Emerging Technology Opportunity Identification Based on Community Detection and Burst Detection: A Case study of Intelligent Robots.

Abstract: Due to a new round of technological revolution and industrial transformation driven by artificial intelligence, emerging technologies have triggered a new round of unprecedented developments. Understanding the technology development trend and identifying potential technology opportunities has become an essential proposition for academia and industry. Based on patent document data, this paper applies text analysis to extract technical terms, introduces the community detection model to technology topics, then constructs a framework for identifying opportunities for emerging technologies from three perspectives: technological R&D trends, competitive environment, and technology layout. The intelligent robot technology is illustrated as an empirical study to clarify the proposed framework. We conclude three main findings: First, intelligent robot technology has undergone three evolution stages and formed 16 key topics, among which IoT robot, sensor fiber resistance, and pneumatic muscle have become hotspots in recent years; Second, China has an absolute advantage in the scale of intelligent robot technology, but it has a noticeable strength gap with other countries and regions in core technologies; Third, compared to the other leading countries in intelligent robots field, the layout of China's overseas technology market is relatively limited, especially in remote control, robot voice and intelligent detection. The proposed opportunity identification framework can clarify emerging technologies' overall context and provide a useful reference for emerging technologies' market layout and technology layout.

Keywords: Intelligent Robot; Emerging Technology; Patent Analysis; Topic Identification; Technology Opportunity Analysis

1 Introduction

The technology's iteration is accelerating rapidly, with old technologies always being eliminated and new ones emerging. Only by timely grasping the trend of emerging technology development and taking the lead in occupying the advantageous layout of emerging technology, the nations/enterprise can win the competitive advantage in the fierce technological and industrial revolution. An accurate grasp of emerging technologies' development trends relies on the effective identification and dynamic monitoring of technology topics.

The pioneering researcher, Professor Alan L. Porter from Georgia Institute of Technology, who proposed the framework of Technology Opportunity Analysis (TOA), indicated that analyzing the changes of related technology or the socio-economic environment in a specific technology field through technology detection and bibliometrics can play a particular role in predicting the technology development in this field (Porter et al., 1995). TOA is a process of identifying emerging technologies and exploring promising technologies in specific technology fields. Later, scholars research and elaborate TOA based on Porter's systematic explanation, which can be mainly divided into three aspects:

- Connotation and functions. Zhu et al., (1998) established an analysis system based on data analysis and expert evaluation to provide the basis for monitoring and early warning and government decision-making in specific technology fields, enriching the research on technology opportunity and scientific management. Yoon and Park (2005) regarded TOA as one of the research methods of technology forecasting, which is in line with many technology management researchers (Shane, 2000; Zhu et al., 2002; Yang & Peiyang, 2013). Combining with the current academic discussion on technology opportunity, Ma et al. (2014) defined technology opportunity as new technology forms or new technology development points that emerged from the existing technologies in a specific field during the technology development, which provides the possibility for the technology innovation to be applied to the production of new technology.
- Methodology and indicators. Researchers prefer a more quantitative method or a combination of qualitative and quantitative methods. From the two dimensions of market and technology, Kang et al. (2007) constructed the research framework to identify and visualize technology innovation opportunities. Yoon et al. (2008) proposed a morphological analysis based on keywords, which uses patent data to identify technology gaps as technology opportunities to support R&D and management. Lee et al. (2009) transformed patent literature into structured data, using a combination of Principal Component Analysis (PCA) and keyword-based patent maps to identify possible technology opportunities in the map gaps. Pan and Xu (2014) put forward a TOA method combining co-word analysis and visualization techniques from three aspects: key technology, technology frontier, and technology trends. Wang et al. (2015) applied text mining and a high-

dimensional data object clustering algorithm to papers and patents to explore technology opportunities by mining the gaps between science and technology. Rodriguez et al. (2016) introduced a new approach to technology opportunity discovery by ranking patent outliers, identifying patent anomalies and patent attributes and citations. Wang et al. (2017) proposed a morphological analysis based on the Subject-Action-Object structure and morphological matrix to identify technology opportunities. Lee et al. (2020) used the word2vec approach to navigate product landscape analysis to identify potential technology opportunities for companies based on the technological capabilities embodied in their existing products.

- Empirical studies. Scholars mainly conducted empirical researches on TOA in the high-tech sector. Ho et al. (2014) summarized the main technological barriers and the corresponding potential solutions for Proton Exchange Membrane Fuel Cells and Direct Methanol Fuel Cells technologies by analysis of citation network. Ma et al. (2014) proposed a framework for TOA regarding technology development, competitive environment, and potential markets to analyze the technology opportunities in the dye-sensitized solar cells field. Chan and Miyazaki (2015) used keyword co-occurrence analysis to explore the knowledge convergence between cloud computing and big data and apply it to analyze emerging technology opportunities in Malaysia. Zhang and Yu (2020) conducted analogies between source and target domains to predict 5G technology opportunities by analogy design and phrase semantic representation.

Most of the above research on TOA focuses on the patent analysis of emerging technologies, which have narrower meanings and limited development time. In this paper, we propose a technology opportunity identification framework that can be applied to a broader technology field by identifying the key technology topics and exploring the evolution of the technology. We detect the technology opportunities from multiple dimensions to examine the technology opportunities with a holistic view.

In recent years, Artificial Intelligence (AI) has successfully sparked great interest from all sectors of society. It is amplifying human potential like never before and is seen as a current strategic high technology and a stalwart in leading disruptive industry changes in the future. Furthermore, as an important scenario for AI, intelligent robots will be used in more diverse fields with enormous prospects for development as AI systems improve in accuracy and complexity.

Based on patent data in the field of intelligent robots, this paper extracts technical terms and constructs co-occurrence networks through text analysis techniques, applies a community detection model for technology clustering, and then introduces an emerging topic measurement model and an emergent topic monitoring model to build a framework for identifying emerging technology opportunities from three perspectives: technology development trends, competitive environment, and technology layout, and conducts an empirical study with the intelligent robots technology. We locate intelligent robots' key technologies and reveal the overall pulse of emerging technology development using the framework, providing a useful reference for future emerging technologies' market layout and technology layout.

2 Framework and Methodology

2.1 Framework

Based on patent data, we extracted technical terms and construct a co-occurrence network through natural language processing techniques, applied a community detection model for technology clustering, and then introduce an emerging topic measurement model and a emergent topic monitoring model to construct a framework for identifying emerging technology opportunities from three perspectives: technology R&D trends, competitive environment, and technology layout. Fig. 1 illustrated the framework of the research.

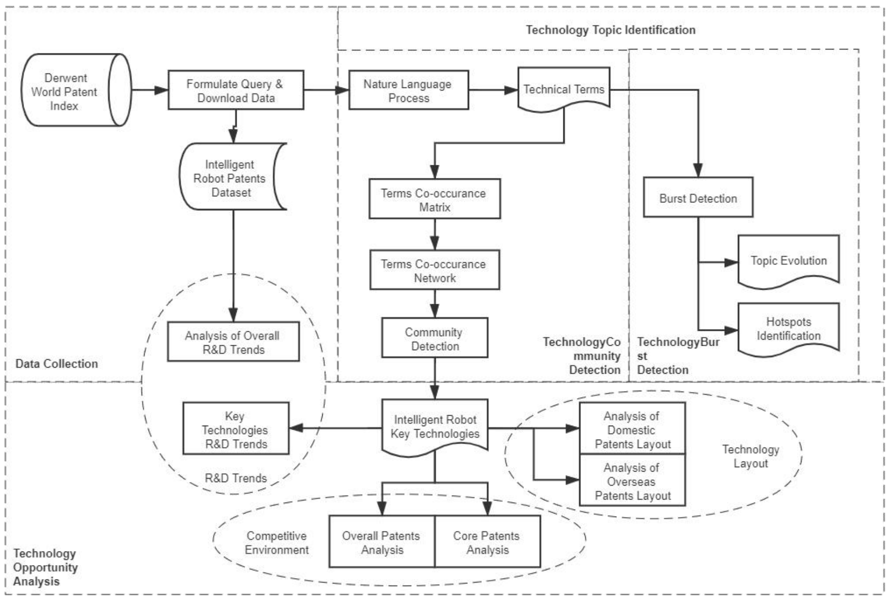


Fig. 1. Research Framework

First, we formulated the patent retrieval query and downloaded the patent documents from the Derwent Innovation database, followed by an overall trends analysis on the patent dataset. Second, we used text analysis techniques to mine the patent data and extract terms from the patent titles that can characterize the terms' full meaning, including tokenization, POS tagging, stemming, lemmatization, and merging terms with similar semantics. Third, after constructing the term co-occurrence network, we used the Leiden algorithm in the community detection to identify intelligent robots' key technology topics; we used the burst detection algorithm to perform topic evolution and hotspot identification of technical terms. Finally, based on the identified key technology topics, we use the TOA framework to explore technology opportunities of intelligent robots.

2.2 Methodology

Natural Language Processing.

Natural language processing (NLP), an important research subject in computer science and artificial intelligence, mainly focuses on making computers understand natural human language. The Natural Language Toolkit (NLTK) package is a set of libraries and programs for NLP developed by Professor Bird et al. (2009) of the University of Pennsylvania. The parse tree model provides a good solution for analyzing text syntax and part-of-speech tags (shown as Fig. 2). We used the NLTK to process the patent titles, including tokenization, stopwords filtering, POS tagging, stemming, lemmatization. We extract n-gram terms from each patent title and performed fuzzy semantic merging of terms with similar semantics.

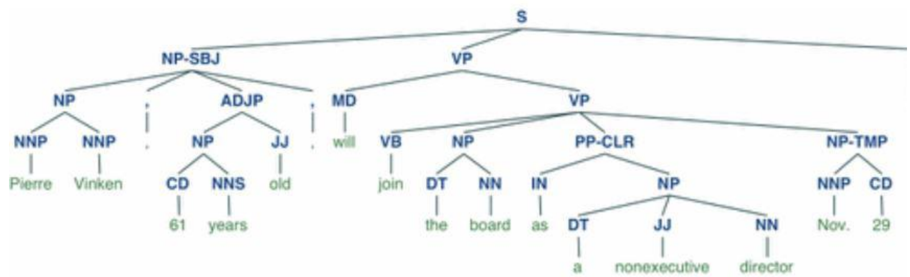


Fig. 2. Parse tree generated with NLTK

Community Detection.

Community detection is used to understand the structure of large and complex networks. Many scholars have employed community detection in the identification of technology topics. Commonly used community detection methods are Kernighan-Lin by Kernighan and Lin (1970) as the representative graph-cut algorithm and the Louvain algorithm by Blondel et al. (2008) as the representative hierarchical clustering algorithm. Kernighan-Lin has the problems of low accuracy and high time complexity when processing high-dimensional graphs. Louvain algorithm is a greedy algorithm. Although it is recognized as one of the fastest non-overlapping community detection algorithms, it may produce poorly connected communities. Traag et al. (2019) improved the Louvain algorithm and introduced the Leiden algorithm, ensuring a good connection between communities. Fig. 3 illustrated the improvement from the Louvain algorithm to the Leiden algorithm. By using the fast local move procedure, the Leiden algorithm runs faster than the Louvain algorithm. Hence, we used the Leiden algorithm to conduct community detection on the co-occurrence network. We got clearer clusters based on word frequency and word contribution by removing some terms with little meaning from the co-occurrence matrix.

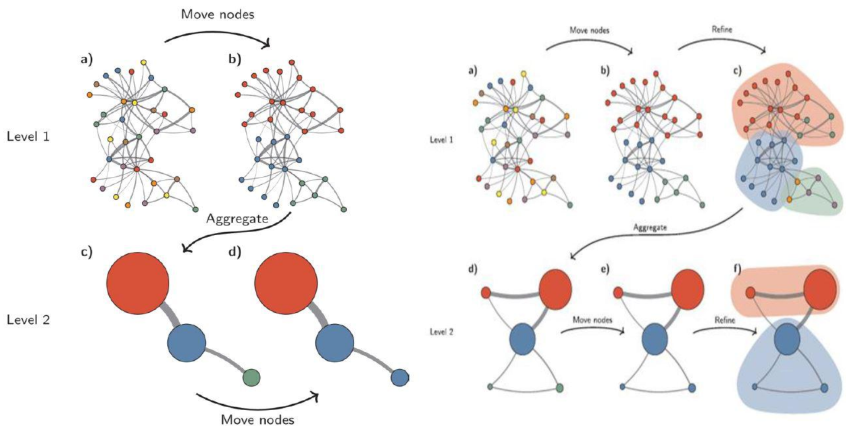


Fig. 3. Improvement from Louvain algorithm to the Leiden algorithm (Traag et al., 2019)

Burst Detection

In 2002, Professor Kleinberg (2003) proposed the Burst Detection algorithm, which can identify the sudden increase or "burst" of terms' use frequency over time. Kleinberg uses text classification technology to classify the documents that need to be detected. The classified documents are defined as a time-sensitive sequence according to their arrival time. The infinite-state automaton models the documents flow as shown in Fig. 4 Text d_{t-1} follows after text d_{t+1}. The time interval between the two documents is x_t, which changes with the amount of text in the unit. When an event occurs in the real world, the documents related to the event increase, causing x_t to become shorter. The state at this time is the Burst State, and the opposite is the Normal State. The change of x_t can detect the transition from the Normal State to the Burst State. In this way, the burst is defined as the transition between states, and detect the burst is to detect the time interval between the arrival of two documents.

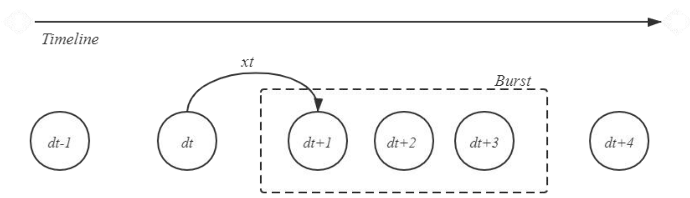


Fig. 4. Documents flow and bursts

In recent years, improvements and extensions on Kleinberg's algorithm have emerged and applied this algorithm to a broader domain. For example, Fujiki et al. (2004) used keywords instead of topics when detecting bursts in BLOGs and BBSs. Also, Toshiaki's algorithm improves and extends Kleinberg's algorithm to handle non-uniformly distributed data. We used burst detection to identify bursts of term frequencies and obtain the burst hot technology topics in this paper.

3 Data Collection and Profiling Analysis

3.1 Data collection

We collect patent data from Derwent Innovation. The platform is based on the Derwent World Patent Index (DWPI), which contains patent data from patent licensing agencies in over 100 countries and regions. It provides access to published patents and scientific literature worldwide.

The author initially formulated the retrieval query by reviewing relevant literature at home and abroad and consulting experts; through repeated verification and justification, the final retrieval query was as follows: ABD=(((Autonomous OR Bio* OR Humanoid OR Smart OR Intelligent) ADJ2 Robot*) OR Bio-robot* OR Biorobot* OR (Robot* Cognit*) OR (Robot* Percept*) OR (Robot* Sens*) OR (Robot* Act*)). Considering the emergence of intelligent robot patents and the time lag between patent application and publication, the time interval in this paper was set from 1956 to 2018. A total of 10,433 intelligent robot-related patents were retrieved (the retrieval was conducted on 20 February 2020).

3.2 Overall R&D Trend Analysis

Based on the patent dataset, the overall R&D trends for intelligent robots patents are plotted against the published patent records for each year, as shown in Fig. 5. R&D trends of intelligent robots patents barely increased for more than two decades in the beginning and only began to grow slowly after the 21st century; in 2015, however, the number of published patent records increased rapidly, almost doubling from the previous years, and after that research and development of patents on intelligent robots entered an era of rapid growth.

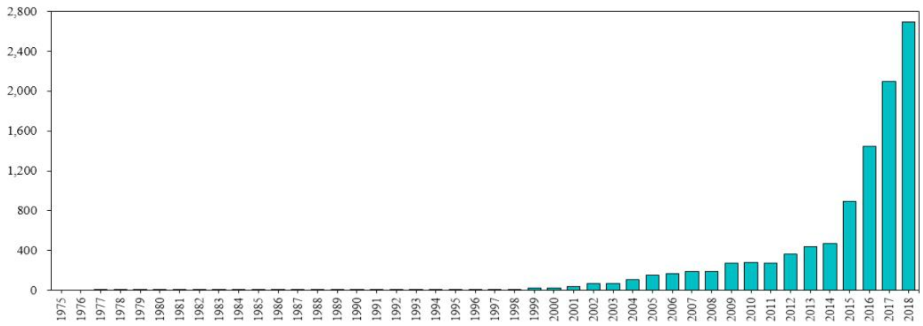


Fig. 5. Overall R&D Trend of Intelligent Robot Patents

Table 1 demonstrates the TOP 30 major patent owners in the field of intelligent robots. As illustrated, these assignees are mainly from China, the US, Japan, Korea, and Europe and are mostly companies and research institutions of a commercial nature. The company with the highest number of patents on intelligent robots is Beijing Guangnian Wuxian Technology Co. Ltd. in China. The second is Samsung Electronics Co Ltd. in Korea, the third is IROBOT in the US, and the fourth and fifth are Sony Corp and Honda Motor Co Ltd in Japan, respectively. Beijing Inst Technology has the highest number of patents for intelligent robots among research institutions, followed by Harbin Inst Technology and Univ South China Technology.

Table 1. Main Assignees of Intelligent Robot Patents

NO	Records	Assignee/Applicant	NO	Records	Assignee/Applicant
1	217	Beijing Guangnian Wuxian Technology Co. Ltd.	16	43	Hangzhou Jolog Robot Technology Co Ltd
2	166	Samsung Electronics Co Ltd.	17	42	Univ Harbin Engineering
3	136	Irobot Corporation	18	41	Univ Tsinghua
4	115	Sony Corp	19	39	State Grid Shanxi Electric Power Corp
5	114	Honda Motor Co Ltd	20	38	Nippon Telegraph & Telephone Corp
6	110	Toyota Jidosha Kk	21	38	Shandong Luneng Intelligent Technology
7	100	Beijing Inst Technology	22	38	Univ Dong-A Res Found Ind-Acad Coop
8	85	State Grid Corp China	23	37	Softbank Robotics Euro
9	74	Google LLC	24	36	Univ Changzhou
10	60	Shenzhen Gowild Intelligent Technology	25	35	Electronics & Telecom Res Inst
11	51	Harbin Inst Technology	26	35	Korea Inst Sci & Technology
12	51	Univ South China Technology	27	35	Sharp Kk
13	48	Hangzhou Changdong Intelligent Technology	28	32	Electronics & Telecommunications Research Institute
14	46	Aldebaran Robotics	29	32	Univ Zhejiang
15	46	Univ Shanghai	30	30	Univ Nanjing Sci & Technology

4 Key Technologies Identification of Intelligent Robots

4.1 Clustering key technological topics

We extracted patent titles from 10,433 intelligent robot patent documents, employed text mining, co-occurrence analysis, and community detection, and obtained 34 clusters, 33 of which are valid. We merged clusters sharing similar topics and finally got 16 topic clusters, as shown in Fig. 6.

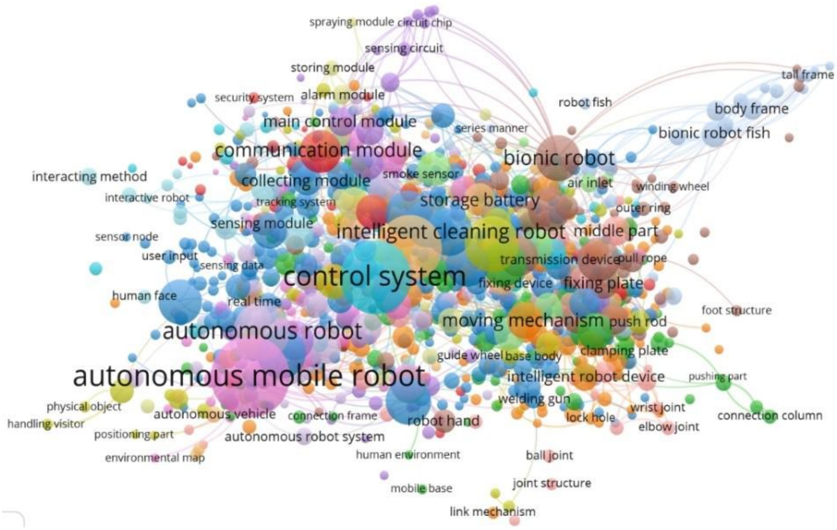


Fig. 6. Clustering Visualization of Intelligent Robot Technologies

After manual analysis and interpretation, we obtained 16 key technologies: Humanoid Robot, Robot Joint, Mechanical Arm, Driving Mechanism, Sensor, Wireless Communication, Servo Motor, System Controller, Remote Control, Path Planning, Robot Voice, Robot Vision, Detection Mechanism, Robot Interaction, Robotic Fish, Intelligent Robots for Different Usage (including Internet of Things Robots, Underwater Robots, Sweeping Robots, Welding robots, Painting robots, etc.). From the analysis, it is clear that the key technologies of current intelligent robots research are similar to those of industrial robots, such as Mechanical Arm, Driving Mechanism, Sensor, System Controller, etc., but also technologies that enable robots with 'intelligence', such as Robot Vision, Robot Voice, Path Planning, etc. Table 2 shows the key technologies and research hotspots of intelligent robots.

Table 2. Key Technologies and Research Hotspots of Intelligent Robots

ID	Key Technologies	Research Hotspots
1	Humanoid Robot	Walking Mechanism | Steering Mechanism | Structure Of Each Part Of The Humanoid Robot (Head, Neck, Hands, Legs, Feet, Etc.)
2	Robot Joint	Degree Of Free | Multi-Joint | Pneumatic Muscles
3	Mechanical Arm	Swing Mechanism | Pushing Mechanism | Lifting Mechanism | Grip Mechanism
4	Driving Mechanism	Control Motor | Rotation Mechanism | Transmission Mechanism | Harmonic Reducer
5	Sensor	Optical Sensor | Infrared Detector | Distance Measuring System | Smoke Sensor | Pressure Sensor | Vision Sensor | Ultrasonic Sensor | Fusion Sensor | Multidimensional Force Sensor | Haptic Sensor
6	Wireless Communication	Transmitter | Receiver | Ultrasonic Signal
7	Servo Motor	Servo Control | Servo Driver | Visual Servo
8	System Controller	Control Circuit | SCM Control | PLC Control | Adaptive Control
9	Remote Control	Cloud Interaction | Communication Module | Position Module | Remote Screen Monitoring
10	Path Planning	Autonomous Mobile Robot | Obstacle Avoidance | Autonomous Navigation | Intelligent Guidance
11	Robot Voice	Voice Signal Processing | Voice Recognition | Voice Interaction
12	Robot Vision	Image Acquisition | Feature Learning | Face Recognition | Expression Recognition | 3D Technology | Moving Target Position | Video Monitoring
13	Detection Mechanism	Anomaly Detection | Alarm Device
14	Robot Interaction	Interactive Method | Multi-Modal Interaction | Cloud Interaction | Voice Interaction | User Interface
15	Robotic Fish	Robot Fish Structure | | Swing Method | Steering Method | Bionic Fish Skin Material
16	Intelligent Robot for Different Usage	Internet Of Things | Intelligent Medical Robot | Intelligent Logistics Robot | Intelligent Cleaning Robot | Intelligent Tutorial Robot | Intelligent Agriculture Robot | Intelligent Pet Companion | Smart Home | Intelligent Welding Robot | Intelligent Spraying Robot | Intelligent Vehicle Service | Unmanned Driving

4.2 Tracing the topic evolution

The technical terms extracted from the patent titles were used as analysis data to detect and visualize the patents' technology topics' evolution using the burst detection algorithm, as shown in Fig. 7. We broadly divide the evolution of intelligent robots technology topics into three time periods: 1978-1993, 1994-2002, and 2003-2018. Between 1978 and 1993, robots were centered on 'Industrial Robots,' which were mainly used in industrial manufacturing and were not yet characterized by intelligence; from 1993 onwards, 'Autonomous Mobile Robots' emerged. This marked the beginning of the transition from powerful stationary machines to highly autonomous and complex mobile platforms. In 2002, the emergence of 'Pet Robots' signaled that robots were no longer only used in industrial scenarios but were beginning to participate in and change people's lives. It also meant that robots were becoming interactive. This was followed by the "Humanoid Robot" in 2004 and the "Intelligent Mobile Robot" in 2006 when robots became associated with "intelligence" for the first time.

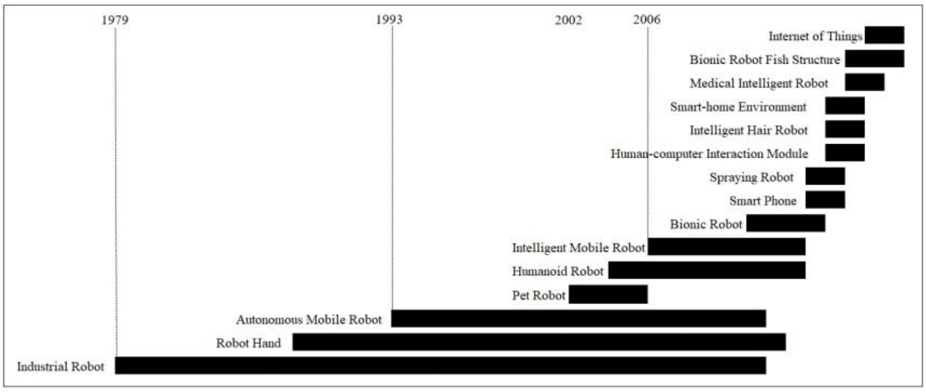


Fig. 7. The Evolution of Intelligent Robot Technologies Topics

The burst weights and burst levels were ranked in descending order by calculating the technology topics' burst indicators. The technologies with the highest burst rating and have not yet reached a steady-state were selected as burst hotspots of intelligent robots, as shown in Table 3.

Table 3. Burst Hotspots of Intelligent Robots

Burst Hotspots	Weight	Duration	Start
Internet-of Thing	5.982	2	2017
Bionic Robot Fish Structure	5.431	3	2016
Charging Pile	5.156	1	2018
Multi-Modal Output	4.858	3	2016
Resistance Layer	4.448	2	2017
Intelligent Robot Human-Computer Interaction	4.399	2	2017
Intelligent Security Robot	4.342	2	2017
Unmanned Aerial Vehicle	4.164	1	2018
Pneumatic Muscle	3.746	1	2018
Grabbing Robot	3.673	1	2018

As illustrated, internet-of thing, bionic robot fish structure, robot charging pile, multi-modal output, resistance layer, intelligent robot human-computer interaction, intelligent security robot, unmanned aerial vehicle, pneumatic muscles, and grabbing robot have become cutting-edge hot spots in intelligent robots in recent years.

5 Key Technologies Opportunities Analysis of Intelligent Robot

5.1 R&D Trend Analysis

We analyzed the trends in the development of key technologies for intelligent robots based on the subject identification results. Although the earliest patent retrieved was published in 1977, the number of published patents from 1975 to 1999 is deficient. For better presentation, the figure only shows the growth trends for the 16 key technology topics for intelligent robots from 1999 to 2018. As illustrated in Fig. 8, specific applications of intelligent robots have been the focus of technology development, and the vast majority of key technologies have accelerated in growth since 2014. Driving Mechanism, Humanoid Robots, Mechanical Arm, Robot Vision, Path Planning, and Remote Control are rapidly developing. Still, the growth trend shows that Humanoid Robot and Robot vision have more momentum for future development. Robot Voice, Sensor, Robot Interaction, System Controller, Wireless Communication, Servo Motor, and Robot Joint, on the other hand, are developing more slowly. In terms of growth, System Controller and Robot Joint may step into the ranks of rapid development in the future. Robotic Fish is growing slowly and fluctuating as a new technology, probably because the technology development has not yet entered a stable state. There is more potential for future growth.

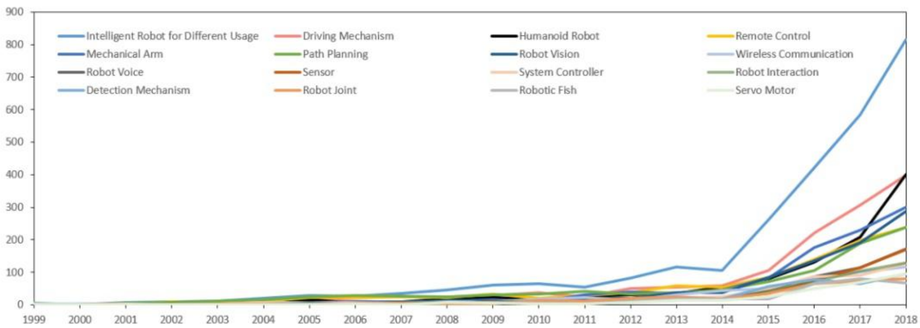
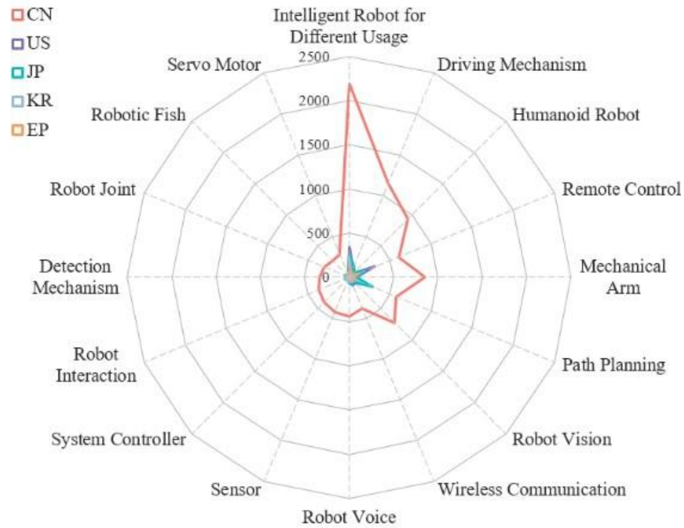


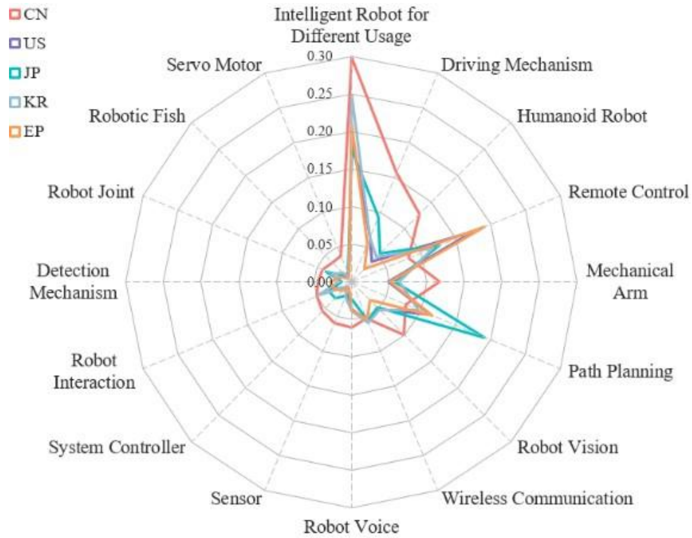
Fig. 8. Analysis of the R&D Trend of Key Technologies of Intelligent Robot

5.2 Competitive Environment Analysis

To provide a specific analysis of the competitive market environment for key technologies of intelligent robots, Fig. 9(a) shows the strength comparison in terms of patent scale in the field of key technologies of intelligent robots in five core competing countries/regions, namely China, Japan, Korea, the US, and Europe, in the form of a technology radar chart, which shows that China has an absolute advantage in the scale of intelligent robot patents. In contrast, these countries/regions, the US, Japan, Korea, and Europe. The patent scale of these countries/regions is relatively small. The layout of key technologies is, to a certain extent, similar. As the absolute value of the number of patents in the five main countries/regions varies considerably, to further compare the layout of each key technology for intelligent robots in the five main countries/regions, the data is standardized to reveal the proportional distribution of each country itself in each technology area, as shown in Fig. 9(b).



(a) Patent Counts



(b) Patent Proportion

Fig. 9. Distribution of 16 Key Technologies in Major Countries/Regions

As illustrated, intelligent robots for different usage focus on all five countries/regions, especially China and South Korea. Also, Europe has the most considerable presence in Remote Control; Japan has the largest presence in Path Planning; South Korea has the largest share of Wireless Communication; and the US is more concerned with Remote Control, Path Planning, and Driving Mechanism.

In addition to standardizing the patent data of different countries/regions, this paper explicitly introduces an analysis of the number of core patents on each country's key technologies to assess their technological strength and form a more scientific understanding of the competitive environment. A core patent is a patent that has a key position in a particular technology field, making an outstanding contribution to the technological development of that field, or has a significant impact on other patents or technologies, and has a high economic value. (Xu et al., 2014) At present, there are many studies and discussions on the identification methods of core patents. Still, this paper mainly uses three indicators to measure core patents: the number of citations, the number of patent families, and the number of claims.

Fig. 10 shows the distribution of the TOP 100 core patents for key technologies of intelligent robots in the five countries/regions, filtered by the frequency of patent citations as the main keyword and the number of patent families, and the number of claims as to the secondary keywords.

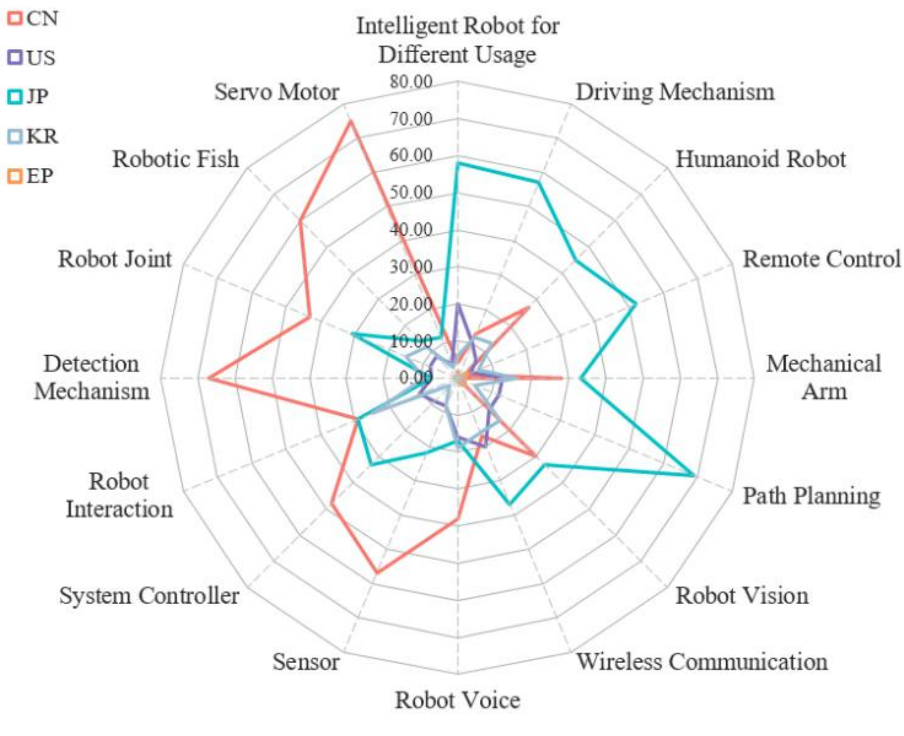


Fig. 3. Radar Chart of Core Patents Comparison of the 5 Countries/Regions

China and Japan are neck and neck in terms of the number of core patents for intelligent robots. Japan is stronger in Intelligent Robot for Different Usage, Driving

Mechanism, Humanoid Robot, Remote Control, Mechanical Arms, Path Planning, and Robot Vision; China is more assertive in Sensor, System Controller, Detection Mechanism, Robot joint, Robotic Fish, and Servo Motor. Among the US, Korea, and Europe, the US's strength lies in Intelligent Robot for Different Usage and Wireless Communication, while Korea is stronger in Robot Interaction. Europe has less of an advantage in core patents, probably because European countries prefer to apply for patents in their own countries rather than in the EU. It is also worth noting that China is at the bottom of the list in Remote Control and Path Planning, probably where China's intelligent robot industry will need to invest more in the future.

5.3 Technologies Layout Analysis

To more clearly demonstrate the layout of intelligent robot patents in several major competing countries/regions, we construct a matrix of the distribution of patent priority countries/regions and patent family countries/areas for intelligent robot technologies, as shown in Table 4. The countries/regions of patent priority can characterize the place of origin of the technology, while the countries/regions distribution of patent families can describe the technology's market layout.

Table 4. Patent Priority and Patent Family of Intelligent Robot Technologies in Main Countries/Regions

	China (7342)	US (1790)	Japan (1475)	Korea (890)	Europe (617)
China (6905)	6896	51	29	11	22
U.S. (1091)	168	1056	188	59	230
Japan (1111)	102	250	1086	47	86
Korea (737)	51	240	46	725	63
Europe (73)	21	49	41	17	72

As illustrated, China is the most prominent source of technology and the largest technology market. Still, as much as 93.93% (6896/7342 = 0.9393) of Chinese intelligent robots are mainly located in the domestic market. In other words, the proportion of overseas patents in China's intelligent robots is deficient, which puts it at a significant disadvantage when competing in the international market in the future. Generally speaking, the technology content of overseas patents is higher, and the scale of overseas patent layout can, to a certain extent, reflect the technological competitiveness of that countries/regions. The proportion of overseas patents in China is the lowest among the five major countries/regions, which implies that China should focus on quality and innovation while developing its patent technology scale to enhance its technological advancement and competitiveness to gain a dominant global position in intelligent robots. Furthermore, the US, Europe, Korea, and Japan have very few patent applications in China, with the highest number being only 168 in the US, which indicates the current situation where China's local technology market is relatively saturated. China may need to seek breakthroughs from overseas markets in the future.

The US's overseas homologation ratio is 41.01%, and its overseas patent applications are mainly distributed in Japan and South Korea. Simultaneously, the number of patents filed in the US by Japan and South Korea is also the highest except for their own countries, which indicates that the three countries have close patent technology ties and many technology exchanges with each other. Although the scale of technology patents in Europe is small, the ratio of overseas patent applications is significant, at 88.33%, in contrast to China's more conservative outward-looking technology layout. This indicates that Europe has a high standard in intelligent robots, attaches importance to overseas technology market competition and rapid technology marketization.

6 Conclusion

As an emerging technology that has been developing rapidly in recent years, intelligent robots have gone through three evolutionary stages: "Industrial Robot," "Autonomous Mobile Robot," and "Intelligent Robot." It has developed sixteen key technologies have been developed, namely Humanoid Robot, Robot Joint, Mechanical Arm, Driving Mechanism, Sensor, Wireless Communication, Servo Motor, System controller, Remote Control, Path Planning, Robot Voice, Robot Vision, Detection Mechanism, Robot Interaction, Robotic Fish and Intelligent Robot for Different Usage. IoT Robot, Bionic Robot Fish Structure, Robot Charging Pile, Multi-modal Output Data, Resistance Layer, Intelligent Robot Human-Computer Interaction, Intelligent Security Robot, Unmanned Aerial Vehicle, Pneumatic Muscle, and Grabbing Robot have become burst hotspots in recent years.

Among the key technology topics of intelligent robots, the Intelligent Robot with different functions has been the focus, the Humanoid Robot will develop rapidly in the coming period, and Robotic Fish has more significant potential for development as a burst hotspot that has not entered a stable state. Globally, China's intelligent robot patents have an absolute advantage in terms of scale. However, there is still room for progress in core patented technologies, particularly in Remote Control and Path Planning. China's patent applications for intelligent robots technology have been mainly local, lacking overseas markets. They are in a significantly weaker position to compete in the international market in the future. In terms of specific areas, China could invest more in Remote Control, Path Planning, Robot Voice, Detection Mechanism, and Robot Joint in the future to seek balanced development.

We have two contributions in this paper: Firstly, when extracting terms from patent titles, instead of extracting individual words, n-gram term phrases with thematic significance are extracted, which provides convenience for subsequent topic identification and hotspots analysis. Secondly, this paper constructs a framework for analyzing intelligent robots' key technologies' opportunities from three perspectives: technology R&D trends, competitive environment, and technology layout. It considers the overall patent scale and introduces a competitive analysis based on the distribution of core patents. The five main countries/regions' technological strengths can be assessed more scientifically, and the competitive technological environment can be understood more comprehensively.

There are two main limitations of this paper: Firstly, when extracting terms from patent titles, the overly long noun terms were not accurately segmented, resulting in some of the terms not being counted in the co-word analysis, which may affect the subsequent effect of the topic clustering identification. Secondly, the framework designed for the opportunity analysis of the clustering results was based solely on the patents' perspective, without considering the impact of market and technology policies on technology opportunities. In analyzing the competitive environment, we only assess the competition between countries at a macro level, and the competition between specific technological innovation individuals, such as commercial enterprises and research institutions, was neglected. In future research, we will continue to improve and expand on these shortcomings.

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