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INVITED PAPER

Artificial Intelligence Trends Based on the Patents Granted by the United States Patent and Trademark Office

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ABSTRACT This paper analyzes artificial intelligence (AI)-related patents that were granted by the U.S. Patent and Trademark Office (USPTO) between January 2008 and December 2018. The study used both the USPTO patent classification systems and a keyword-based search to obtain AI-related patent information. By considering the AI-related patents, growth in AI-related research and development (R&D) activities, as well as AI trends during the period, are investigated. The leading countries and companies in AI and widely used techniques and applications of AI in each region are identified in order to evaluate the level of attention paid to AI in different countries and industries.

INDEX TERMS Artificial intelligence, patents, trends, USPTO.

I. INTRODUCTION

Artificial intelligence (AI) is widely used in different industries, such as power electronics [1], transportation [2], healthcare [3], and telecommunications [4]. Its application is evident in everything from email spam filters, ridesharing applications, and online shopping, to manufacturing, autonomous vehicles, surveillance, and security. AI is now considered a market differentiator, and many companies have developed significant intellectual property in the domain. This is especially evident by the fact that since 2013, there have been approximately 170,000 AI-related patents filed worldwide, and this represents half of the total number of all filed AI-related patents [5].

To further increase the development of AI technologies, many countries have been actively promoting and funding efforts in AI algorithm development, AI hardware, and AI-based applications. For example, in 2017, the State Council of China released a development plan geared to ensure China as the global leader in AI by 2030 [6]. In February 2019, an executive order on maintaining American leadership in AI was issued by the U.S. president [7]. Interestingly, a March 2019 article in Japan's Nikkei newspaper [8] claimed that China overtook the United States in the number of filed AI-related patents per year in 2015. The article also mentioned that China filed more than 30,000 AI-related patents in 2018, which was 2.5 times the number of U.S. AI-related patents. On the other hand, according to Forbes [9], more than 154,000 AI-related patents have been filed in the world since 2010 and about 80,000 patents were filed in the United States. Although the study methods behind these numbers and their criteria for a patent to be related to AI were not revealed, they still show rapid growth in AI activities.

Patents can represent technological innovations in an organization [10], [11] and can be an indicator for research and development (R&D) activities. Patent information is a useful source to recognize the key players of a technology and understand their productivity [12]. Patent analysis, can help understanding of developments and trends in a particular region, determine the novelty and quality of patents in each region, and identify technological demands and gaps in countries [13]. Researchers have used patent analysis as a tool to study about different technologies [14], [15]. AI patent analysis, which uses the information attached to AI-related patents, is one of the ways a country or entity can determine

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the progress of AI technology and AI technological trends in order to create an AI strategic plan by considering the situation of competitors and potential vacuum areas of R&D activities in each region. The geographic region of a patent can be identified by assuming the patent owner's (assignee's) location is the origin of the innovation.

Tseng and Ting [16] analyzed AI-related patents that were retrieved from the United States Patent and Trademark Office (USPTO) dataset, to examine AI technology developments and compare trends in different countries. They identified and retrieved AI-related patents based on U.S. patent classification (UPC) system codes and categorized them into four sub-technology fields, including problem reasoning and solving (UPC 706/1-11), machine learning (UPC 706/12-26), network structure (UPC 706/27-44), and knowledge processing system (UPC 706/45-62). They did an overall ranking of countries, as well as rankings in each of the four sub-technology fields based on the number of AI-related patents and citations. Fujii and Managi [17] used the International Patent Classification (IPC) system to identify AI-related patents and classify them into four groups of biological models, knowledge-based models, specific mathematical models, and other AI technologies. They obtained the total number of AI-related patents and number of patents in each group granted by different patent offices and for different patent applicants. Their analysis showed that both U.S. and non-U.S. companies are interested in obtaining patents from the USPTO and that universities have a considerable number of AI-related patents. They also found that from 2000 to 2016, R&D priorities shifted from the biological and knowledge-based models to specific mathematical models and other AI technology. However, identifying AI-related patents based only on patent classification systems can result in ignoring the patents that are related to AI but were classified under classes unrelated to AI. This situation most likely applies to patents that take advantage of AI in other application fields such as transportation [18].

In 2019, the World Intellectual Property Organization (WIPO) published a study on AI-related patents and paper publications [5]. They evaluated AI trends in different regions by considering patents geographically based on filing offices and provided information about quantity, contexts, and applications of patents. However, considering filed patents, instead of granted patents, for an investigation on a technology can be misleading because patent applications can contain low-quality innovation that cannot be interpreted as representative of R&D activities, whereas granted patents must have a minimum requirement of an innovation. Moreover, patent applicants usually select the filing office based on commercial purposes and therefore patent office location does not show the origin of an invention.

In order to assess the state of the art and determine the trends related to AI technologies and applications, this study evaluated the patents granted by the USPTO between January 2008 and December 2018. Both patent classification systems and a keyword-based search were used to retrieve patent information. The approaches to retrieve the AI-related patent dataset from the USPTO database is presented in Section 2. Section 3 discusses the findings and the results that identify AI technological situations and trends in different regions. Section 4 provides the conclusions.

II. DATA COLLECTION AND METHODOLOGY

The USPTO database, which is used for this study, is the largest repository of filed patents, with more than 50% of the issued patents associated with non-U.S. entities [19]. Each U.S. patent has two major sections—the specifications and the claims. The specifications section includes the title, abstract, background, summary, drawings, and detailed description. The claims section points out and defines the subject matter that is considered as the invention and explains aspects of the invention that are protected by the patent.

The USPTO classifies patent applications using the International Patent Classification (IPC) system and the Cooperative Patent Classification (CPC) system. The IPC system is used by more than 100 different patent offices around the world, and the CPC system is a joint partnership between the USPTO and the European Patent Office (EPO) to use a common classification scheme. The patent classification codes can be used to identify AI-related patents, since each classification code has its own particular description and reveals the technical contents of a patent.

In this study, the CPC and IPC codes as well as a keyword-based search were used in order to identify AI-related patents. The keyword-based search captured patents in the AI domain that were not classified under an AI-related code. For example, ''User identification and personalized vehicle settings management system'' [18] is an AI-related patent that has been classified under classes unrelated to AI. The specifications section was searched for AI-related keyword matches. A patent was considered as an AI-related patent if it was assigned at least one AI-related classification code or there was an AI-related keyword match in the specifications section. Other papers used both patent classification systems and keyword-based search to obtain comprehensive results [5], [20]. The keywords and AI-related classification codes used in this paper are presented in the appendix.

After identifying the AI-related patents, two researchers reviewed independently 500 of them to determine the relevance of the patents to AI. The 500 patents were selected randomly from all the identified patents (123,545 patents). Both researchers found that 100% of reviewed patents were related to AI which showed integrity of the data for this study.

III. FINDINGS

The total number of AI-related patents granted by USPTO per year increased from 4,598 in 2008 to 20,639 in 2018. Meanwhile, there was an increase in total granted patents, although the portion of AI-related patents still increased from 2.5% to 6.1% during these years (figure 1). The growth in number of AI-related patents can be interpreted as the growth in AI-related R&D activities that emphasizes the need for a

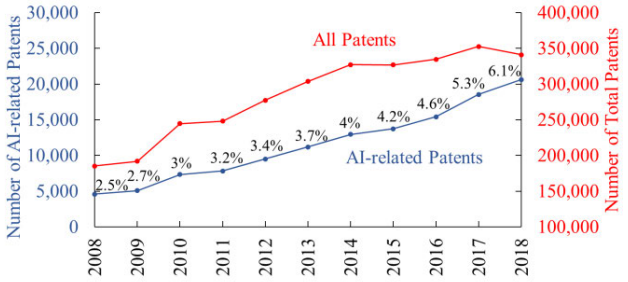

FIGURE 1. Number of patents granted by USPTO, 2008-2018.

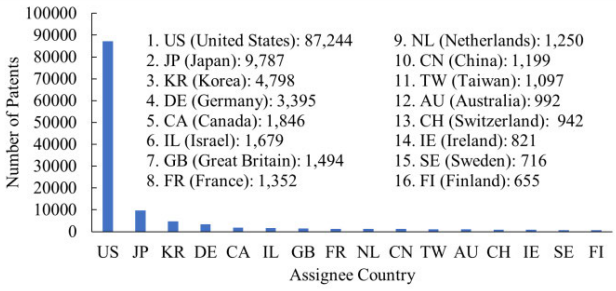

FIGURE 2. Number of AI-related patents per assignee country (patents granted by USPTO between 1/1/2008 and 12/31/2018).

TABLE 1. Assignee countries with highest number of AI-related patents in 2018.

Country	*No. of Patents*	*Percent*
United States	14,318	69.2%
Korea	1,378	6.7%
Japan	1,197	5.8%
Germany	504	2.4%
China	389	1.9%
Israel	332	1.6%
Others	2,521	12.2%
TOTAL	20,693	100%

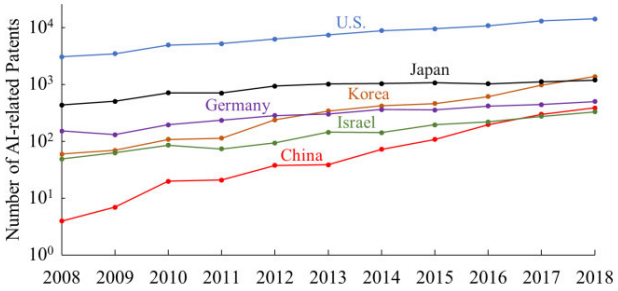

FIGURE 3. Number of AI-related patents for the selected assignee countries per year (patents granted by USPTO).

technological strategy plan for the countries and organizations that want to excel in AI technology.

A. ASSIGNEE COUNTRIES

From the beginning of 2008 to the end of 2018, more than 123,500 AI-related patents were granted by the USPTO. The United States had the highest number of AI-related patents (87,244), followed by Japan (9,787) and Korea (4,798). The high proportion of U.S. assignees in AI-related patents had been seen before in previous studies [16]. Figure 2 shows the number of AI-related patents for the top 16 countries with the highest number of AI-related patents.

The six countries with the highest number of AI-related patents in 2018 (Table 1), including the United States, Korea, Japan, Germany, China, and Israel, were selected for further investigation. Figure 3 and Figure 4 show the number of AI-related patents and the total number of patents for the selected countries, respectively. In addition, Figure 5 provides information about the proportion of AI-related patents in all granted patents. All the selected countries experienced increasing trends in number and proportion of AI-related patents. The United States had by far the highest number of AI-related patents during the period, although Israel had the highest proportion of AI-related patents. In 2018, about 13% of patents by Israel were related to AI which shows high AI activities by assignees from this country. Japan and Germany used to be the second- and third-ranking countries in the number of AI-related patents at the beginning of the period, but Korea overtook them in 2013 and 2018, respectively, and became the second-ranking country with the highest number of AI-related patents after the United States.

The United States, Korea, and Israel have been concentrating on more AI R&D activities since 2008 in comparison with the other countries because they had considerable increase in both the number of AI-related patents and the proportion of AI-related patents at the same time. For example, in 2018, although Japan had a high number of AI-related patents just 2% percent of their total patents were related to AI. Also, China had just about 2% increase in proportion of AI-related patents during the period.

B. INVENTOR COUNTRIES

A patented invention can be the work of more than one inventor. It was found that the majority (79%) of the AI-related patents granted by the USPTO between January 2008 and December 2018 have more than one inventor (Figure 6) and there are even patents with more than 50 inventors. The inventors of the identified AI-related patents were from 130 different countries, although most of them were from the United States. Figure 7 shows the number of occurrences of a country as the residency of the inventors.

For the six assignee countries with the highest number of AI-related patents in 2018, most of the patents were domestic (Table 2). A domestic patent is a patent with assignee and inventors from the same country. Specifically, for Korea and Israel more than 90% of inventors are domestic. However, inventors with residency in the United States made considerable contributions to patents with assignees from Germany and Japan.

TABLE 2. Country of residence for the inventors of AI-related patents with assignees from U.S., Korea, Japan, Germany, China, and Israel.

	Inventors' country of residence						
Assignee Country	U.S.	Korea	Japan	Germany	China	Israel	Others
U.S.	87.2%	0.1%	0.5%	0.8%	1.9%	1.3%	8.3%
Korea	5.4%	91.2%	0.1%	0.0%	1.0%	0.3%	2.0%
Japan	15.5%	0.1%	77.8%	0.6%	1.7%	0.0%	4.3%
Germany	17.1%	0.1%	0.2%	74.0%	1.0%	0.8%	6.9%
China	2.8%	0.0%	0.3%	0.3%	89.5%	0.0%	7.1%
Israel	5.5%	0.0%	0.2%	0.4%	0.1%	90.9%	3.0%

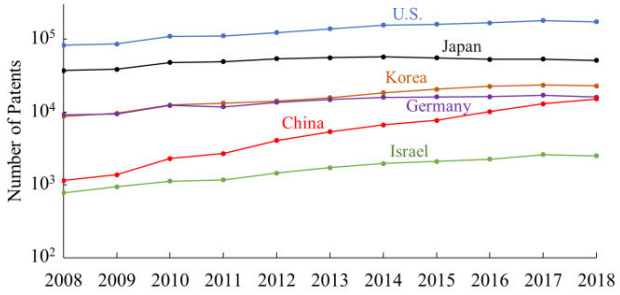

FIGURE 4. Number of total patents for the selected assignee countries per year (patents granted by USPTO).

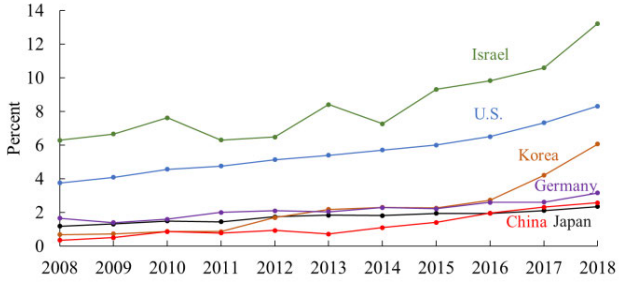

FIGURE 5. Ratio of AI-related patents to all patents for the selected assignee countries per year.

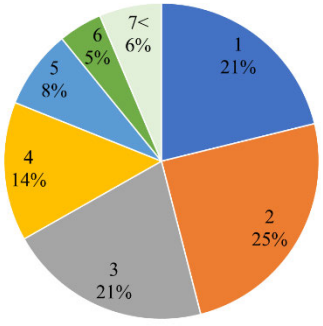

FIGURE 6. Number of inventors for AI-related patents (granted between January 2008 and December 2018).

About 10.5% (∼13,000) of total identified AI-related patents (∼123,500) were the results of collaboration between inventors from different countries. By considering these patents, which were results of cross-border collaborations, the most probable countries of residence of cross-border collaborators for each of the selected countries were obtained

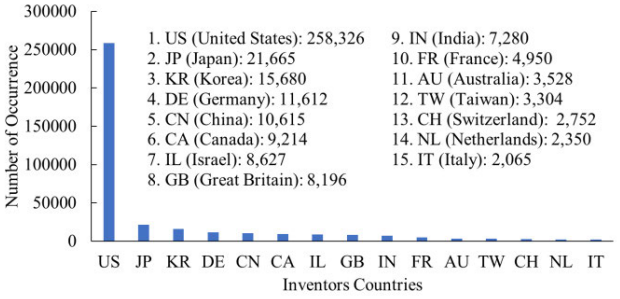

FIGURE 7. Inventors' country of residence for AI-related patents (granted between 1/1/2008 and 12/31/2018).

(Figure 8). The U.S. inventors were the main cross-border collaborators of inventors from Korea, Japan, Germany, China, and Israel. 79% of foreign collaborators with Chinese and Israeli inventors were from the United States. On the other hand, the inventors from the United States had high collaboration with the inventors from India (12%), China (12%), Canada (12%), Great Britain (10%), Germany (9%), and Israel (7%). Chinese inventors are also the main collaborators with Korean and Japanese inventors.

C. TOP TEN ASSIGNEES

The top ten assignees with the highest number of AI-related patents, granted by the USPTO between January 2008 and December 2018, were all companies and there was no university between them, as shown in Figure 9. IBM had the highest number of AI-related patents (∼7100) followed by Microsoft (∼5000) and Google (∼4000). IBM, Microsoft, and Google were the three assignees with the highest number of AI-related patents since 2012, although, in 2018 Samsung overtook Microsoft and Google and became the second-ranking assignee after IBM (Figure 10). Google had the highest number of AI-related patents in 2015, whereas, they were not even in the top 10 assignees until 2011. LG, Qualcomm, Amazon, and Facebook emerged in the top 10 assignees after 2012. On the other hand, Siemens, Sony, and Yahoo, which used to be in the top 10 assignees, disappeared before 2017.

D. AI APPLICATIONS

Applications of AI in R&D activities can be identified by considering the most frequently repeated classification codes

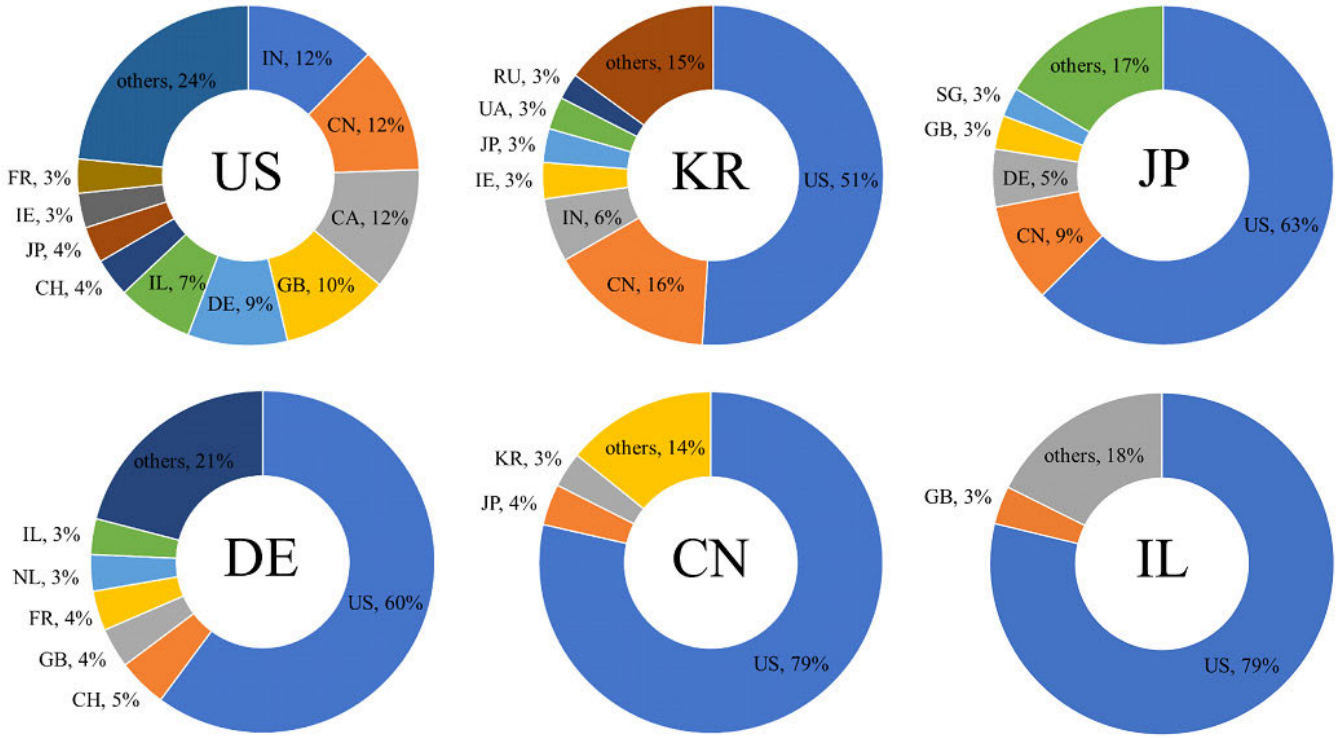

FIGURE 8. Cross-border collaborations of six countries including United States, Korea, Japan, Germany, China, and Israel in AI-related patents granted by the USPTO between 2008 and 2018 (US: United States, IN: India, CN: China, CA: Canada, GB: Great Britain, DE: Germany, IL: Israel, CH: Switzerland, JP: Japan, IE: Ireland, FR: France, KR: Korea, UA: Ukraine, RU: Russia, SG: Singapore).

TABLE 3. Most frequently used IPC codes in AI-related Patents Granted by USPTO Between January 2008 and December 2018.

IPC code	*No. of patents*	*Percent*	*IPC code*	*No. of patents*	*Percent*
1. G06F 17/30	14631	11.8	26. G06F 17/50	1626	1.3
2. G06K 9/00	13712	11.1	27. G05D 1/00	1572	1.3
3. H04L 29/06	5429	4.4	28. G06F 3/0484	1566	1.3
4. G06F 17/00	4979	4.0	29. G06F 15/173	1542	1.2
5. G06K 9/62	4868	3.9	30. G06F 11/00	1540	1.2
6. H04L 29/08	4394	3.6	31. G06F 3/0488	1528	1.2
7. G06F 19/00	4121	3.3	32. H04W 4/00	1510	1.2
8. G06F 7/00	4024	3.3	33. G06Q 40/00	1508	1.2
9. G06T 7/00	3848	3.1	34. G06Q 50/00	1502	1.2
10. A61B 5/00	3575	2.9	35. G06F 3/00	1496	1.2
11. G06F 15/16	3512	2.8	36. H04L 12/24	1473	1.2
12. G06K 9/46	3305	2.7	37. G06Q 10/10	1467	1.2
13. G06Q 30/02	2949	2.4	38. H04L 12/26	1461	1.2
14. G06F 17/27	2693	2.2	39. H04L 12/58	1434	1.2
15. G06N 5/02	2615	2.1	40. G06N 5/04	1433	1.2
16. G06F 15/18	2402	1.9	41. G06Q 10/06	1341	1.1
17. G06N 99/00	2392	1.9	42. G06N 5/00	1323	1.1
18. G06F 3/01	2233	1.8	43. G06F 3/048	1323	1.1
19. G06F 9/44	2098	1.7	44. G09G 5/00	1307	1.1
20. G06Q 30/00	2067	1.7	45. G06Q 30/06	1292	1.0
21. H04N 7/18	1736	1.4	46. G06F 3/0481	1261	1.0
22. H04N 5/232	1723	1.4	47. H04N 5/225	1242	1.0
23. H04W 4/02	1720	1.4	48. G06K 9/32	1201	1.0
24. G06Q 10/00	1709	1.4	49. G10L 15/00	1180	1.0
25. C12Q 1/68	1687	1.4	50. G06F 17/28	1154	0.9

in AI-related patents. It was seen that AI-related patents were spread under many different IPC codes (Table 3), however, 11.8% and 11.1% of AI-related patents were classified under G06F 17/30 and G06K 9/00, respectively. G06F 17/30 is related to digital computing or data processing, and G06K 9/00 is about recognizing printed characters.

TABLE 4. Descriptions 10 most frequently used IPC codes in AI-related patents granted by the USPTO Between January 2008 and December 2018.

IPC code	*Description*
G06F 17/30	Physics > computing; calculating; counting > electric digital data processing > digital computing or data processing equipment or methods, specially adapted for specific functions > information retrieval; database structures therefor
G06K 9/00	Physics > computing; calculating; counting > recognition of data; presentation of data; record carriers; handling record carriers > methods or arrangements for reading or recognizing printed or written characters or for recognizing patterns, e.g. Fingerprints
H04L 29/06	Electricity > electric communication technique > transmission of digital information, e.g. Telegraphic communication > arrangements, apparatus, circuits or systems, not covered by a single one of groups > characterized by a protocol
G06F 17/00	Physics > computing; calculating; counting > electric digital data processing > digital computing or data processing equipment or methods, specially adapted for specific functions
G06K 9/62	Physics > computing; calculating; counting > recognition of data; presentation of data; record carriers; handling record carriers > methods or arrangements for reading or recognizing printed or written characters or for recognizing patterns, e.g. Fingerprints > methods or arrangements for recognition using electronic means
H04L 29/08	Electricity > electric communication technique > transmission of digital information, e.g. Telegraphic communication > arrangements, apparatus, circuits or systems, not covered by a single one of groups > transmission control procedure, e.g. Data link level control procedure
G06F 19/00	Physics > computing; calculating; counting > electric digital data processing > digital computing or data processing equipment or methods, specially adapted for specific applications
G06F 7/00	Physics > computing; calculating; counting > electric digital data processing > methods or arrangements for processing data by operating upon the order or content of the data handled
G06T 7/00	Physics > computing; calculating; counting > image data processing or generation, in general > image analysis
A61B 5/00	Human necessities > medical or veterinary science; hygiene > diagnosis; surgery; identification > Measuring for diagnostic purposes; identification of persons

TABLE 5. Most frequently used IPC section and class codes.

IPC code	No. of patents	Percent	Description
1. G06F	49236	39.9	Physics > computing; calculating; counting > electric digital data processing
2. G06K	20097	16.3	Physics > computing; calculating; counting > recognition of data; presentation of data; record carriers; handling record carriers
3. H04L	13122	10.6	Electricity > electric communication technique > transmission of digital information, e.g. Telegraphic communication
4. G06Q	11670	9.4	Physics > computing; calculating; counting >data processing systems or methods, specially adapted for administrative, commercial, financial, managerial, supervisory or forecasting purposes;
5. H04N	10767	8.7	Electricity > electric communication technique > pictorial communication, e.g. Television
6. G06T	9475	7.7	Physics > computing; calculating; counting > image data processing or generation, in general
7. G06N	8918	7.2	Physics > computing; calculating; counting > computer systems based on specific computational models
8. A61B	6985	5.7	Human necessities > medical or veterinary science; hygiene > diagnosis; surgery; identification
9. H04W	6457	5.2	Electricity > electric communication technique > wireless communication networks
10. G01N	5273	4.3	Physics > measuring; testing > investigating or analyzing materials by determining their chemical or physical properties
11. G10L	4917	4.0	Physics > musical instruments; acoustics > speech analysis or synthesis; speech recognition; speech or voice processing; speech or audio coding or decoding
12. H04M	4380	3.5	Electricity > electric communication technique > telephonic communication

Descriptions of 10 most frequently used codes are shown in Table 4.

In an IPC code, the first letter shows the section of a patent. Each section is divided into classes, which is shown by a two-digit number. Each class comprises one or more subclasses, and a letter shows the patent subclass. Then, each subclass is broken down into groups, including main groups and subgroups (Figure 11) [21]. Application of a patented invention can be determined by considering just the section and class (and subclass) of the patent, which are the first four characters of the classification codes. Table 5 shows the most frequently occurring sections and classes of AI-related patents, which present the most considered applications of AI. The most frequent application of AI was in data processing, in a way that 39.9% of AI-related patents were classified under G06F (electric digital data processing).

It is followed by G06K (recognition of data; presentation of data; record carriers; handling record carriers) and H04L (transmission of digital information, e.g. Telegraphic communication) with 16.3% and 10.6%, respectively.

The highly considered sections and classes can be compared between different countries, as shown in Figure 12. The selected countries used AI in data processing (G06F) more than other areas except Japan, which mostly took advantage of AI in recognition and presentation of data (G06K). The United States was the leading country in using AI in data processing in a way that about 43% and 12% of AI-related patents with U.S. assignees dealt with data processing (G06F) and data processing for special purposes (G06Q), respectively; these percentages are higher than the percentages for the other countries. However, in the other application fields of AI, the other countries paid more

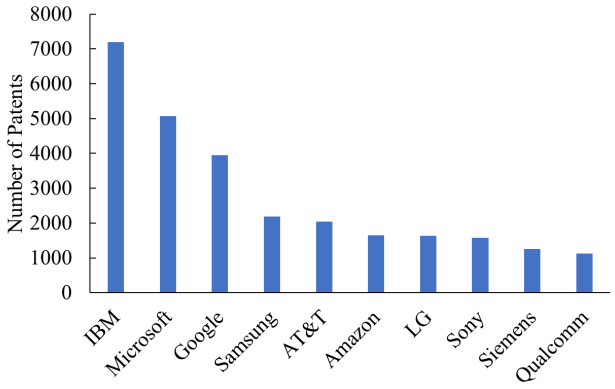

FIGURE 9. Assignees with the highest number of AI-related patents granted by the USPTO between January 2008 and December 2018.

attention than the United States. For example, 14% and 18% of AI-related patents by Korean assignees were under two areas of electric communication technique including wireless communication networks (H04W) and telephonic communication (H04M), respectively, while the other countries have no considerable activities under these groups. Another interesting observation is that Israel had more focus on using AI in the area of ''medical or veterinary science; hygiene'' in comparison with the other countries, and about 13% of AI-related patents by assignees from Israel were associated with A61B.

There were changes in application areas of AI during the period. Figure 13 shows the most frequently used IPC sections and classes in the classification of the AI-related patents in 2008, 2011, 2014, and 2017. Data processing (G06F) was the main application of AI over the period, of which 43% of AI-related patents were under the code in 2017. Transmission of digital information (H04L) is one of the areas that experienced an increase in the use of AI for R&D activities, and it became the second-most application of AI in 2017. In 2017, about 17% of AI-related patents were classified under H04L code whereas in 2008 just 3% of AI-related patents were under this code. On the other hand, investigating or analyzing materials (G01N) was one of the main applications of AI in 2008 but in 2017, this field was no long included in the 10 main applications of AI. Image data processing or

2008	
Microsoft	323
IBM	260
Silverbrook	87
Siemens	77
Hewlett-Packard	58
Sony	55
AT&T	47
Intel	46
Mitsubishi Electric	40
Samsung	37

2009	
Microsoft	406
IBM	281
Siemens	82
Silverbrook	74
Sony	74
Hewlett-Packard	73
AT&T	54
Metrologic Instruments	52
Samsung	46
Tokyo Electron	43

2010	
Microsoft	524
IBM	388
Siemens	134
Sony	123
Silverbrook	105
Hewlett-Packard	91
AT&T	77
Yahoo!	67
General Electric	58
Samsung	58

2011	
Microsoft	423
IBM	408
Silverbrook	141
Siemens	120
AT&T	110
Sony	107
Google	101
Yahoo!	85
Hewlett-Packard	74
General Electric	69

2012	
Microsoft	461
IBM	450
Google	188
Sony	169
AT&T	149
Siemens	136
Canon	112
Samsung	98
Hewlett-Packard	97
Xerox	82

2013	
IBM	540
Microsoft	442
Google	407
Sony	199
AT&T	182
LG	171
Siemens	126
Canon	114
Hewlett-Packard	100
Qualcomm	97

2014	
IBM	570
Google	564
Microsoft	447
AT&T	259
LG	224
Sony	199
Canon	135
Qualcomm	131
Hewlett-Packard	130
Samsung	123

2015	
Google	708
IBM	657
Microsoft	425
LG	224
AT&T	219
Qualcomm	189
Amazon	179
Canon	170
Sony	164
Samsung	124

2016	
IBM	927
Google	661
Microsoft	486
Amazon	334
LG	267
AT&T	250
Qualcomm	200
Samsung	194
Sony	156
Intel	136

2017	
IBM	1230
Google	676
Microsoft	537
Samsung	496
Amazon	424
LG	320
AT&T	297
Intel	210
Qualcomm	202
Facebook	201

2018	
IBM	1481
Samsung	853
Microsoft	601
Google	559
Amazon	449
AT&T	398
LG	330
Intel	254
Facebook	202
Qualcomm	167

FIGURE 10. Assignees with the highest number of AI-related patents per year (patents granted by USPTO).

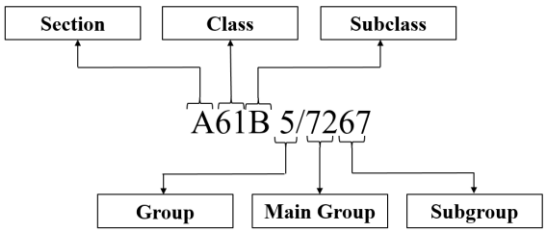

FIGURE 11. IPC code taxonomy.

generation (G06T) and wireless communication networks (H04W) were two new AI applications which covered 12% and 8% of AI-related patents in 2017, respectively.

E. AI TECHNIQUES

Most of the keywords used to identify AI-related patents are associated with AI techniques. It is possible to find out the most considered AI techniques in the patents by looking at the number of repetitions of each keyword. Since descriptions of a patent are usually written by its inventors, it would be informative to consider the keywords per inventors' country of residence. The ''neural network'' keyword was highly used by the inventors from the selected countries (Table 6). ''neural network'' was mentioned in 23.7% and 23.1% of the patents by the inventors from the United States and Israel, respectively. ''Machin learn'' was also frequently used by Israeli (25.1%), U.S. (21.4%), and Chinese (17.8%) inventors whereas Korean inventors did not use this keyword considerably (just 4.6%). ''pattern recogni'' is another keyword that was frequently used by inventors. Specifically, 38.9% of patents with an inventor from Korea contain this keyword.

Moreover, the number of repetitions of each keyword can be obtained for different years to show changes in the popularity of keywords (techniques) with respect to time. Figure 14 shows the 10 most frequent keywords in the AI-related patents per patent application year for 2008, 2011, 2014, and 2017. There was a considerable increase in repetition of ''machine learn'' in descriptions of AI-related patents.

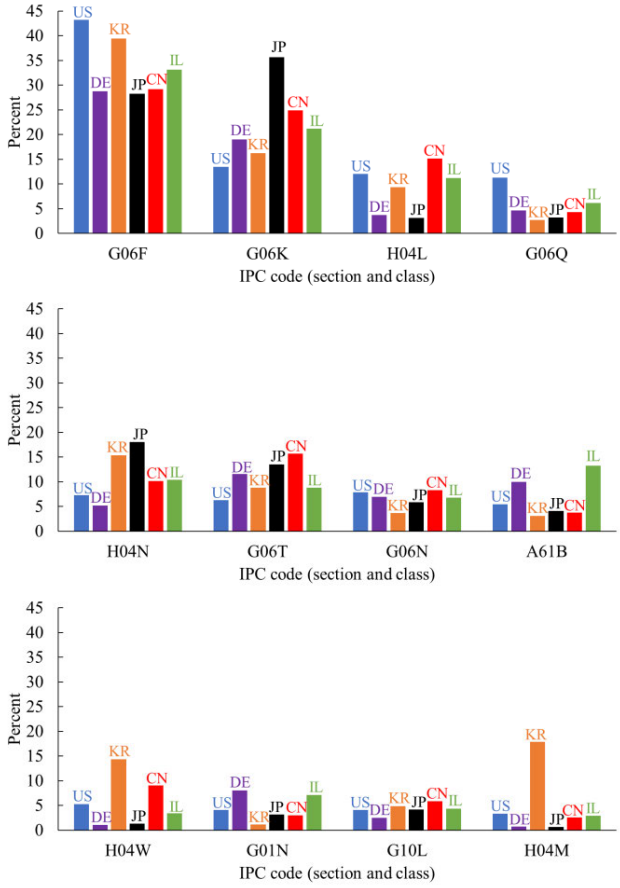

FIGURE 12. Most frequently used IPC sections and classes codes per assignee country (for AI-related patents granted by the USPTO between January 2008 and December 2018).

In 2017, 35% of AI-related patents contained ''machine learn'' and it was the most frequently used keyword between all the AI-related keywords which can be interpreted as a high application of machine learning techniques. ''genetic algorithm'' ''fuzzy logic'', and ''data mining'' were among the 10 most frequently used keywords in 2007 that disappeared

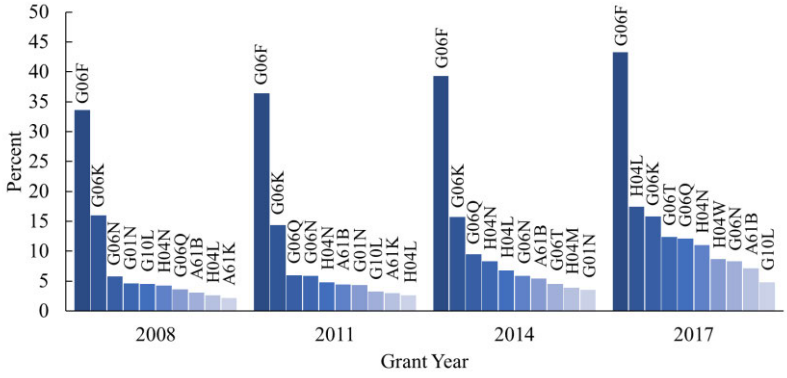

FIGURE 13. Most frequently used IPC classes and sections in the AI-related patents (granted by the USPTO between January 2008 and December 2018).

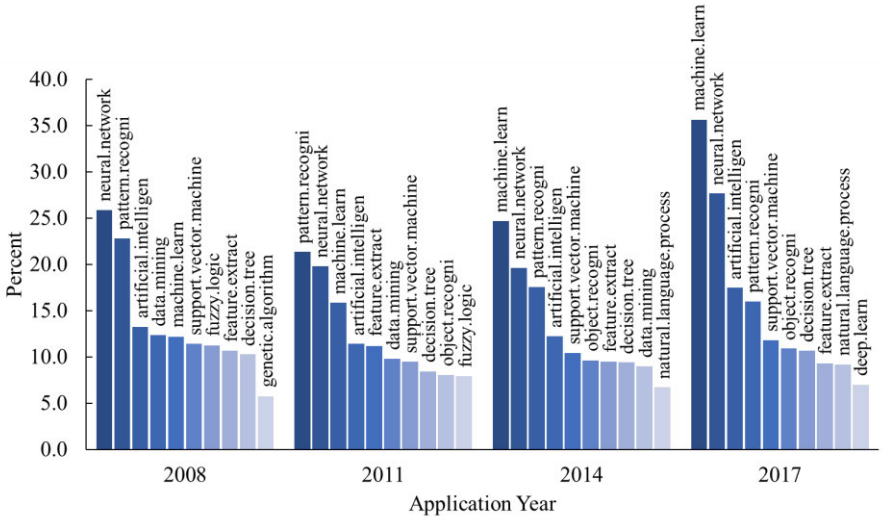

FIGURE 14. Most frequently used keywords in the AI-related patents (granted by the USPTO between January 2008 and December 2019).

TABLE 6. Most frequently used keywords in the AI-related patents with at least one inventor from the selected countries (patents granted by the USPTO between January 2008 and December 2018).

U.S.		Korea		Japan	
keyword	**%**	**keyword**	**%**	**keyword**	**%**
neural.network	23.7	pattern.recogni	38.9	pattern.recogni	21.6
machine.learn	21.4	artificial.intelligen	19.8	feature.extract	18.0
pattern.recogni	18.6	feature.extract	9.3	neural.network	17.5
artificial.intelligen	14.2	neural.network	9.0	object.recogni	14.4
data.mining	11.6	object.recogni	7.7	machine.learn	11.6
decision.tree	11.2	support.vector.machine	6.7	support.vector.machine	10.1
support.vector.machine	10.7	machine.learn	4.6	genetic.algorithm	5.5
fuzzy.logic	9.4	sparse.code	3.5	k-means	5.5
feature.extract	9.3	adaboost	3.3	adaboost	5.1
object.recogni	7.4	natural.language.process	2.9	artificial.intelligen	4.6
Germany		**China**		**Israel**	
keyword	**%**	**keyword**	**%**	**keyword**	**%**
pattern.recogni	25.3	feature.extract	20.2	machine.learn	25.1
neural.network	19.2	machine.learn	17.8	neural.network	23.1
machine.learn	12.9	neural.network	17.0	pattern.recogni	22.0
object.recogni	9.5	support.vector.machine	15.5	support.vector.machine	11.8
data.mining	9.4	pattern.recogni	13.5	feature.extract	11.3
feature.extract	8.6	artificial.intelligen	11.0	decision.tree	10.2
fuzzy.logic	7.0	data.mining	9.0	data.mining	10.2
artificial.intelligen	6.2	decision.tree	7.3	artificial.intelligen	9.4
support.vector.machine	6.1	k-means	6.8	object.recogni	7.9
decision.tree	6.0	object.recogni	6.3	genetic.algorithm	6.3

during the period. ''natural language process'' and ''deep learn'' emerged among the top 10 keywords in 2014 and 2017, respectively, which shows that a high number of researchers started to use these techniques in the patents.

IV. DISCUSSION, IMPLICATIONS, AND CONCLUSIONS

In this study, a dataset containing more than 123,500 artificial intelligence (AI)-related patents, granted between January 2008 and December 2018, was extracted from the U.S. Patent and Trademark Office (USPTO) database using both patent classification systems and a keyword-based search. The number of AI-related patents per year increased from about 4,500 in 2008 to more than 20,500 in 2018. At the same time, the ratio of AI-related patents to the total patents increased from 2.5% to 6.1%. These increases show growth in attention paid to the AI during the 2008-2018 period.

The countries and assignees that play crucial roles in AI-related research and development (R&D) were identified

by making use of the patent information. U.S. assignees had the highest share of AI-related patents (70.6%), followed by Japan (7.9%) and Korea (3.8%). The same three countries were also the highest occurring countries of residence for inventors. The high numbers of assignees and inventors from the U.S., Japan, and Korea show high activity of these countries in AI-related R&D.

Assignees from the United States, Korea, Japan, Germany, Israel, and China had the highest number of AI-related patents in 2018 and were considered for further investigations. All the selected assignee countries experienced an increasing trend in number of AI-related patents and ratio of AI-related patents to all patents during the period of 2008-2018. However, the results show that the United States, Korea, and Israel have been paying more attention to AI-related R&D activities than the other countries because, aside from the increase in number of AI-related patents, they had 4.4% to 6.8% increase in the proportion of AI-related patents between all patents. For the other countries, this proportion was less than 2.2%.

The higher R&D activities of the United States and Korea in the domain of AI can also be confirmed by looking at the top 10 assignees with the highest number of AI-related patents in 2018. This number included 8 assignees from the United States (IBM, Microsoft, Google, Amazon, AT&T, Intel, Facebook, and Qualcomm) and 2 assignees from Korea (Samsung and LG). The absence of assignees from other countries in the top 10 suggests that if there is no change in policies and investments for the other countries, the United States and Korea will be the world leaders in AI in the future.

Between 2008 and 2018, the main applications of AI were data processing, recognition and presentation of data and record carriers, and electric communications however; applications of AI experienced some changes during this time. For example, transmission of digital information and image data processing were two highly considered applications of AI that attracted more attention after 2014. In contrast, applications of AI in investigating or analyzing materials were not among the top 10 applications after 2014. For the selected countries, the main application of AI was data processing whereas Japan took advantage of AI in recognition and presentation of data and record carriers more than other fields. About 43% of the AI-related patents by U.S. assignee countries were associated with data processing. Korea actively worked on some of the electric communication applications of AI including wireless communication networks and telephonic communication, whereas it seems other countries almost ignored these applications except China, which used AI in wireless communication networks. In addition, China concentrated more on using AI in transmission of digital information than the other countries. The two countries that were relatively active in exploiting AI for medical purposes were Israel and Germany.

Moreover, checking the keyword repetition in the identified patents text showed that there was a high concentration of machine learning and neural networks by experts during the last decade. ''Fuzzy logic,'' ''data mining,'' and ''genetic algorithm'' were among the top 10 frequently repeated keywords in AI-related patents in 2008, which can be interpreted as high usage of these techniques in that time. However, they were not among the top 10 frequently repeated keywords in 2018. On the other hand, ''natural language process'' and ''deep learn'' were highly repeated in patents after 2014 which shows these areas attracted more researchers.

The results obtained in this study can be used by countries and organizations to learn how their competitors are developing intellectual property in the AI domain. R&D experts can use these results to identify the considered AI applications and techniques in R&D activities around the world during 2008-2018. This knowledge is a valuable tool for governments, academia, and companies to bridge the gap in the race for AI superiority.

There are limitations with this study. In this paper the patent data were from the USPTO database which is the largest repository of patents [19]. However, expanding the analysis to include patent data from other patent offices around the world, like Europe Patent Office (EPO), China National Intellectual Property Administration (CNIPA), Japan Patent Office (JPO), and WIPO, can improve the reliability of the results and is a consideration for future study. However, the different patent formats, languages, and classification systems used by patent offices of different countries are a challenge to identifying AI-related patents. For example, in the other databases not all the patents are in English which can be a challenge for identifying AI-related patents by using keywords.

In addition, the technology innovations do not always occur in the form of patents. As an example, sometimes companies prefer not to protect an invention by a patent since it requires sharing a complete description of the invention with the public. This fact makes it difficult to observe technology trends and developments by patent analysis and is a limitation in any study based on patents data.

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