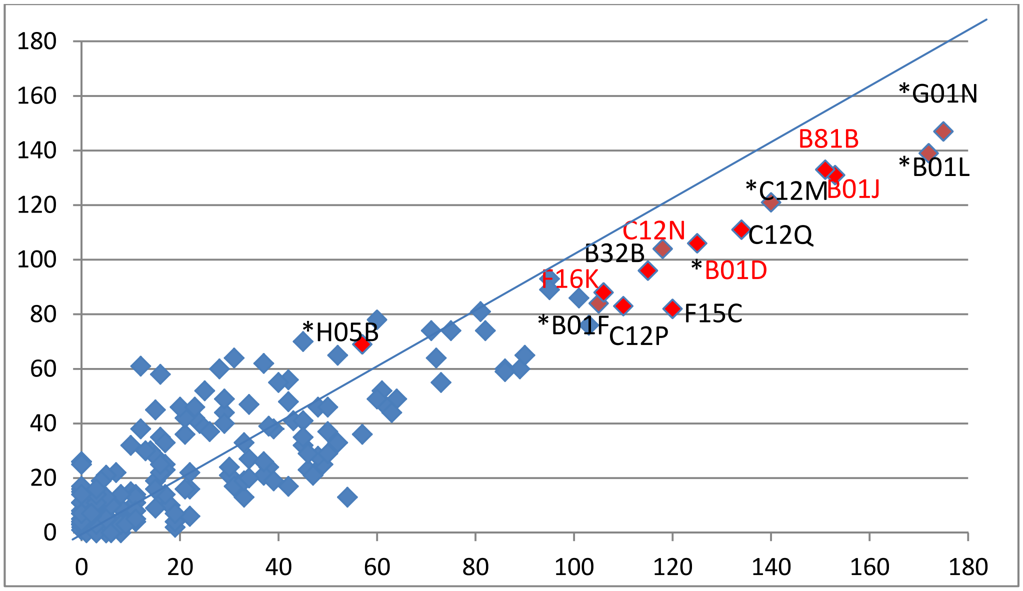

Fig.6.technological knowledge diffusion breadth state map

TABLE2 COMPARISON OF DIFFUSION DEPTH AND DIFFUSION BREADTH OF TYPICAL FIELDS

Diffusion Depth	Diffusion Breadth	IPC codes	Interpretation
IV_{dd}	II_{db}	B01D	separation
		B81B	micro-structural devices or system, e.g. micro-mechanical devices
		B01J	chemical or physical processes, e.g. catalysis, colloid chemistry; their relevant apparatus
		F16K	valves; taps; cocks; actuating-floats; devices for venting or aerating
		C12N	micro-organisms or enzymes
II_{dd}	II_{db}	C12Q	measuring or testing processes involving enzymes or micro-organisms
		F15C	fluid-circuit elements predominantly used for computing or control purposes
		B32B	layered products, i.e. products built-up of strata of flat or non-flat, e.g. cellular or honeycomb
		B01F	mixing, e.g. dissolving, emulsifying, dispersing
		C12P	fermentation or enzyme-using processes to synthesis a desired chemical compound or composition or to or to separate optical isomers from a racemic mixture
II_{dd}	IV_{dd}	B81C	Processes or apparatus specially adapted for the manufacture or treatment of micro-structural
I_{dd}	I_{db}	H05B	electric heating; electric lighting not otherwise provided for
III_{dd}	II_{db}	G01N	investigating or analyzing materials by determining their chemical or physical properties
		B01L	chemical or physical laboratory apparatus for general use
		C12M	Apparatus for enzymology or microbiology

B01D, B81B, B01J, F16K, C12N present opposite diffusion depth or diffusion breadth. These fields fall into IV_{dd} in diffusion depth state map and II_{db} in diffusion breadth state map. We can infer that the field can be an emerging technological field which draws upon an existing body of various fields' knowledge. At the same time the possibility of combination and intercrossing with other fields is small since the technological field is relatively new, so the field appears weak diffusion depth. However, the field has become a relatively mature basic application field due to its well-developed level. In this opinion, some other fields that can combine knowledge with that field would absorb knowledge from the field widely. B81C falls into IV_{dd} in diffusion depth state map and II_{db} in diffusion breadth state map. It means that the technological field is in a high-speed development stage and it needs to absorb large amount of knowledge yet in the limited specific scope. Meanwhile, this technological field belongs to the basic theory or application which is required as a supplement in widely fields and the knowledge demand of other fields is not large. Therefore, diffusion breadth outside of this field is strong yet the amount of diffusion appears relatively small.

V. CONCLUSION

In this paper, we propose a modified method to analyze technological knowledge diffusion at the technological field level from two aspects of diffusion depth and diffusion breadth. The presented method includes extracting patent citation pairs and converting technological knowledge diffusion between patents into technological knowledge diffusion between technological fields by a correspondence of the patent document and the patent class. In this regard, we propose a corresponding method for considering each IPC codes instead of the only primary IPC codes for each patent citation pair in order to reflect the information of the technological fields comprehensively. Building on diffusion depth state map and diffusion breadth state map to examine diffusion types of different technological fields, we can identify technological diffusion state at the technological field level for R&D planners for exploiting the R&D opportunities. This study uses patent data of the microfluidics to show the working of the proposed method. We identify that C12Q, F15C, B32B, B01F, C12P, H05B accord with the consistent diffusion depth and diffusion breadth state and B01D, B81B, B01J, F16K, C12N present opposite diffusion depth or diffusion breadth. Then we explain the development stage and characteristics of typical fields.

This paper is to develop a modified method on how to analyze diffusion state of technological knowledge at the technological field level. However, it has some limitations. Firstly, we consider the importance of technological fields that the patent belongs to is equal when calculating of the weight of each diffusion pair between IPC codes. Secondly, we only put forward an example to prove the availability of the method. These limitations also represent future research directions. It would be interesting to seek better method of calculating the weight of diffusion pair between classifications. A comparison of different case studies would be useful for mining diffusion regularity.

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