sciendo Applied Mathematics and Nonlinear Sciences 6(1) (2021) 129–140

Applied Mathematics and Nonlinear Sciences

https://www.sciendo.com

Investigating the impacts of artificial intelligence technology on technological innovation from a patent perspective

Yi-Hui Qiu[1], Xin Yang[1], Zong-Ze Li[1], Chiyu Zhang[2], Shui-Xuan Chen[3]

[1]Department of economics and management, Xiamen University of Technology, Xiamen

[2]Fujian, China School of Information, The University of British Columbia, Vancouver, Canada

[3]Mechanical Department, Xiamen University of Technology, Xiamen Fujian, China

Email address: qiuyihui@xmut.edu.cn, 917998714@qq.com, 973054140@qq.com; chiyuzh@mail.ubc.ca; Csx@xmut.edu.cn

Submission Info

Communicated by Juan Luis García Guirao
Received November 30th 2020
Accepted January 31st 2021
Available online March 19th 2021

Abstract

Artificial intelligence (AI) technology has been widely applied in various fields in recent years. Nevertheless, no systematic study has yet been conducted on the effects of AI technology on different fields. In this study, the impacts of the latest AI technology on technological innovation in different fields were analysed and quantized systematically from a patent perspective. Moreover, trends on AI technological innovation in some fields were analysed thoroughly. We conducted this study on a dataset of patents related to AI technology. Based on the patent dataset, we carried out a statistical analysis on technology fields, which we defined and classified based on international patent classification (IPC) number. Distributions of IPC in different fields were also analysed to determine the trends on AI technological innovation. The research conclusions can provide useful information to investors and enterprises, who are interested in the state of the art concerning AI technology.

Keywords: AI technology, patent analysis, technological innovation

1 Introduction

Artificial intelligence (AI) technology has achieved rapid development in recent years. During the Imagenet Large Scale Visual Recognition Challenge in 2012, scholars from the University of Toronto proposed a classification model based on deep learning and achieved outstanding effects. The classification model has attracted industry-wide attention for AI technology [1, 2]. In 2016, the AlphaGo developed by DeepMind Company defeated Li Shishi, the World Go Champion, thereby bringing further attention to AI technology as well [5]. The goal of AI technology is to endow intelligence to machines with the hope that these can have the ordinary

ISSN 2444-8656 doi:10.2478/AMNS.2021.1.00015

intelligence of humans and even surpass it in the future to accomplish specific tasks, including image classification, playing the game of go, natural language understanding, text generation, etc [3]. Theoretically, tasks that require human intelligence in any industry might be assisted and even substituted by AI technology. In fact, recent reports, news, advertisements and financial statements of companies reveal that, indeed, AI technology has already been applied to various industries.

The impacts of AI technology can be seen in various fields, including service for life, medical care, retail industry, financial industry, agriculture, education, etc [2]. Nevertheless, the abovementioned information was acquired from nonacademic channels (e.g. news, advertisements and financial statements) and its authenticity cannot be proven. Questions have emerged as to whether all of these fields are affected by AI technology, whether AI technology has been applied to these fields and whether the relevant technological innovations have been developed. If the answer is yes, then it would be interesting to know which fields have experienced greater AI influence, and therefore, show more AI technological innovation. To the best of our knowledge, no previous study has carried out a systematic statistical analysis on these problems. To investigate the abovementioned problems, the effects of the latest AI technology on technological innovation in various fields were analysed systematically in the current study. Moreover, the technological innovations of a field were analysed and quantified from the perspective of patents. Abundant AI technology-related patents were downloaded from a patent database for statistical analysis. Fields that apply AI technology were defined and classified from the perspective of international patent classification (IPC). Moreover, new trends for AI technology in some fields were analysed thoroughly. On one hand, research conclusions can provide useful information to the following individuals or organizations: (1) consumers who want to buy the latest products based on AI technology, (2) investors who want to invest in AI technological companies and (3) enterprise decision-makers who want to promote AI technological innovations in their respective companies. On the other hand, the research conclusions provide a reference for the application of AI technology in other fields of technological innovation.

2 Theoretical background

2.1 Patents

A patent is an expression of intellectual property and gives legal protection to the owner of the patented idea or technology. A patent also reflects the innovative activity of a technological field from a specific aspect. The IPC table is compiled according to the *International Patent Classification Agreement/Strasbourg Agreement* signed in 1971. It is an international universal tool for the classification and retrieval of patent literatures and is essential in all countries around the world. The IPC has been organizing, managing and retrieving mass patent literatures and has made indelible contributions for over 30 years since its development. Due to the continuous emergence of new technologies, the number of patent literatures has increased by about 1.5 million every year. So far, the total number of patent literatures is about 50 million. Based on the corresponding number of patents, the technological field distribution of enterprises, or the key technological distribution of industries and key industrial distribution of relevant countries can be discussed. On one hand, the technological distribution of enterprises can disclose the inputs and investments made by an enterprise to specific technological fields. On the other hand, it is used to compare the technological directions of other enterprises, thus providing critical information for partners, purchasers, cooperators and strategic alliances.

2.2 Artificial intelligence

Deep learning technology has achieved rapid development in recent years. It is an emerging technology centred on the application of multilayer artificial neural network algorithms first proposed by Hinton in 2006. The deep convolutional neutral network model proposed by Alex and Hinton won the first prize at the 2012 Imagenet Large Scale Visual Recognition Challenge, and its score was significantly higher than that of the second prize winner. This model demonstrated the practical application of deep learning technology, which has

since attracted wide attention for the first time and raised concerns in both academe and the industry [4]. In 2016, when the AlphaGo based on deep reinforcement learning technology defeated Li Shishi, a renowned nine-level Go player, this further attracted extensive reports from the media.

Furthermore, AI technology began to penetrate into various fields and build a bridge for mutual integration and mutual development between emerging technologies and relevant fields [6]. For example, in automatic speech recognition and intelligent voice assistant, a more accurate acoustic model could be developed based on the depth neutral network [10]. In the field of real-time visual translation, words in pictures can be recognized through deep learning. Google brought the automatic driving field to a new level based on the deep learning algorithm [8]. In the medical field, AI technology can be applied to recognize cancer cells, find new drugs and promote technological innovations [7]. In finance, AI technology can be used to predict the stock price and recognize fraud [9]. Jun Liu explains the influence of AI on enterprise technological innovation from four aspects: knowledge creation, knowledge spillover, learning ability, and investment in research and development (R&D) and talents. Through empirical research, the promotion effect of AI on the low-tech industry is stronger than that of the high-tech industry. However, there is a lack of quantitative measurement of proxy variables and data for such variables as "knowledge creation", "knowledge overflow" and "learning and absorption capabilities" [20]. In the marketing field of enterprises, AI technology can also be used to come up with accurate marketing strategies and recommendations.

3 Data and method

3.1 Patent data

The patent data used in this study were collected from the Derwent Patent Database, a subsidiary of Clarivate Analytics. The Derwent Patent Database covers the patent databases of about 60 authorized patent agencies in the world and has collected over 20 million worldwide since 1963, thus providing comprehensive patent information.

The patent data analysed in this study included some AI-related patents downloaded from the Derwent Patent Database. In this study, target patents (the analysed patents) with relevant AI technological keywords in the title and abstract were retrieved [11–13, 15–18]. The keywords included "deep learning," "deep neural network" and "convolutional neural network," which were provided by three researchers and engineers engaged in AI technological research and development. The retrieval technique based on keywords was adopted in this study. This is because there is no IPC yet for AI and we cannot obtain the desired patents directly through the IPC number. Additionally, as several keywords are applied basically in the latest AI technology, the data search based on keywords is relatively comprehensive.

In this study, a total of about 25,000 AI-related patents were retrieved. The statistics on the publishing years of these patents can be found in Figure 1. As shown in the figure, the number of AI patent applications has consistently increased year-by-year since 2014. The paper of Hinton was published in 2012, and only a few leading large-sized companies were followed up initially. In the following 2–3 years, the practicability of AI technology has been verified in these companies. As a result, more companies invested capital and manpower into AI technology, thus increasing associated patents continuously. In March 2016, AlphaGo of Google defeated Li Shi-shi, a nine-level Go player. The relevant paper and technology was published in *Nature*, which attracted extensive attention to AI. Henceforth, the number of AI patent applications after 2016 increased quickly. The statistical analysis of the IPC numbers of these patents revealed that AI patent applications mainly concentrate in the fields of Human Necessities, Performing Operations, Transporting, Physics and Electricity (Figure 2).

3.2 Introduction to field classification

Our goal is to analyse the distribution of AI patents in different fields. First, fields were defined and the applied definitions were adopted from a previous work [19]. In the present work, many economic activities refer

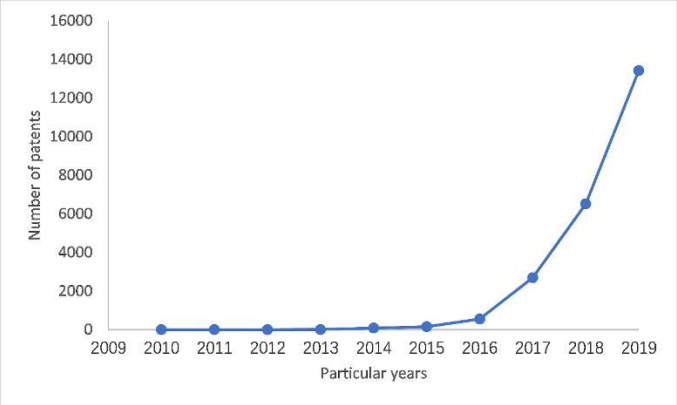

Fig. 1 Quantity distribution of AI patents in different years.

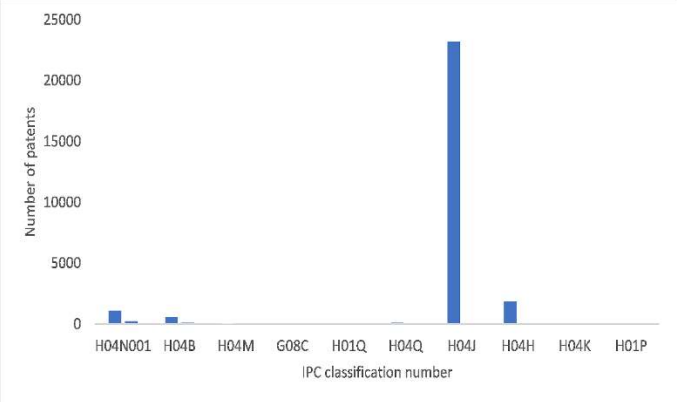

Fig. 2 IPC distribution of AI patents.

to study knowledge-intensive products and services, and technology is a primary factor of competition. Various technology classification methods can be found in the system of specific patent classification, which refers to either IPC or American patent classification. However, these classification methods have been proven to vary in terms of certain aspects. Therefore, Fraunhofer ISI and the scientific technological observation station cooperated with the International Patent Institute (INPI) of France and developed a more systematic technological classification according to the codes of IPC, thereby resulting in the ISI-OST-INPI classification method [11,12].

The old version of the ISI-OST-INPI classification was designed when only a few advanced industrialized countries were doing international trade. Nevertheless, the ISI-OST-INPI classification has been characterized by the increasing correlation among emerging countries in recent years. Therefore, given that international comparison must cover more countries, a new version of the ISI-OST-INPI classification method based on IPC-9 code was developed. The new ISI-OST-INPI classification method further divided the information technology field into several fields, which can be distinguished at a higher level. In addition, ordinary fields of process engineering have been abandoned completely [18], as the covered fields have no definite references to mechanical engineering or chemistry. The new ISI-OST-INPI classification method also includes new fields that have definite relations with mechanical engineering or chemistry [13,17]. In this study, the ISI-OST-INPI classification method was applied in Vargas et al. [18], covering a total of 20 fields. The IPC number of each field is shown in Figure 3.

Technology fields	IPC
Electrical machinery, equipment, energy	F21#, H01B, 1C, H01F, H01G, H01H, HO1J, H01K, H01M, H01R, H01T, H02#, H05B, H05C, H05F, H99Z
Audiovisual technology	G09F, G09G, G11B, H04N-003, H04N-005, H04N-009, H04N-013, H04N-015 H04N-017, H04R, H04S, H05K
Telecommunications	G08C, H01P, H01Q, H04B, H04H, H04J, H04K, H04M, H04N-001, H04N-007, H04N-011, H04Q
Numerical communication	H04L
Basic communication process	H03#
Computer technology	(G06# not G06Q), G11C, G10L
Information Technology Management Method	G06Q
Semiconductor	H01L
Optics	G02#, G03B, G03C, G03D, G03F, G03G, G03H, H01S
Measuring	G01B, G01C, G01D, G01F, G01G, G01H, G01J, G01K. G01L, G01M, (G01N not G01N-033), G01P, G01R, G01S; G01V, G01W, G04#, G12B, G99Z
Biomaterial analysis	G01N-033
Control	G05B, G05D, G05F, G07#, G08B, G08G, G09B, G09C, G09D
Medical technology	A61B, A61C, A61D, A61F, A61G, A61H, A61J, A61L, A61M, A61N, H05G
Organic Fine Chemicals	(C07B, C07C, C07D, C07F, C07H, C07J, C40B) not A61K, A61K-008, A61Q
Biotechnology	(C07G, C07K, C12M,C12N, C12P,C12Q, C12R, C12S) not A61K
Drug	A61K not A61K-008
Polymer Chemistry, Polymer	C08B, C08C, C08F, C08G, C08H, C08K, C08L
Food Chemistry	A01H, A21D, A23B, A23C, A23D, A23F, A23G, A23J, A23K, A23L, C12C, C12F, C12G, C12H, C12J, C13D,C13F, C13J,C13K
Basic Material Chemistry	A01N,A01P,C05#,C06#,C09B,C09C,C09F,C09G,C09H,C09K,C09D,C09J, C10B,C10C,C10F,C10G,C10H,C10J,C10K,C10L,C10M,C10N,C11B,C11C, C11D,C99Z
Materials, Metallurgy	C01#, C03C, C04#, C21#, C22#, B22#

Fig. 3 IPC distribution in various fields.

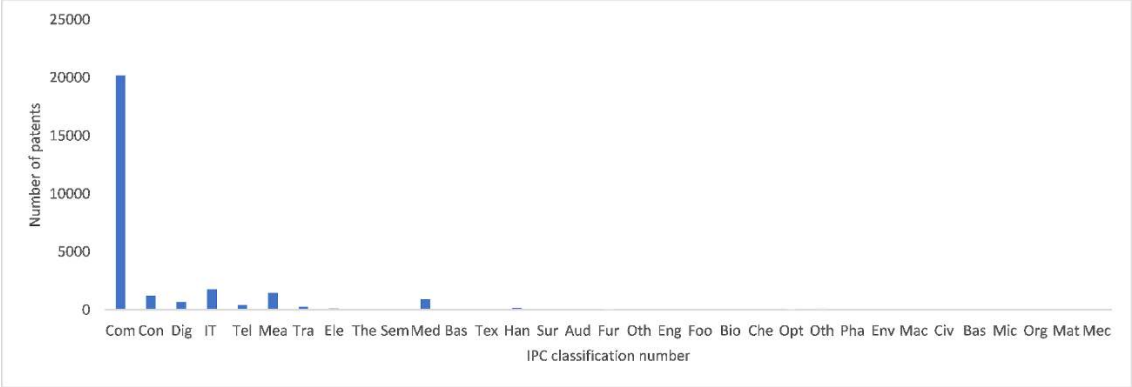

Fig. 4 Quantity of AI patents in different fields.

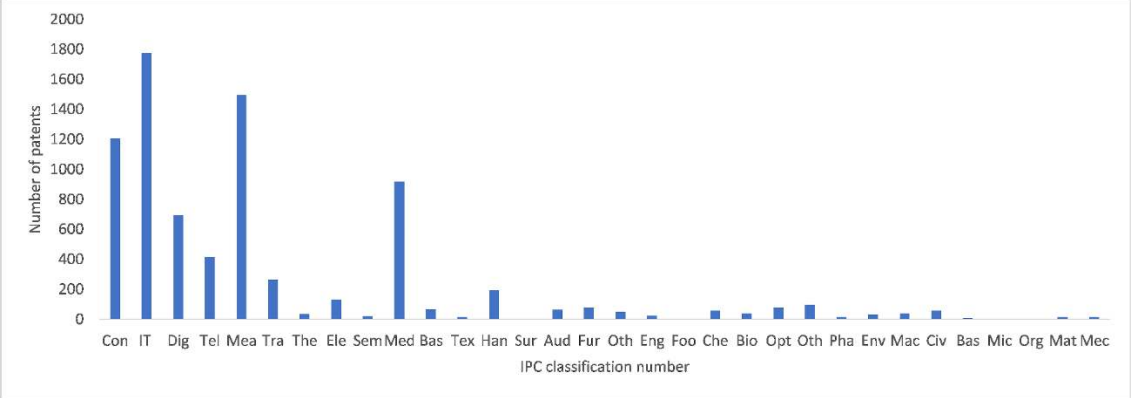

Fig. 5 Patent distribution after deleting the COM field.

4 Results

4.1 Analysis results

About 25,000 patent data related to AI were downloaded from the Derwent Patent Database. A statistical analysis of the quantity of AI patents in different fields was carried out. The specific data are shown in Figure 4. Specifically, the number of AI patents in the computer technology field is the highest and is significantly higher than the expected results in other fields. AI technology is a branch of computer technology. Hence, patents that use AI technology basically can be divided into G06, G11C and G10L of IPC in computer technology, resulting in various AI patents in the computer technology field.

It can also be seen from Figure 4 that AI technology has been applied and developed in other technological fields. For the convenient observations of the development of AI patents in other fields, all retrieved patent data were screened. Computer technology, which is the field with the most AI patents and observation data, were deleted. Instead, the quantity and distribution of AI patents in other fields were observed (Figure 5). The patent distribution map after deleting computer technology is thus obtained. The results indicate that AI technology has been applied to the fields of Control, IT Methods for Management, Measurement, Telecommunications and Medical Technology. Moreover, AI technology has rapidly developed in these fields.

4.2 Further division

Several fields with many AI patents were selected and analysed thoroughly, including Control, Measurement, Telecommunications and the Medical field. Statistical analysis on the distribution of the IPC number in each

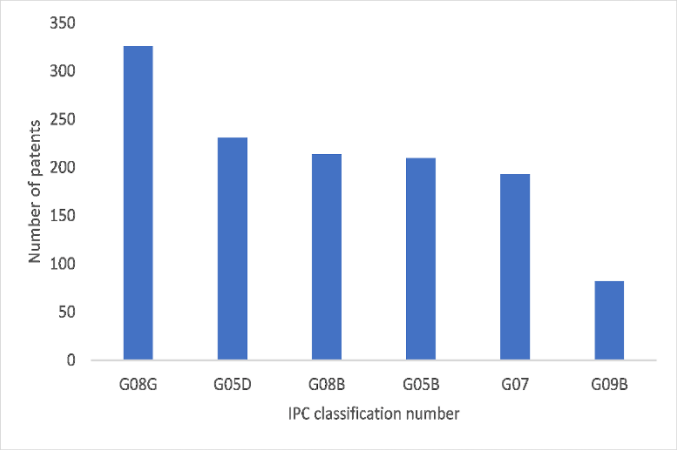

Fig. 6 IPC distribution in control.

field was carried out. The statistical analysis results are introduced in the following sub-sections.

4.2.1 Analysis of the control field

The quantity distribution of AI patents in Control is shown in Figure 6 in which the horizontal axis is the IPC number and the vertical axis is the quantity. The definitions of several IPC numbers on the horizontal axis are shown in Figure 7. As can be seen, the number of AI technological patents is concentrated in G08 signal device and G05 control adjusting. In the signal device field, technological innovation in G08G traffic control system is especially outstanding. In the field of traffic control system, abundant technological advancements have been achieved in intelligent traffic systems with the development of AI technology, mainly focused on vehicle positioning and traffic navigation system, information system, signal coordination control system and automatic highway system [10]. Owing to these achievements, the quantity of AI patents in the traffic control system has rapidly increased. Recently, there have been a great deal of research achievements in intelligent control, especially in the sub-fields of expert control, intelligent robot control, intelligent process control, intelligent fault diagnosis, and intelligent scheduling and planning. As a result, the quantity of AI patents in the field of Control has also increased.

IPC	Technology fields
G05D	Physics, Controlling, Regulating, Systems for controlling or regulating non-electric variables
G08B	Physics, Signaling, Signaling or calling systems, Order telegraphs, Alarm systems
G08G	Physics, Signaling, Traffic control systems
G07	Physics, Controlling, Regulating, Control or regulating systems in general, Functional elements of such systems, Monitoring or testing arrangements for such systems or elements
G05B	Physics, Controlling, Regulating, Control or regulating systems in general, Functional elements of such systems, Monitoring or testing arrangements for such systems or elements
G09B	Physics; Educating; Cryptography; Display; Advertising; Seals; Educational or demonstration appliances; Appliances for teaching, or communicating with, the blind, deaf or mute; Models; Planetaria; Globes; Maps; Diagrams

Fig. 7 Definitions of IPC numbers under control.

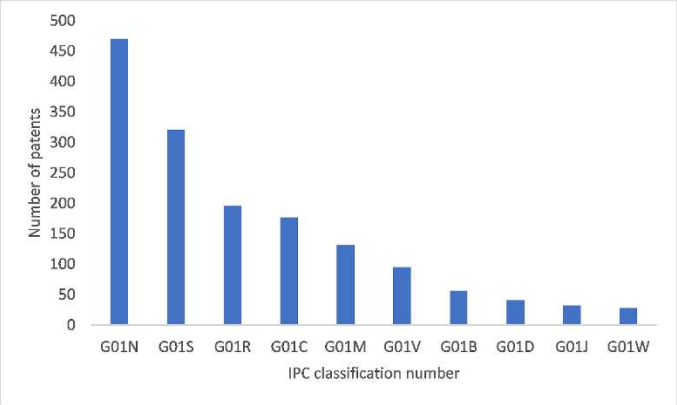

Fig. 8 IPC distribution in measurement.

4.2.2 Analysis of the measurement field

The quantity distribution of AI patents in Measurement is shown in Figure 8. As can be seen, the development of AI technology has significantly influenced the innovation power of the G01 test field. G01N refers to the testing or analysis of the rapid development of AI technology in the material field based on the chemical or physical properties of materials. This is because AI technology is good at seeking the "hidden" causal relationships in mass data and can process structured data in scientific research. Nevertheless, the data of material field is often structured, of high quality and marking [13, 18]. AI technology can significantly promote the R&D of new materials. The definitions of some IPC numbers under Measurement are listed in Figure 9.

4.2.3 Analysis of the telecommunications field

The quantity distribution of AI patents in Telecommunications is shown in Figure 10. The definitions of some IPC numbers in Telecommunications are listed in Figure 11. It can be seen from Figure 10 that Telecommunication accounts for the most number of patent applications of AI technology. In particular, the numbers of AI technological patents in image communication, telephone communication and transportation are very remarkable. In Telecommunications, AI technology can realize resource scheduling effectively and increase the availability and efficiency of the network. As a result, users can gain a better sense of experience. Furthermore, the optimized network design and configuration can be realized for network management and maintenance. It can perceive network conditions immediately, eliminate faults in a timely manner and improve the communication quality [8]. AI technology can also protect the communication safety of users. Based on the assistance of such AI technologies in the development of Telecommunications, the quantity of AI technology in this field has increased dramatically.

4.2.4 Analysis of the Medical Technology field

The quantity distribution of AI patents in Medical Technology is shown in Figure 12. The definitions of some IPC numbers are presented in Figure 13. Obviously, the number of AI patents covered in A61B in the medical field is far higher than those in the other sub-classes. Hence, the AI technological innovations in the medical field are mainly concentrated in A61B, which refers to diagnosis, surgical and identification technologies. This might be related with many technological innovations and breakthroughs of recent AI technologies in imaging. By learning abundant medical images, AI can assist doctors in the accurate positioning of lesion areas and decrease the likelihood of misdiagnoses. Moreover, computers simulate the thinking and diagnosis reasoning of doctors by "learning" relevant professional knowledge, thus enabling such medical professionals to give reliable diagnoses as well as therapy and treatment programmes [7]. Due to the application and development of these technologies, the quantity of AI patents concerning diagnosis and identification has also increased in recent years.

IPC	Technology fields
G01R	Physics, Measuring, Testing, Measuring electric variables, Measuring magnetic variables
G01G	Physics, Measuring, Testing, Weighing
G01C	Physics, Measuring, Testing, Measuring distances, Levels or bearings, Surveying, Navigation, Gyroscopic instruments, Photogrammetry or videogrammetry
G01N	Physics, Measuring, Testing, Investigating or analyzing materials by determining their chemical or physical properties
G01S	Physics, Measuring, Testing, Radio direction-finding, Radio navigation, Determining distance or velocity by use of radio waves, Locating or presence-detecting by use of the reflection or reradiation of radio waves, Analogous arrangements using other waves
G01M	Physics, Measuring, Testing, Testing static or dynamic balance of machines or structures, Testing of structures or apparatus not otherwise provided for
G01L	Physics; Measuring; Testing; Measuring force, stress, torque, work, mechanical power, mechanical efficiency, or fluid pressure
G01V	Physics, Measuring, Testing, Geophysics, Gravitational measurements, Detecting masses or objects, Tags
G01D	Physics, Measuring, Testing, Measuring not specially adapted for a specific variable, Arrangements for measuring two or more variables not covered by a single other subclass, Tariff metering apparatus, Transferring or transducing arrangements not specially adapted for a specific variable, Measuring or testing not otherwise provided for
G01W	Physics, Measuring, Testing, Meteorology
G01J	Physics; Measuring; Testing; Measurement of intensity, velocity, spectral content, polarization, phase or pulse characteristics of infra-red, visible or ultra-violet light; Colorimetry; Radiation pyrometry
G01B	Physics; Measuring; Testing; Measuring length, thickness or similar linear dimensions; Measuring angles; Measuring areas; Measuring irregularities of surfaces or contours
G01P	Physics; Measuring; Testing; Measuring linear or angular speed, acceleration, deceleration, or shock; Indicating presence or absence of movement; Indicating direction of movement
G01H	Physics; Measuring; Testing; Measurement of mechanical vibrations or ultrasonic, sonic or infrasonic waves
G01K	Physics, Measuring, Testing, Measuring temperature, Measuring quantity of heat, Thermally-sensitive elements not otherwise provided for
G01F	Physics; Measuring; Testing; Measuring volume, volume flow, mass flow, or liquid level; Metering by volume
G04	Physics, Horology

Fig. 9 Definitions of IPC numbers in measurement.

4.2.5 Other fields

In other fields, AI technology is represented by technological innovations in vehicle, mechanical arms, sports, optics and metal processing (Figure 14) [16]. The definitions of the IPC numbers of the horizontal axis are shown in Figure 15. In vehicles, unmanned vehicles comprise the most popular research direction. Many scientific research achievements related to unmanned vehicles have been obtained with the aim of realizing the goal of having real, safe unmanned driving as soon as possible. The mechanical arm can realize refined and intelligent processing by designing a computer control system. In sports, sports programmes can be customized through AI technology. AI technology can offer personalized sports training plans for different individuals. In optics, AI technology can assist studies on ultraprecise/micro and nano-fabrication, wafer-level optical application and optical filming [18]. In metal processing, AI technology can realize communication between computer and metal cutting controller as well as execute automatic control over cutting based on accurate database supervision and management [17].

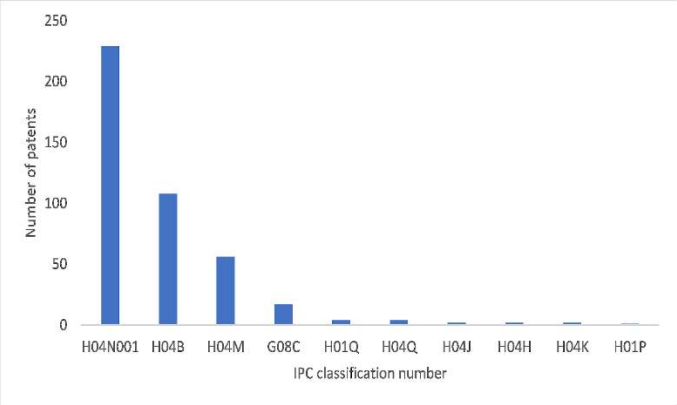

Fig. 10 IPC distribution in telecommunications.

IPC	Technology fields
H04N001	Electricity, Electric communication technique, Pictorial communication
H04M	Electricity, Electric communication technique, Telephonic communication
H01Q	Electricity; Basic electric elements; Antennas, i.e., radio aerials
H04B	Electricity, Electric communication technique, Transmission
H04Q	Electricity, Electric communication technique, Selecting
H04J	Electricity, Electric communication technique, Multiplex communication
H04H	Electricity, Electric communication technique, Broadcast communication
G08C	Physics; Signaling; Transmission systems for measured values, control, or similar signals
H01P	Electricity, Basic electric elements, Waveguides, resonators, lines, or other devices of the waveguide type
H04K	Electricity, Electric communication technique, Secret communication, Jamming of communication

Fig. 11 Definitions of IPC numbers in telecommunications.

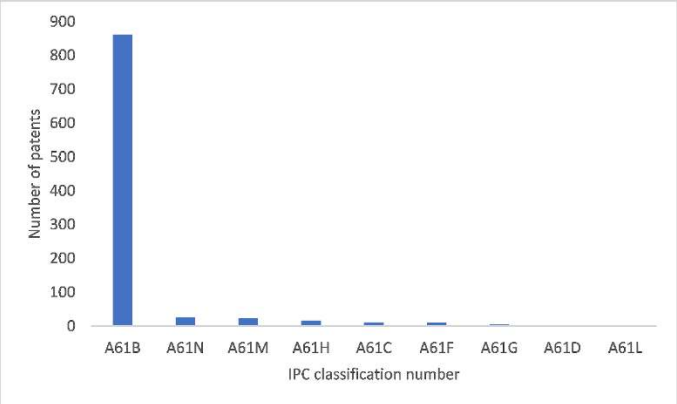

Fig. 12 Distribution of IPC in medical technology.

IPC	Technology fields
A61B	Human necessities, Medical or veterinary science, Hygiene, Diagnosis, Surgery, Identification

Fig. 13 Definitions of the IPC number in medical technology.

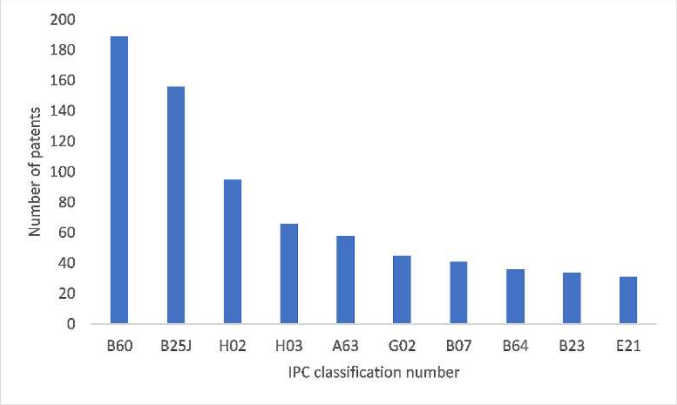

Fig. 14 Distribution of IPC in other fields.

IPC	Technology fields
B60	Performing operations, Transporting, Vehicles in general
B25J	Performing operations, Transporting, Hand tools, Portable power-driven tools, Handles for hand implements, Workshop equipment, Manipulators, Manipulators, Chambers provided with manipulation devices
H02	Electricity; Generation, conversion, or distribution of electric power
H03	Electricity, Basic electronic circuitry
A63	Human necessities, Sports, Games, Amusements
G02	Physics, Optics
B07	Performing operations, Transporting, Separating solids from solids, Sorting
B64	Performing operations, Transporting, Aircraft, Aviation, Cosmonautics
B23	Performing operations, Transporting, Machine tools, Metal-working not otherwise provided for
E21	Fixed constructions, Earth or rock drilling, Mining

Fig. 15 Definitions of IPC numbers in other fields.

5 Conclusions

The effects of the latest AI technologies on the technological innovations in various fields are explored from the perspective of patents. The results demonstrate that the quantities of AI patents in the fields of Control, IT Methods for Management, Measurement, Telecommunications and Medical Technology are significantly higher than those in other fields. This reveals that AI technology has influenced the technological innovation of these fields significantly. Based on a detailed analysis of some fields, AI technological innovations in Control are mainly focused on G08 signal device and G05 control adjustment. In Measurement, AI technological innovations are focused on G01N, which refers to material testing or analysis based on the chemical or physical

properties of materials. In Telecommunications, AI technological innovations refer to the patents of electronic communications techniques. In Medical Technology, AI technological innovations are focused on A61B (technologies for diagnosis, surgery and identification). Future studies may consider conducting an analysis from the perspective of patent quality, as the quantity of patents may not be the best way to measure innovation. Moreover, the definitions and classifications of various fields are a potential research direction as well. Finally, the definitions of fields applied in this study have been proposed several years ago. Thus, they may no longer be suitable for the current classifications of industrial fields.

Acknowledgements: This work was sponsored by the National Natural Science Foundation of China (Grant No. 71804157), Fujian Province Social Science Foundation of China (No. FJ2017C002), the Natural Science Foundation of Fujian Province of China (No. 2019H0037), Xiamen science and technology planning project of China (No. 3502Z20183042), Social Science Planning Project of Fujian Province of China (No. FJ2018C009), and the science and technology projects sponsored by China Tabacco Jiangxi Industrial LLC (Development and application of environmental protection cleaning system for chain cutting machine).

References

[1] Szegedy, C., et al., Going deeper with convolutions. 2015 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2015.
[2] He, K., et al., Deep Residual Learning for Image Recognition. 2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2016.
[3] Devlin, J., et al., BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding. arXiv, 2018.
[4] Silver, D., et al., Mastering the game of Go without human knowledge. Nature, 2017. 550(7676): p. 354-359.
[5] Ardito, L., A. Messeni Petruzzelli and V. Albino, Investigating the antecedents of general purpose technologies: A patent perspective in the green energy field. Journal of Engineering and Technology Management, 2016. 39: p. 81-100.
[6] Ardito, L., D. D'Adda and A. Messeni Petruzzelli, Mapping innovation dynamics in the Internet of Things domain: Evidence from patent analysis. Technological Forecasting and Social Change, 2018. 136: p. 317-330.
[7] Silver, D., et al., Mastering the game of Go with deep neural networks and tree search. Nature, 2016. 529(7587): p. 484-489.
[8] Huang, J. and R. Chen, Exploring the intellectual structure of cloud patents using non-exhaustive overlaps. Scientometrics, 2019. 121(2): p. 739-769.
[9] Huang, J. and K. Tan, An Extension-Based Classification System of Cloud Computing Patents. International Journal of Information Technology & Decision Making, 2020. 19(04): p. 1149-1172.
[10] Deng, J., et al., ImageNet: a Large-Scale Hierarchical Image Database. 2009 IEEE Conference on Computer Vision and Pattern Recognition, 2009.
[11] Krizhevsky, A., I. Sutskever and G.E. Hinton, ImageNet Classification with Deep Convolutional Neural Networks. Communications of the ACM, 2017. 6(60): p. 84-90.
[12] Leu, H., C. Wu and C. Lin, Technology exploration and forecasting of biofuels and biohydrogen energy from patent analysis. International Journal of Hydrogen Energy, 2012. 37(20): p. 15719-15725.
[13] Vaccario G, Tomasello M V, Tessone C J, et al. Quantifying knowledge exchange in R&D networks: a data-driven model
[14] . Journal of Evolutionary Economics, 2018.
[15] Liu, S., et al., Development of a Patent Retrieval and Analysis Platform – A hybrid approach. Expert Systems with Applications, 2011. 38(6): p. 7864-7868.
[16] Ardito, L., D. D'Adda and A. Messeni Petruzzelli, Mapping innovation dynamics in the Internet of Things domain: Evidence from patent analysis. Technological Forecasting and Social Change, 2018. 136: p. 317-330.
[17] van den Oord, A., et al., WaveNet: A Generative Model for Raw Audio. 9th ISCA Speech Synthesis Workshop, 2016: p. 13-15.
[18] Vargas, M.R., et al., Deep Learning for Stock Market Prediction Using Technical Indicators and Financial News Articles. 2017 IEEE International Conference on Computational Intelligence and Virtual Environments for Measurement Systems and Applications (CIVEMSA), 2017: p. 60-65.
[19] Yoon, J. and K. Kim, An analysis of property–function based patent networks for strategic R&D planning in fast-moving industries: The case of silicon-based thin film solar cells. Expert Systems with Applications, 2012. 39(9): p. 7709-7717.
[20] Jun Liu, Huihong Chang, Jeffrey Yi-Lin Forrest, et al. Influence of artificial intelligence on technological innovation: Evidence from the panel data of china's manufacturing sectors. 2020, 158(C).