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Research on technology cluster evolution of global MEMS sensors based on patent co-occurrence analysis[①]

Liang Qinqin(梁琴琴)[②]

(Institute of Scientific and Technical Information of China, Beijing 100038, P. R. China)

Abstract

At present, microelectro mechanical systems (MEMS) sensors have gradually replaced traditional mechanical sensors and are applied to several fields. Many developed countries pay high attention to technological innovation of MEMS sensors, and have applied a large number of patents since 2000. In this study, the patents of MEMS sensor from 2000 to 2015 are researched, the patents data is collected from Derwent Innovation Index (DII), and the method of co-classification analysis is used to investigate the technology cluster evolution of MEMS sensors. Results show that the technology diffusion occurrs in each technical field and the technology relevance between different technical fields is changed over time. On the whole, the evolution process of MEMS sensor is the manufacture and material of sensor chip, the electronic components and measuring function, the computing and control technology, and applications to biochemical field and communication.

Key words: co-classification analysis, technology cluster, microelectro mechanical system (MEMS), patent analysis

0 Introduction

MEMS (microelectro mechanical systems) sensor is a micro device which aggregates micro sensor, micro actuator, micromechanical structure, micro power, micro energy, signal processing and control circuit, high performance electronic integrated device, interface and communication. It integrates lithography, corrosion, film, silicon micro machining, non silicon micro machining and precision machining technology. MEMS sensors have many advantages compared with traditional mechanical sensors, such as, small volume, light weight, low cost, low power consumption, high reliability, suitable for batch production and easy to integrate and realize intelligence[1], so it is the important branch of MEMS technology. At present, MEMS sensors have been widely used in consumer electronics, automotive industry, aerospace, machinery, chemical, pharmaceutical, biological and other fields[2-8]. Many developed countries such as the United States, Japan, and Germany, have regarded MEMS sensors as one of the strategic technology areas and invested a large amount of money for special research.

The patent information reflects the latest science and technology invention and creation, through processing and analyzing the information contained in patent literature, many diverse and perplexing information in the patent data[9] can be revealed. Some researchers have discussed the development of MEMS sensors from the patent point of view[10-14], however, they mainly focused on development trend, research institution and technical distribution, and so on, but did not study the diffusion and agglomeration of technology which generate the development of technology fields.

Technology cluster is an important form of technology diffusion and agglomeration. Rosenberg[15] found that diffusion of technology would lead to technology cluster; the technology diffusion process is around the primary technology to carry out a series of incremental innovation, secondary innovation, in order to improve the original innovation, and the formation of cluster technology. In addition, Ibrahim[16] put forward in the research of technological innovation theory that technology had the characteristics of grouping in a certain time and space, that was, technology clusters.

MEMS sensors are the product of multi-discipline, involving electronics, machinery, materials, physics, chemistry, biology, medicine and other disciplines and

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② To whom correspondence should be addressed. E-mail: liangqq@ istic. ac. cn

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technologies, moreover, they are applied in many fields, and have caused a new direction of technology development, so the diffusion and agglomeration of MEMS sensor technology are particularly active, which promote the development of MEMS sensors. Therefore, to carry out the study on the changes of MEMS sensor technology cluster in the global scope, to analyze the path and direction of technology diffusion is of great significance to the country in technology innovation and application of MEMS sensors in future.

1 Data source and research methodology

As can be seen from Refs [10-14], although MEMS technology emerged in 1960s, the technology developed slowly before 2000. From the end of the last century and the beginning of this century, with the third wave of industrialization, the number of patents for MEMS technology has increased rapidly, as does the development of MEMS sensors. Therefore, the time scope of patent data is priority year from 2000 to 2015.

In this study, the Derwent Innovations Index (DII) database is used as the data source, and the subject search is adopted. The geographical scope includes 34 countries, regions and World Intellectual Property organizations. In order to search accuracy and comprehensiveness, 'MEMS' and 'sensor' are selected as key words, MEMS synonyms are chosen too, such as micro, miniature and mini, and for 'sensor' without further restrictions, such as 'pressure sensor'. The patent retrieval strategy is TS = (sensor SAME (micro or miniature or mini or MEMS)). The search time is September 6, 2015, and 25 617 patents are obtained.

Thomson Data Analyzer (TDA) patent analysis software and UCINET social network analysis software were used for patent data cleaning, mining and visual analysis. In the co-occurrence analysis, co-classification analysis was used based on Derwent Manual Code (MC). MC by Derwent technical staff manual indexing, said all the technical innovation invention involved, more standardized and clear, but also better reflect the characteristics of the patent technology. MC initials represent a wide variety of technical areas (see Table 1). Removed the MC default patent records, using UCINET software rendering co-occurrence network, the nodes in the network stand for technology (MC), the node size associated with this technique was proportional to the number of patents in the field.

Table 1 List of technical fields matched with each category of Derwent Manual Code (MC)

MC Section	Technical Field
A	Plasdoc
B	Farmdoc
C	Agdoc
D	Food, Fermentation, Disinfectants, Detergents
E	Chemdoc
F	Textiles, Paper, Cellulose
G	Printing, Coating, Photographic
H	Petroleum
J	Chemical Engineering
K	Nucleonics, Explosives, Protection
L	Glass, Ceramics, Electro(in)organics
M	Metallurgy
N	Catalysts
P	General Engineering
Q	Vehicles
S	Instrumentation, Measuring, and Testing
T	Computing and Control
U	Semiconductors and Electronic Circuitry
V	Electronic Components
W	Communications
X	Electric Power Engineering

2 Results and discussions

2.1 Determination of critical time nodes

From 2000 to 2015, the global MEMS sensor technology showed a steady growth trend, which can be divided into four stages, i. e. 2000 – 2007, 2008 – 2011, 2012 – 2013, and 2014 – 2015 (Fig. 1).

Stage of initial development (2000 – 2007): In this stage, although the development was slow, the number of patents was larger than that before 2000, which was benefited from the expanding demand of automotive electronics market, the number of patents increased in the annual 50 – 100 rate.

Stage of slow development (2008 – 2011): In this stage, the number of patents fluctuated slightly around 1 400 per year; the reason was that the demand of automotive field had reached saturation, and the application in the field of medical electronics and consumer electronics was still at the beginning stage.

Stage of rapid growth (2012 – 2013): In this stage, the number of patents increased by about 2000 a year, and demand from the consumer electronics market was a major stimulus.

Stage of stable development (2014 – 2015): The number of patents was close to that of the gear 2013, with the increase of automotive electronics and consumer electronics market demand, as well as constant demand for the emerging field of chemical, biological and medical and so on, the future demand for MEMS sensors would still keep the current rate of increase.

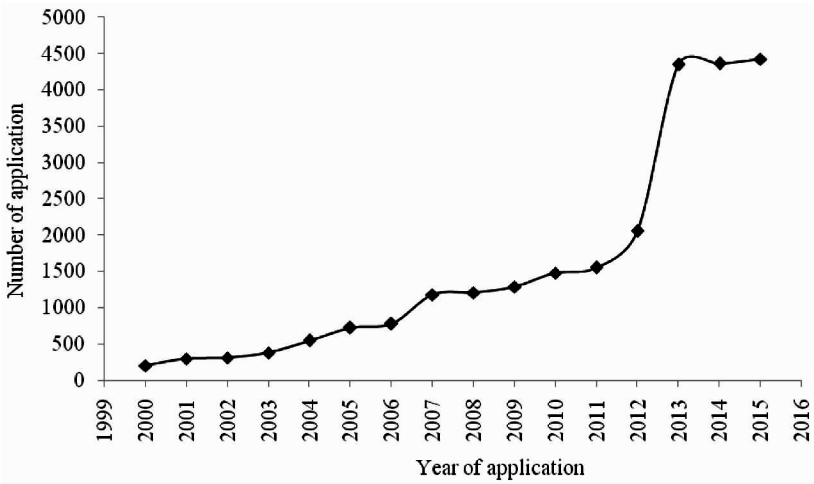


Fig. 1 Patent applied trend of global MEMS sensors

Analysis shows that the years of 2007, 2012 and 2013 were three key time node of the MEMS sensor development, which would be used to study the technology cluster. In addition, 2000 and 2015 as the starting and ending time of patent search in this study are also researched.

2.2 Studies on technology cluster of critical time node

The technology co-occurrence networks in 2000, 2007, 2012, 2013 and 2015, were drawn respectively, the basis of the drawing is shown in Table 2, and then visualized with UCINET software. The MC co-occurrence networks in five important years were shown in Fig. 2.

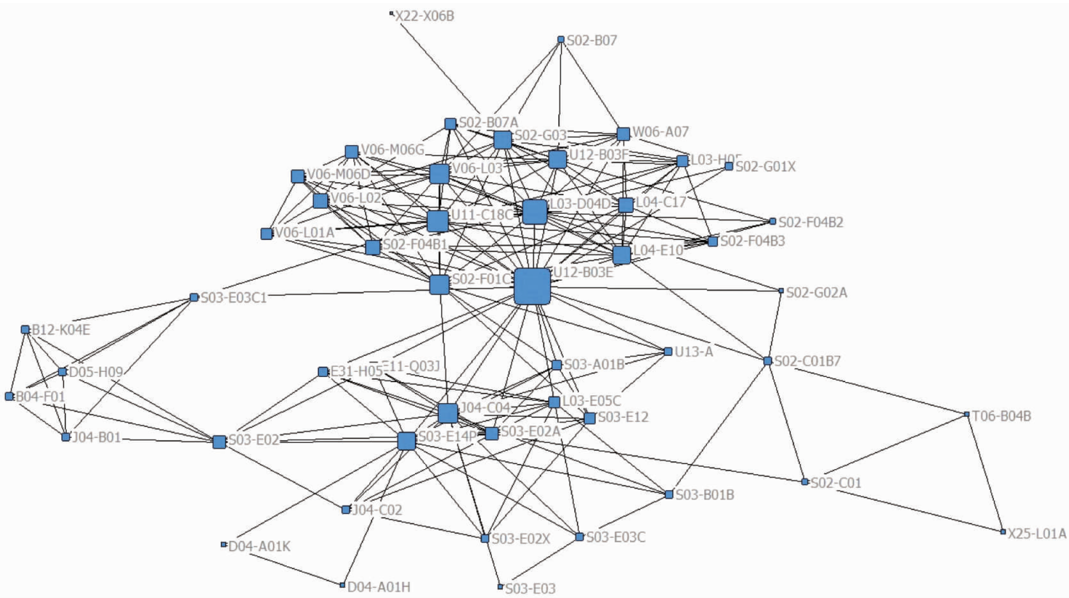
In 2000, the association between section U (semiconductors and electronic circuitry) and section L (glass, ceramics, electro (in) organics) was strong, and the technology innovation mainly focused on the matrix material of MEMS sensor, and had formed a

Table 2 Drawing basis of MEMS sensor technology network in each year

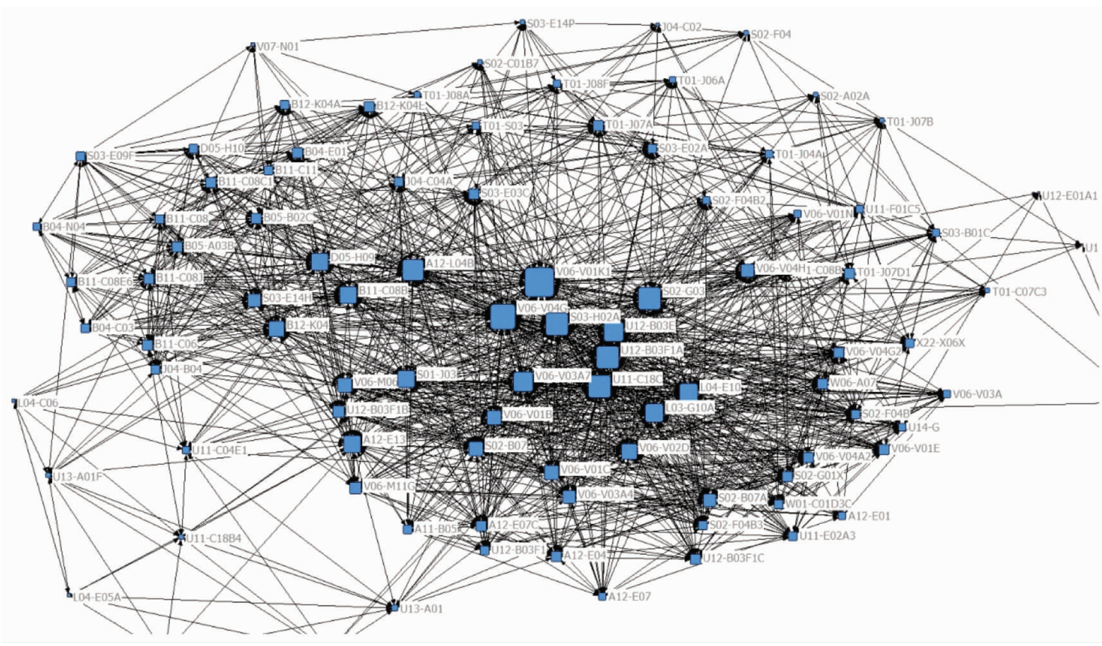
Year	Number of patents	Number of MC	Minimum co-occurrence frequency	Number of MC in technical network diagram
2000	200	433	4	50
2007	1176	1839	12	96
2012	2055	2422	20	93
2013	4353	3241	40	96
2015	4426	2828	35	99

technical cluster in a certain scale. Small scale technology agglomeration was formed within section S (instrumentation, measuring, and testing) between the subdivision technology, and measuring and testing MEMS sensors was the potential direction of development.

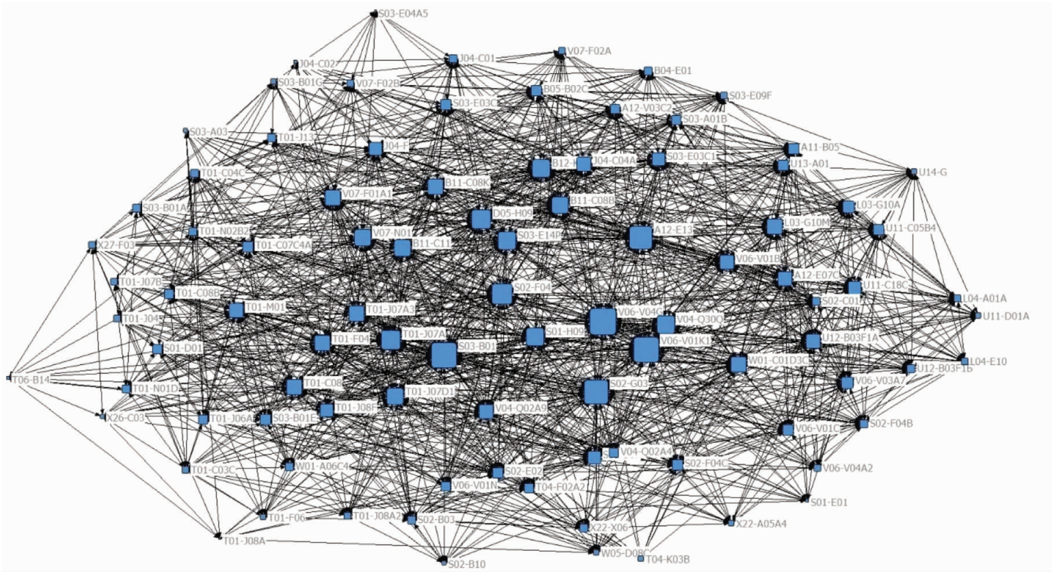
In 2007, U (semiconductors and electronic circuitry), V (electronic components) and S (instrumentation, measuring, and testing) sections formed a close technology cluster, the measuring and testing MEMS sensors which were in the latent development stage in 2000 were becoming the focus of research, and electronic components and electronic circuits were the main research directions. In addition, the research related to section B (farmdoc) began to form a certain scale, with a strong correlation of section S (instrumentation, measuring, and testing), which means the application of MEMS sensor in the field of biology and medicine began to enter the vision of researchers, and had become a potential development direction in the future.



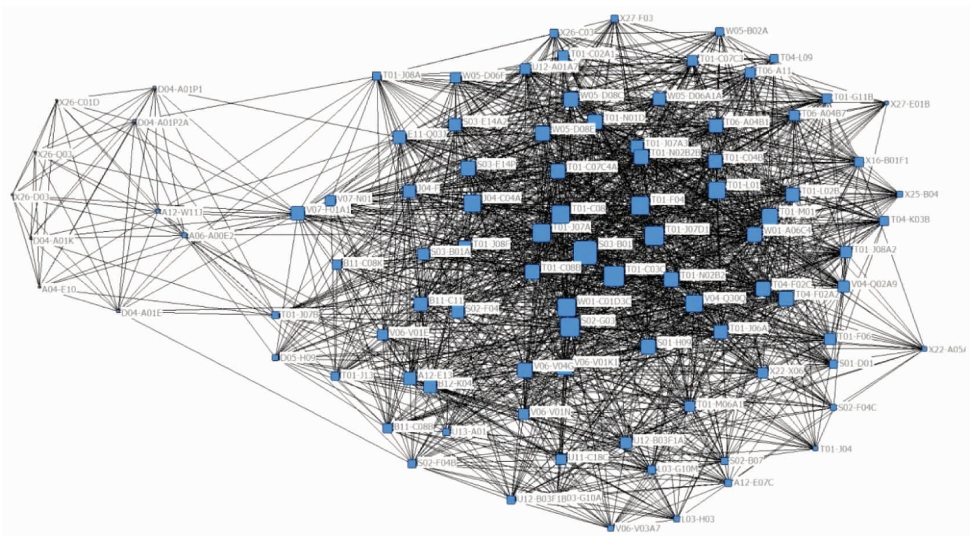
(a) 2000



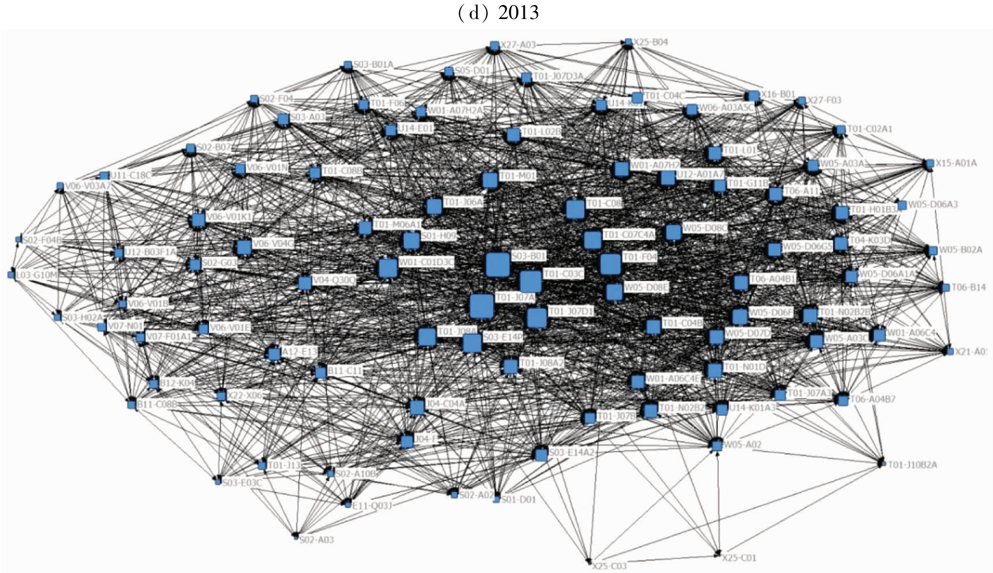
(b) 2007



(c) 2012



(d) 2013



(e) 2015

Fig. 2 Technology co-occurrence network of MEMS sensor in five key time node

In 2012, V (electronic components), B (farmdoc) and S (instrumentation, measuring, and testing) sections were closely related to the formation of technology clusters, and technological innovation mainly focused on micro biosensors, which was the potential direction of development in 2007. At the same time, the association between S section (instrumentation, measuring, and testing) and T section (computing and control) had begun to form a certain scale, and the research of MEMS sensor computing and control system had begun to emerge and become a potential development direction.

2013 was a year of rapid development of the MEMS sensor, MEMS sensor research went hand in hand in several technical areas, formed three different scale technology clusters, i. e. T(computing and control) and S(instrumentation, measuring, and testing) sections, T(computing and control) and W(communications) sections, as well as J(chemical engineering) and S(instrumentation, measuring, and testing) sections. T-S cluster occupied the main position, followed by T-W cluster, and the smallest size was J-S cluster. That is, the potential direction of the 2012, research of sensor computing and control system was becoming a hot spot. In addition, strong demand for the consumer electronics market prompted the formation of T-W clusters on mechanical sensor and electrical sensors, chemical industry demand that made J-S technology cluster ion sensor and biosensor had also begun to take shape.

There were two different technology clusters in 2015, namely, T(computing and control) and S(instrumentation, measuring, and testing) sections, T (computing and control) and W (communications) sections. Among them, the main technology cluster was T-W. It showed that the research hotspot of 2015 was still the research of MEMS sensor computing and control system for communication field under the impetus of strong market demand.

2.3 Evolution analysis of technology clusters

In order to describe different technical fields (MC) diffusion, the structure characteristics of the patent technology co-occurrence network of MEMS sensor in 2000, 2007, 2012, 2013 and 2015 were measured, and the 'breadth-depth' two-dimensional matrix was established[17] from the two perspectives of the number of co-occurrence domains and co-occurrence strength of different categories in social networks. In order to further analyze the evolution of different section network structures, the 'breadth' represented the number fields co-occurring with the technology, the 'depth' was measured by the co-occurrence strength which was the ratio of network connection times and network scale, where the network connection times referred to the number of times in which a technical field co-occurrence with other technical areas; the network scale referred to the number of nodes in the network, which was related to the number of technical field.

Taking the year 2000 as an example, the social network includes 11 species of MC, B, D, E, J, L, S, T, U, V, W and X. The number of co-occurrence fields and co-occurrence strength of each major category are shown in Table 3, and the sum and average of co-occurrence fields and co-occurrence strength are calculated respectively, and the results are also shown in Table 3. When drawing the 'breadth-depth' quadrant, the number of co-occurrence fields and co-occurrence strength of each MC class relative to the average value are taken, thus the breadth and depth of the co-occurrence are obtained, as shown in Table 4. In other years, the 'breadth-depth' quadrant map is drawn as the same as the year 2000.

According to the 'breadth-depth' two-dimensional matrix, there were four types of technology co-occurrence: one was the 'high breadth high depth' type (HH), nodes in this area and the core in the network; the second was the 'high breadth low depth' type (HL), which was the important nodes; the third was the 'low breadth high depth' type (LH), which was the peripheral nodes; the fourth was a 'low breadth low depth' type (LL), the edge nodes in the network. Fig. 3 shows the different sections of distribution patterns of MEMS sensors in each year.

Table 3 The co-occurrence field number and co-occurrence strength of each MC section in 2000

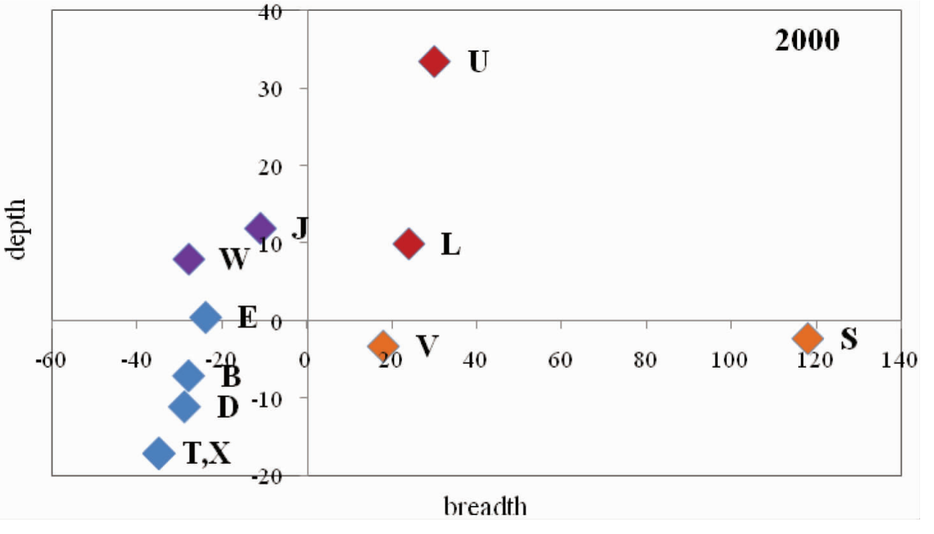
MC section	Number of co-occurrence fields	Co-occurrence strength
B	10	13
D	9	9
E	14	20.5
J	27	32
L	62	30
S	156	17.7
T	3	3
U	68	53.5
V	56	16.8
W	10	28
X	3	3
Total	418	226.5
Average value	38	20.6

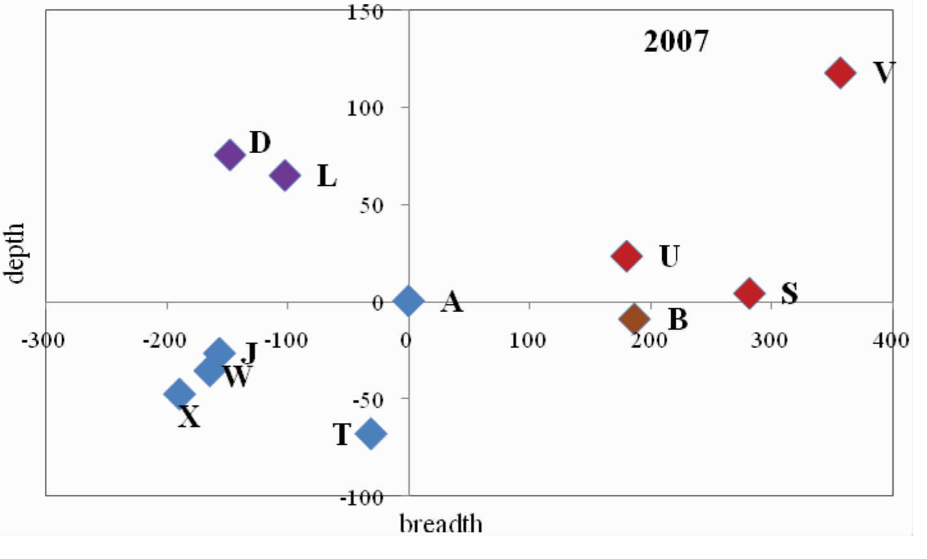
Table 4 The co-occurrence breadth and depth of each MC section in 2000

MC section	Co-occurrence breadth	Co-occurrence depth
B	−28	−7
D	−29	−11
E	−24	0.5
J	−11	12
L	24	10
S	118	−2.3
T	−35	−17
U	30	33.5
V	18	−3.2
W	−28	8
X	−35	−17

In 2000, section U and section L in the HH quadrant, were the core nodes in the network; section V and section S being in the same HL quadrant, belong to important nodes of the network; section W and section J in the LH quadrant, were peripheral nodes; sections of E, B, D and X were in the LL quadrant, and at the edge of the network. There were few studies in this period.

In 2007, section U was still in the HH quadrant and section L diffused to the LH quadrant, becoming a peripheral node; sections of V and S entered the HH quadrant from HL quadrant, becoming the core node; section B from LL into the HL quadrant, became an important node; section D from LL into the LH quadrant was a peripheral node; sections of J, W, X and T were the edge nodes in the network.





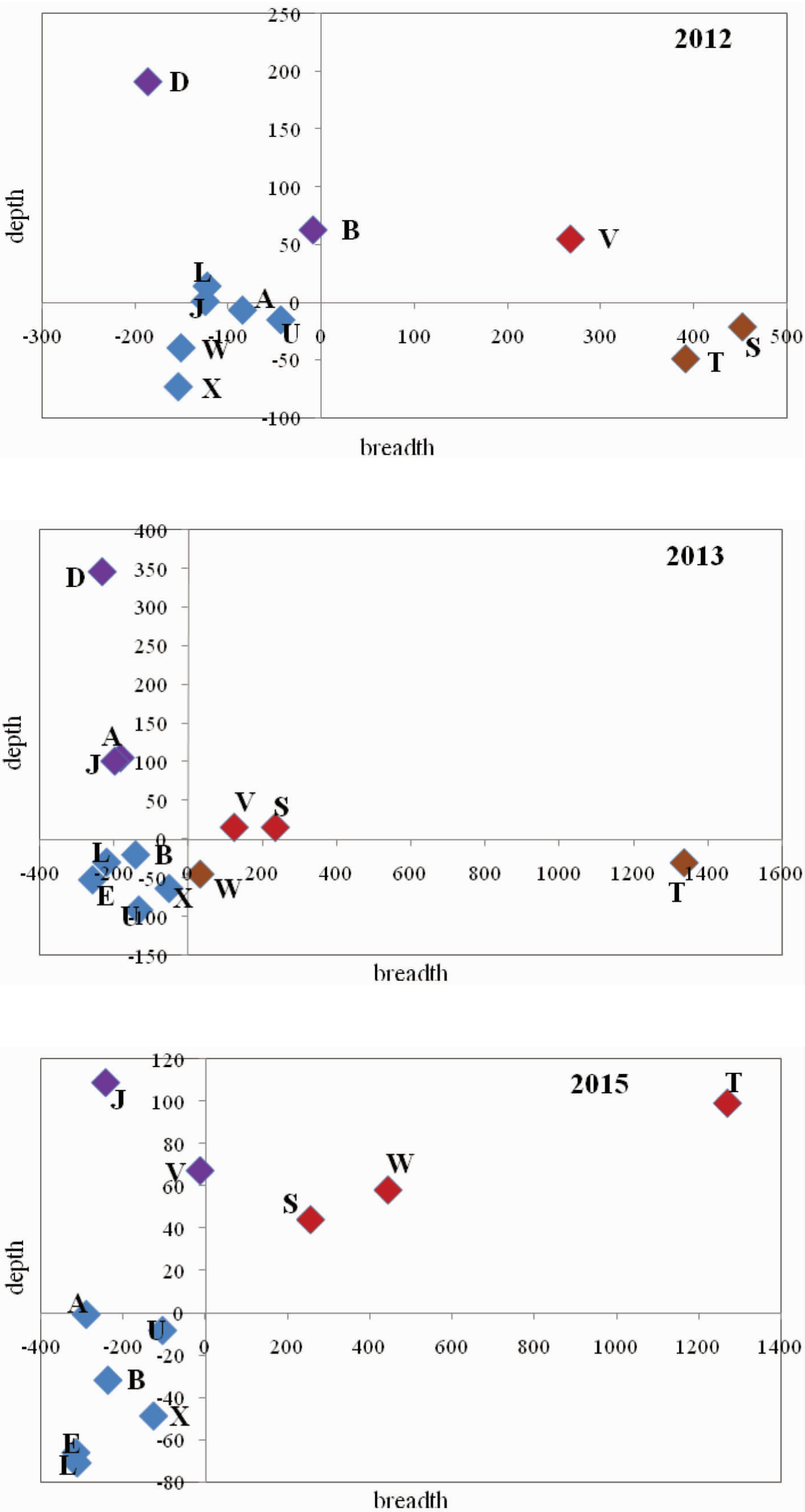


Fig. 3 Distribution patterns of MEMS sensors in different sections in each year

In 2012, section V located in HH quadrant, was the unique core node in this period; It was worth noting that the section U fell to the LL quadrant from the HH quadrant in 2007 and became the edge node; section S from HH dropped back to HL quadrant, section T rose to HL from LL quadrant, the two sections became important nodes; section B moved to LH quadrant from HL quadrant, being a peripheral node; J, A, U, W and X sections in the LL quadrant, belonged to edge node.

In 2013, section V was still in HH quadrant, section S rose to HH quadrant from HL quadrant, so V and S sections were core nodes in this time; T and W sections were important nodes in HL quadrant, among them, section W was from LL quadrant; J section entered into LH quadrant, while sections of L and B slid from the LH quadrant to the LL quadrant.

In 2015, sections S, T and W were core nodes in HH quadrant, there was no node in HL quadrant, section V slid to LH quadrant from HH quadrant. Namely, researches were carried out mainly in S, T and W three sections.

3 Conclusions

MEMS sensors are the product of multidisciplinary convergence, and the diffusion and integration between different technological directions are very active. In this study, based on the MC of DII patent data, technology diffusion and technology association of the global MEMS sensors were investigated, and the evolution of technology cluster with time changing was analyzed, obtaining the following conclusions, which provided reference for the development of MEMS sensor in China.

At different time points, MEMS sensors formed different technical association relationships. In 2000, chip manufacturing and material technology of MEMS sensors had the strongest association with the formation of dominant technology clusters; In 2007, electronic components and circuits MEMS sensors, as well as the development of their measuring and testing capability formed strong technical associations; In 2012, the development of the MEMS sensor measurement function was closely related to the application in the biochemical field; In 2013, the development of the MEMS sensor measurement function was closely related to its control system; In 2015, the application research in communication field was increased on the basis of technology cluster in 2013.

The technology diffusion of MEMS sensor varies with time. MEMS sensor materials technology (L section) and manufacturing technology (U section) gradually diffused from the core node to the edge node. The development of MEMS sensor function mainly focused on measurement and test (S section), and has been in the core nodes and key nodes alternately diffusion since 2007. MEMS sensor electronic component (V section) was also a long-term research focus, since 2007, mostly in the core node, only in 2015 diffused to the peripheral nodes. MEMS sensor control technology (T section) has gradually spread to core nodes as time goes on, and it is still the focus of research. The application of MEMS sensors in biomedical field (B section) mainly spreads between important nodes and peripheral nodes, but has not become the core nodes.

On the whole, the degree of technology aggregation of MEMS sensor in the world is gradually strengthened with the elapse of time and the increasing of technology relevance between different technological directions. The evolution process of MEMS sensor technology cluster is as follows: the chip manufacturing technology and material technology, sensor electronic component, the development of measuring and testing function, computing and control technology, applications in biochemical fields, applications in communications.

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Liang Qinqin, born in 1982. She received her Ph. D in Applied Chemistry from Sichuan University in 2011. Her research interests include advanced manufacturing, high-end manufacturing and intelligent manufacturing.