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RESEARCH ARTICLE

Knowledge graph analysis and visualization of AI technology applied in COVID-19

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Abstract
With the global outbreak of coronavirus disease (COVID-19) all over the world, artificial intelligence (AI) technology is widely used in COVID-19 and has become a hot topic. In recent 2 years, the application of AI technology in COVID-19 has developed rapidly, and more than 100 relevant papers are published every month. In this paper, we combined with the bibliometric and visual knowledge map analysis, used the WOS database as the sample data source, and applied VOSviewer and CiteSpace analysis tools to carry out multi-dimensional statistical analysis and visual analysis about 1903 pieces of literature of recent 2 years (by the end of July this year). The data is analyzed by several terms with the main annual article and citation count, major publication sources, institutions and countries, their contribution and collaboration, etc. Since last year, the research on the COVID-19 has sharply increased; especially the corresponding research fields combined with the AI technology are expanding, such as medicine, management, economics, and informatics. The China and USA are the most prolific countries in AI applied in COVID-19, which have made a significant contribution to AI applied in COVID-19, as the high-level international collaboration of countries and institutions is increasing and more impactful. Moreover, we widely studied the issues: detection, surveillance, risk prediction, therapeutic research, virus modeling, and analysis of COVID-19. Finally, we put forward perspective challenges and limits to the application of AI in the COVID-19 for researchers and practitioners to facilitate future research on AI applied in COVID-19.

Keywords COVID-19 · Coronavirus disease · Knowledge graph · AI · Data visualization · Visual analysis

Introduction

Coronavirus disease 2019 (COVID-19) is an epidemic virus, which is sweeping all over the world; the World Health Organization (WHO) declared that COVID-19 is a Public Health Emergency of International Concern (PHEIC) (Soghaier et al. 2015) and confirmed it as an epidemic on 11 March 2020. There have been 198,778,175 confirmed cases of COVID-19 by 3 August 2021 reported to the WHO (WHO 2021). It can be seen that the COVID-19 is very harmful and highly contagious and leads to the number of people infected with the COVID-19 to increase exponentially, which has brought great challenges to the government management and the medical system. Artificial intelligence (AI) is the ability of a machine or computer system which can imitate human intelligence processes, learn from experiences, and perform human-like activities. The machine or the computer with AI can think and learn. It is also a field of study that tries to make computers "smart." As a subset of AI, machine learning (ML) tries to emphasize learning rather than computer programs, and deep learning (DL) is a technology to realize machine learning. Deep learning enables machine learning to realize many applications and expands the field of artificial intelligence. AI is widely used in various fields because of its high efficiency, accuracy, and labor cost savings. Therefore, AI applied in COVID-19, such as outgoing personnel management, tracking, resource scheduling, virus detection, diagnosis, and early warning, highlights its importance. There have been many scholars and experts who are devoted to the

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related research. Last year, the application of computer vision technology against the COVID-19 pandemic was summarized (Ulhaq et al. 2020) and discussed from computed tomography (CT) image, X-ray imagery, and prevention and control aspects. During the study of diagnosis, prevention, and prediction of COVID-19 by computer-aided AI, a lot of training and testing data are needed. Therefore, the open-source code and data are reviewed (Refat 2020; Shuja et al. 2020). In Alafif et al. (2020), ML and DL methods are summarized, including available data sets, tools, and performance analysis. In addition to the detection and diagnosis of COVID-19, AI plays crucial roles in the internet of things for patient tracking, management, treatment, risk analysis, and so on (Ramoliya et al. 2020). Medical image is important in medical field analysis; the literature (Shi et al. n.d) summarizes the applications of COVID-19 medical images, which include acquisition, segmentation, diagnosis, and follow-up process. A framework iResponse is proposed to autonomously coordinate the pandemic COVID-19, including resource planners, data analytics and decision-making, and data storage and management (Alam et al. 2021). In order to against the COVID-19, CXR image, clinical attributes, and clinical outcomes are used with AI technology to distinguish severe cases and mild cases (Soda et al. 2020).

To sum up, AI technology has been widely applied to the fields of clinical medicine, public health and preventive medicine, basic medicine, computer science and technology, biology, bioengineering, applied economics, and so on. All of these fields involve the COVID-19. Especially with the emergence of COVID-19 mutant Delta, there a more research literature. In the research, we employ VOSviewer and CiteSpace analysis tools to multi-dimensional statistical analysis for 1893 literature in the WOS database of AI in COVID-19.

The main contributions of the paper are the following:

- Identify the tendencies of article and citation counts on AI applied in the COVID-19, which provided a valuable reference for COVID-19 research.
- Collect some important cited journals that constitute the knowledge field of AI applied in COVID-19 research, which would be expected to facilitate scholars to find suitable journals for publishing AI applied in COVID-19 related papers quickly.
- Describe the overall publication trends and subject categories of literature of AI applied in COVID-19, which would help researchers explore the development trends and status of related research.
- Identify the countries and institutions which have actively participated in AI applied in COVID-19 research. That would enable researchers to know international collaboration and potential collaborators on the research for AI applied in COVID-19.
- Discuss the challenge and limit for the related research fields of AI applied in COVID-19, which would help the researcher choose the research domains and future directions.

The remainder of the paper is organized as follows: the "Data and methods" section provided data sources and analysis methods. In the "Statistical analysis" section, statistical analysis was made from annual distribution, publication sources, subjects, countries, institutions, etc. The related research of AI applied in COVID-19 was discussed in the "Discussion" section. The "Conclusion" section gave the conclusion and put forward the challenges and limits of AI applied in COVID-19.

Data and methods

Data

Web of Science (WoS) database is the most authoritative scientific literature index tool of the world and one of the more authoritative scientific databases of the world. In the study, the WoS was utilized to search and collect data. Limited query keywords are "COVID-19" and "AI," "deep learning," "machine learning," or "neural network," with unlimited research directions and languages. The index database is the Web of Science Core Collection, including Science Citation Index, Social Sciences Citation Index, and Sciences Citation Index Expanded. The research literature published from 1 January 2020 to 31 July 2021 was considered. A total of 1983 documents meeting the requirements were retrieved. Then, we discarded the duplicated documents by examining Letter (13), Correction (9), Editorial Material (40), Meeting Abstract (16), and News Item (2). The articles and reviews are remained (1903) as the research sample of this paper.

In the paper, we adopted the term "COVID-19" or "AI" for the data search; there are more than 10,000 results obtained. Most of the results cannot be associated with the two keywords simultaneously, but only research on COVID-19 or artificial intelligence. So we use the term "COVID-19" or "AI" as the keywords for data query, and the consequences include most of the related topic documents that include AI applied in COVID-19, but do not include DL applied in COVID-19. Considering that there are many branches in AI, such as machine learning, it is one of the research foci in recent years. Of course, as the subsets of ML, DL and NN received with concern. Therefore, more terms such as "machine learning," "deep learning," and "neural network" are considered in the data search, as they are the most relevant terms for "AI." Built on the two sets of terms, that is, "COVID-19" and "AI" and its extended list, we conducted data searches, respectively. Based on the investigation into the results of the search and data analysis, the search terms and the results are acceptable.

Method

Bibliometry is a powerful tool for analyzing the trends in scientific research in different disciplines (Glenisson et al. 2005). It uses mathematical and statistical methods to quantitatively analyze all knowledge carriers, including publications of institutes, countries, subject categories, and journals, describing the distribution of article count and citations (Kulak et al. 2018). Knowledge atlas uses visualization technology to describe knowledge resources and their carriers, mine, analysis, construct, draw and display knowledge, and their relationship. In this paper, we take bibliometric analysis and knowledge graph as the main research methods and means. Moreover, VOSviewer and Citespace tools are utilized to analyze the application of AI in COVID-19. Firstly, we use the built-in analysis function of Wos to make statistical analysis on the time distribution, sending organization, and quantity of all search results. Then, the statistical analysis function of Citespace software is used to create the citation-sequence diagram of literature in the field of AI applied in COVID-19, which reproduces the historical development process of the research field of AI applied in COVID-19 from the perspective of the paper. At the same time, compare the statistical analysis results of WoS and Citespace, VOSviewer from the aspects of the year, organization, and highly influential author, to understand the research trend of the whole discipline. Finally, combined with VOSviewer software, the sample keywords are analyzed by co-word analysis and co-citation analysis to obtain the current research hotspot and future development trend.

Statistical analysis

Annual distribution analysis

Based on the result analysis tool provided by WoS, 1903 documents are statistically analyzed according to the time axis. The chronological distribution of AI applied in COVID-19-related articles is shown in Fig. 1. From this figure, it can observe the monthly distribution of article count and citation count. Article count is just an obvious decrease in 2020; it reaches 113 in November 2020; from January 2021, it is over 100, and it sustained growth. The articles that will be published in the next half of 2021 cannot be considered and analyzed. Citation count is higher in 2020 than in 2021, because we know it usually takes time for publications to be indexed in a database. Another reason is that 2020 is the early stage of the COVID-19 outbreak. The new experimental data and methods in the article are worthy of reference. Due to the sharp increase in the number of articles from 2020 to 2021, AI applied to COVID-19 has attracted more and more interest in academic circles. In the future, the articles count and the citation count will continually increase over time.

Top publication sources, subjects, countries, and institutions

The queried 1903 articles are contributed by 538 publication sources, among which the top 15 journals are shown in Table 1, and the least number in journals has 18 articles. The sum of articles from the top 40 publication sources is about 50% of the total. The top 5 article counts are the following: *IEEE Access* (102 articles), *Journal of Medical Internet Research* (73 articles), *Scientific Reports* (58 articles), *Cmc-Computers Materials & Continua* (49 articles), and *Plos One* (47 articles). Regarding citation count (C)

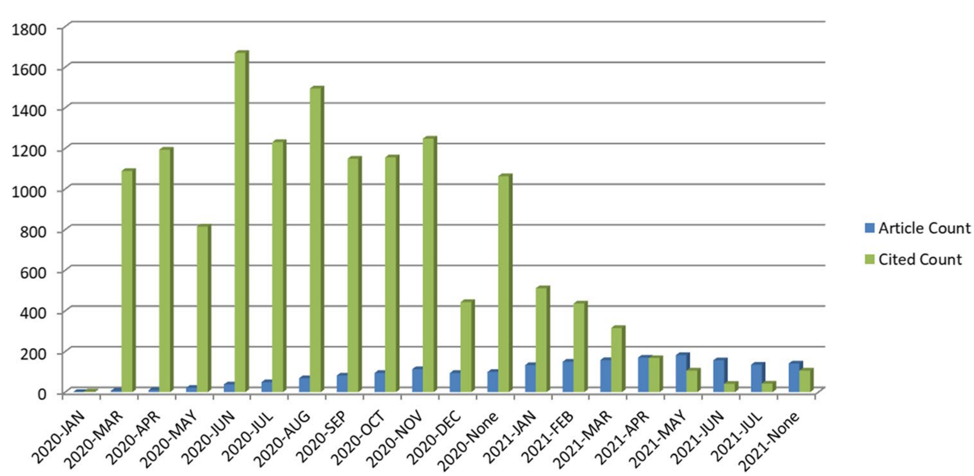

Fig. 1 Distribution and trend of articles and citations

Table 1 Top 15 publication sources

Publication source	A	C	ACP	IF
IEEE Access	102	675	6.62	3.379
Journal Of Medical Internet Research	73	287	3.93	5.428
Scientific Reports	58	272	4.69	4.379
Cmc-Computers Materials & Continua	49	173	3.53	3.772
Plos One	47	277	5.89	3.240
International Journal Of Environmental Research And Public Health	46	617	13.41	3.390
Chaos Solitons & Fractals	45	1013	22.51	5.944
Applied Intelligence	34	325	9.56	5.086
Applied Sciences-Basel	33	81	2.45	2.679
Computers In Biology And Medicine	29	623	21.48	4.589
Sensors	29	73	2.52	3.576
Applied Soft Computing	27	213	7.89	6.725
Sustainability	21	91	4.33	3.251
European Radiology	18	161	8.94	5.315
IEEE Journal Of Biomedical And Health Informatics	18	76	4.22	5.772

A article count, *C* citation count, *ACP* average citations per article, *IF* impact factor in 2020

for all the 538 publication sources, the top five are the following: *Chaos Solitons & Fractals* (1013 citations), *IEEE Access* (675), *Computers in Biology and Medicine* (623), *International Journal of Environmental Research and Public Health* (617), and *Bmj-British Medical Journal* (563, not in the top 15 publication source). Taken together, the performance of the journal of *Chaos Solitons & Fractals* is worthy of special focus, which gives a significant contribution to AI applied in COVID-19.

About average citations per article (ACP), the top five for all the 538 publication sources are the following: *Bmj-British Medical Journal* (563 ACP, 1 article, 563 citations), *Nature Medicine* (126 ACP, 2 articles, 252 citations), *Cell* (118, 3, 354), *European Journal of Clinical Microbiology & Infectious Diseases* (106, 1, 106), and *Molecular Informatics* (83, 2, 166). Obviously, the nine articles with the highest citation rate are in these five publication sources.

In VOSviewer, set the minimum number of documents of a source to 10, and then 34 sources are selected. For each of the 34 sources, the total strength of the citation links with other sources is visualized. The network visualization of these sources is shown in Fig. 2.

The 1903 articles concerning knowledge graphs are distributed in 153 WoS subjects, among which the top 21 with a

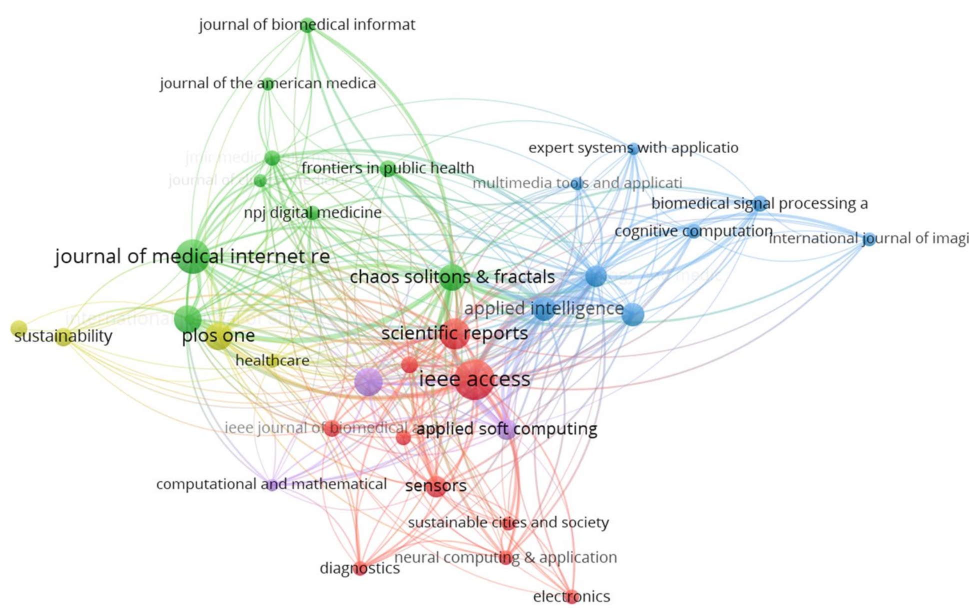

Fig. 2 The network visualization of sources

minimal article count of 90 are shown in Table 2. Computer science is the most relevant subject in the field with the articles 603, followed by Engineering (422), Computer Science, Information Systems (287), and Engineering, Electrical and Electronic (244). According to the cluster analysis, as Fig. 3 shows, in 2020, the computer science category, most articles are cited, the medicine, general & internal category, materials science category followed. Compared to 2020, fewer articles in 2021 are cited no matter which category. By considering the indicators, the performance of computer science and information system engineer is worth highlighting, indicating its great relevance and contribution to AI applied in COVID-19; experts and scholars of the medicine general and internal also pay much attention to the research of AI applied in COVID-19. With continued prevalence and variation of the COVID-19, the listed subjects had a significant increase in AI applied in COVID-19 research. As long as a good cure for COVID-19 cannot be found, and COVID-19 is still epidemical, there will be continued growth in related research in the future.

Table 2 Top 21 Wos category

WoS category	Article count
Computer Science	603
Engineering	422
Computer Science, Information Systems	287
Engineering, Electrical & Electronic	244
Computer Science, Artificial Intelligence	215
Science & Technology – Other Topics	203
Computer Science, Interdisciplinary Applications	184
Medical Informatics	181
Multidisciplinary Sciences	157
Health Care Sciences & Services	148
Telecommunications	137
Physics	118
Environmental Sciences	115
Environmental Sciences & Ecology	115
Chemistry	108
Public, Environmental & Occupational Health	97
General & Internal Medicine	96
Engineering, Biomedical	96
Materials Science	96
Materials Science, Multidisciplinary	95
Radiology, Nuclear Medicine & Medical Imaging	91

The 1903 articles concerning AI and COVID-19 are contributed by 61 countries/regions, among which the top 16 countries/regions with a minimal article count of 66 are shown in Table 3. The USA has 514 articles, followed by China (408 articles) and India (272). Regarding citation count, ranked among the top three countries are China (4202), USA (3405), and England (2059), respectively.

About ACP, the top five countries are Belgium (41.06), Netherlands (35.15), Austria (34.39), Greece (18.67), and Singapore (16.94). There are concerns that although these countries have fewer articles Belgium (16), Netherlands (26), Austria (18), Greece (24), and Singapore (34) compared to the top-ranked countries, their articles have higher quality according to the ACP values. In the top-ranked 16 countries of articles, the top five countries of ACP are Canada (13.77), Germany (13.3), England (12.18), Turkey (11.56), and China (9.85).

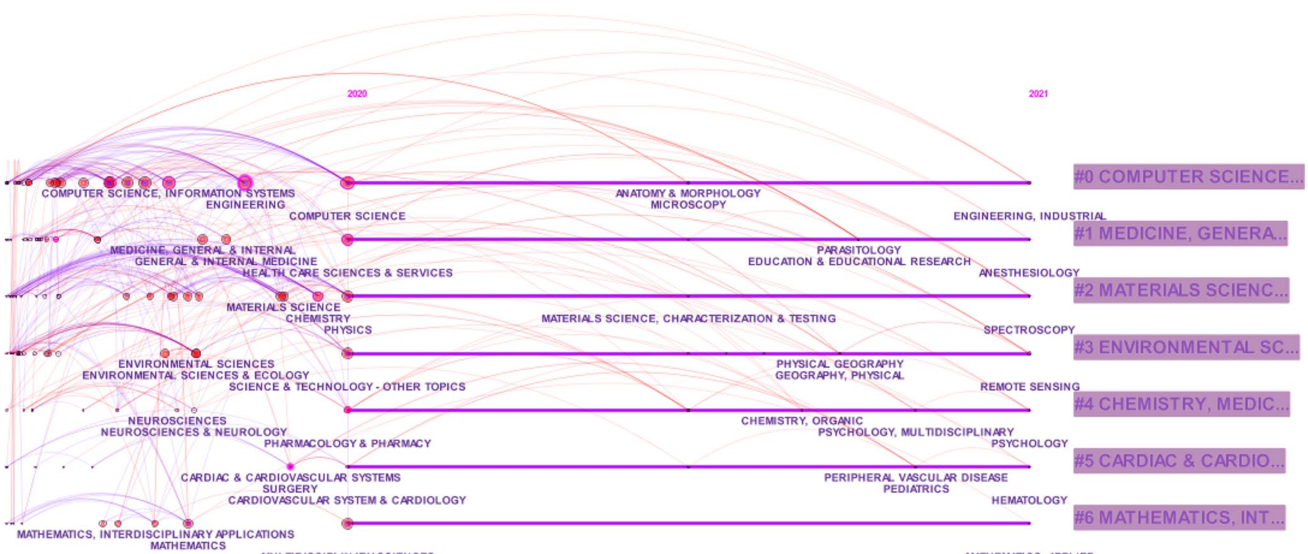

Fig. 3 Category cluster analysis

Table 3 Top 15 countries

Country	A	C	ACP
USA	514	3405	6.62
People's Republic of China	408	4020	9.85
India	272	1708	6.28
Saudi Arabia	173	727	4.20
England	172	2095	12.18
Italy	116	1011	8.72
Canada	106	1460	13.77
South Korea	103	657	6.38
Australia	92	440	4.78
Turkey	88	1017	11.56
Spain	87	481	5.53
Egypt	76	487	6.41
Pakistan	75	301	4.01
Germany	69	918	13.30
Iran	66	504	7.64

A article count, *C* citation count, *ACP* average citations per article

Table 4 Top 15 institutions

Institutions	A	C	ACP
King Saud University	44	246	5.59
Huazhong University Science & Technology	38	528	13.89
Chinese Academy of Sciences	35	661	18.89
King Abdulaziz University	32	156	4.88
Harvard Medical School	31	154	4.97
Wuhan University	30	448	14.93
Stanford University	26	100	3.85
Zhejiang University	25	337	13.48
University of Chinese Academy of Sciences	24	478	19.92
Massachusetts Gen Hospital	22	353	16.05
Cairo University	21	243	11.57
Fudan University	21	86	4.10
Shanghai Jiao Tong University	21	104	4.95
Taif University	21	83	3.95
University Toronto	21	557	26.52

A article count, *C* citation count, *ACP* average citations per article

Considering the above indicators, the number of articles of the USA, China, and India is larger; in contrast, the citation count is also large. They make a significant contribution to the research field of AI in COVID-19. Comparing the article counts for each country in the 2 years, almost all countries have shown an increase in AI applied COVID-19 research.

The 1903 articles concerning AI and COVID-19 are contributed by most institutions. The top 15 institutions among them with a minimal article count of 21 are shown in Table 4. Among the top 15 institutions, seven institutions come from China, which indicates the positive role of China in AI applied COVID-19. Among these institutions, the King Saud University is the most prolific institution with 44 articles, followed by the Huazhong University Science & Technology (38 articles) and the Chinese Academy of Sciences (35). Regarding citation count, the top three are the Chinese Academy of Sciences (661), University Toronto (557), and Huazhong University Science & Technology (528). About ACP, among the listed institutions, the top three are the University of Toronto (26.52), University of Chinese Academy of Sciences (19.92), and Chinese Academy of Sciences (18.89). Considering the mentioned indicators, the Chinese Academy of Sciences deserves more attention, whose articles, citation counts, and ACP are greater than other listed institutions and make a greater contribution to AI in COVID-19. According to comparing the article count and citation count of the institution in the 2 years, more institutions have shown a significant interest in AI in COVID-19 research.

In the statistical analysis of the authors, this paper selects total citations of articles and h-index as the evaluation index and analyzes the author cooperation network combined with CiteSpace, where the top 15 authors of article count are listed in Table 5. It can be seen that most of the authors of high-quality papers are scholars from the Republic of Cyprus, Egypt, and Saudi Arabia. The top two authors of the number of articles published are Fadi Alturjman of the Near East University and M Shamim Hossain of the King Saud University, who published more articles in the fields in 2 years. The author with the biggest total citation number (138 citation counts) is M Shamim Hossain of the King Saud University, followed by Mohamed Loey of the Benha University (125), Nour Eldeen M Khalifa of the Cairo University (125), and Fadi Alturjman of Near East University (120). Their articles have a higher number of references which means that their authors have studied this field relatively early and have a great impact. Although the articles count published by some scholars (the number of WoS records) is not high, the h-index is high, which indicates that these scholars have high authority on research fields of AI applied COVID-19. As Yudong Zhang of the the University of Leicester, Guowei Wei of the Michigan State University, Mannudeep K Kalra of the Harvard Medical School, and Ellen Kuhl of the Stanford University, all have high h-index. Nevertheless, they have relatively few articles in AI applied COVID-19. In general, in the top 15 authors, 7 authors come from the USA, which shows that the USA contributes more in the field of AI applied in COVID-19.

Table 5 Top 15 authors

Author	A	C	H	Institutions
Fadi Alturjman	10	120	28	Near East University
M Shamim Hossain	10	138	42	King Saud University
Aboul Ella Hassanien	8	94	42	Cairo University
Yudong Zhang	8	62	55	University of Leicester
Mohammad Shorfuzzaman	8	30	8	Taif University
Luca Saba	8	29	36	Università degli studi di Cagliari
Mohamed Loey	7	125	5	Benha University
Nour Eldeen M Khalifa	7	125	6	Cairo University
Rui Wang	7	77	26	Michigan State University
Mannudeep K Kalra	7	13	48	Harvard Medical School
Guowei Wei	6	77	50	Michigan State University
Fatemeh Homayounieh	6	13	8	Massachusetts General Hospital
Jiahui Chen	6	77	12	Michigan State University
Mufti Mahmud	6	13	15	Nottingham Trent University
Ellen Kuhl	5	51	52	Stanford University

A article count, *C* total citations count, *H* h-index

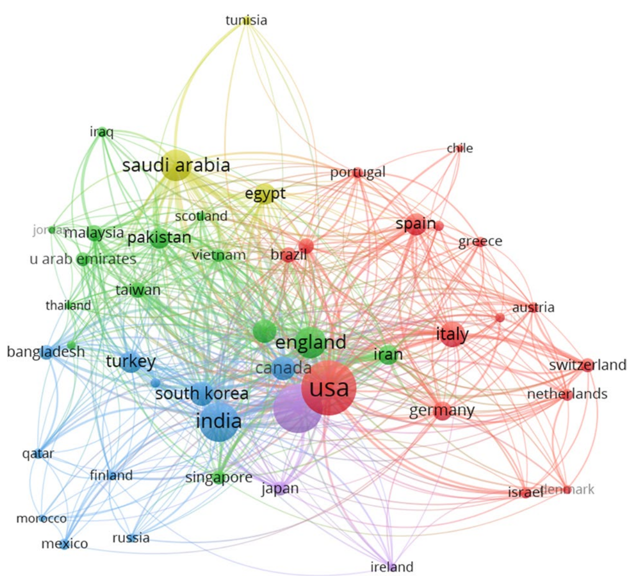

Fig. 4 Collaboration network visualization of countries

Cooperative analysis

When the maximum number of countries per article is 10, the minimum number of articles of a country is 10; there are 47 countries, and the collaborative network visualization of the 47 countries is shown in Fig. 4. Among the 47 countries, there are five clusters. Austria, Australia, Bangladesh, Egypt, and Ireland collaborated with others 15, 13, 10, 2, and 2 countries, respectively. The USA, China, and India as the three larger countries in article count, there is less cooperation between them. The USA, Italy, and Germany collaborate more; China collaborates with Japan and Ireland more; India collaborates with Canada and South Korea more. It is noteworthy that countries from the same continent cooperate more closely than countries from different continents.

When the maximum number of organizations per article is 10, the minimum number of articles of organization is 10, there are 49 institutions, and the network visualization of the 49 collaborative institutions is depicted in Fig. 5. Among these 49 institutions, the China and USA have 11 institutions, respectively; Saudi and Egypt have 3, respectively; Turkey, the UK, India, Iran, Australia, Vietnam, and South Korea have 2, respectively. The other country has 1, respectively. The Huazhong University Science & Technology, Tsinghua University, Fudan University, Shanghai Jiao Tong University, Wuhan University, University of North Carolina, and Zhejiang University are the most collaborative institutions. The Harvard Medical School, Harvard University, Imperial College London, Massachusetts Gen Hospital,

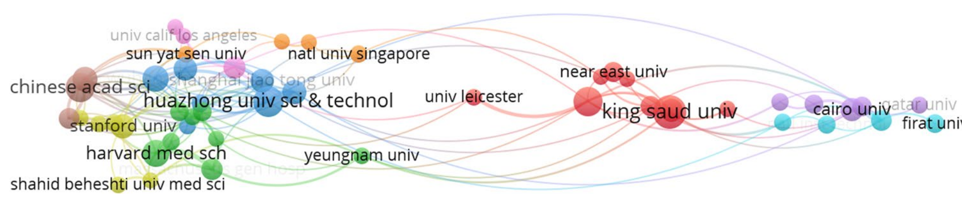

Fig. 5 Collaboration network visualization of institutions

MIT, University Hong Kong, Yeungnam University, and University of Oxford are the most collaborative institutions. Overall most of the cooperative institutions come from the same country.

There are 5,652 keywords in 1903 articles, and the top 14 keywords are shown in Table 6, with “COVID-19” (appearing in 1091 articles, occupying 57.33%) being the most frequently used, followed by “Machine learning” (462, 24.28%), “Deep learning” (421, 22.12%), “Artificial Intelligence” (240, 12.61%), and “SARS-CoV-2” (174, 9.14%). These top listed keywords include the virus (COVID-19, SARS-CoV-2, and Coronavirus), location and characteristics of lesions (Pandemic, Pneumonia, and Lung), methods (Machine Learning, Deep Learning, Artificial Intelligence, Convolutional Neural Network, and Transfer Learning), and aims (Feature Extraction, Classification). Set the minimum number of occurrences of a keyword to 20, there are 71 keywords, and the network visualization of these 71 keywords is shown in Fig. 6.

Table 6 Top 14 occurrences of keywords

Keyword	A	P
COVID-19	1091	57.33
Machine Learning	462	24.28
Deep Learning	421	22.12
Artificial Intelligence	240	12.61
SARS-CoV-2	174	9.14
Coronavirus	156	8.20
Computed Tomography	83	4.36
Convolutional Neural Network	72	3.78
Pandemic	71	3.73
Transfer Learning	69	3.63
Pneumonia	67	3.52
Feature Extraction	54	2.84
Lung	53	2.79
Classification	49	2.57

A article, *P* proportion

Discussion

This study examines the status, trends, and main issues with AI in COVID-19 research using bibliometrics, Citespace, and VoSviewer tools. The overall growth of articles and citations shows that people’s interest in this research field has increased significantly in the past year and a half. AI is having more and more impact on dealing with COVID-19. With the global epidemic and variation of COVID-19, it can be reasonable to predict that research on AI in COVID-19 will be more prosperous. Analyses of the publication source, institutions, and countries declare that articles contributed to diagnose, classify, and predict the COVID-19 by AI have been recognized and become more popular, particularly in the past year and a half. Analyses of the publication source and subject highlight the contribution of *IEEE Access* and the *Journal of Medical Internet Research* in the field, furthermore the close relevance of the framework of deep learning in detection, classification, track, and diagnosis of COVID-19. It is comprehensible for habitual thinking to solve problems with intelligent methods. In addition, analysis and representation of knowledge graphs bring great interest by the intelligence method. From the perspective of countries and institutions, China and the USA contribute about 50% to the 1903 AI in COVID-19 studies, and with

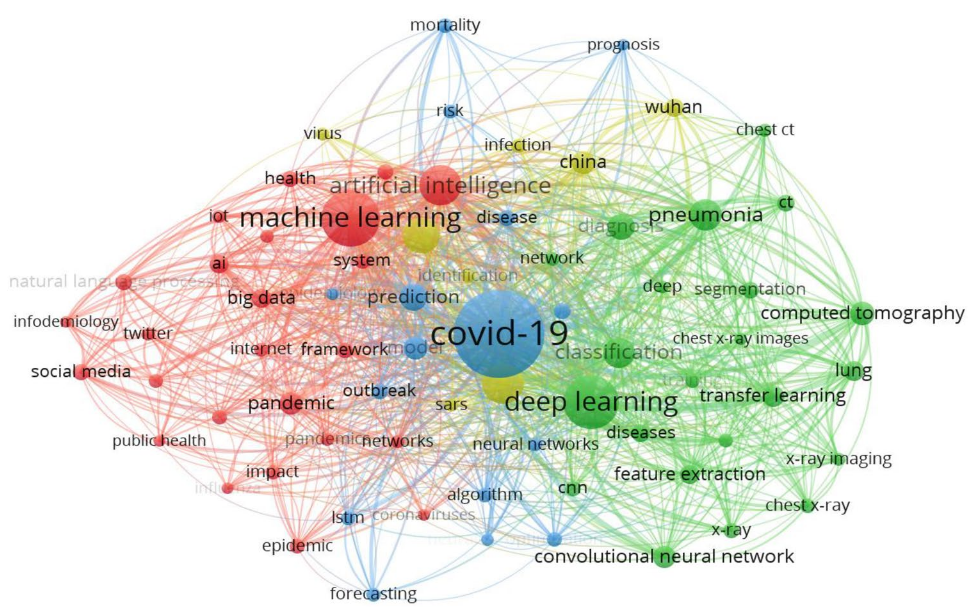

Fig. 6 Collaboration network visualization of keywords

7 out of the top 15 prolific institutions coming from China. The results of the scientific cooperation analysis also show that there is close cooperation between institutions and countries, and it is recommended to strengthen interregional and inter-agency cooperation. Results of keyword analysis show many similarities and confirm the reliability of each other. Therefore, the following discussion combines the results in various parts, focusing on the relationship between AI in COVID-19 and its impact on future research. In general, six main themes covering the main content of the results have been selected for discussions: diagnosis and screening of COVID-19, disease surveillance, risk prediction, therapeutic research, virus modeling and analysis, and implement isolation measures.

Diagnosis and screening of COVID-19

COVID-19 is a virus threatening the whole world, and it transmits rapidly. Though there have been vaccines, the virus is mutating continually. The urgent core issue is to prevent the epidemic from spreading further into uncontrollable and chaotic conditions. Therefore, it is important to screen, detect, and diagnose the virus in the early stage. From early last year, researchers had endeavored to study the methods to predict and screen the virus by temperature, medical image, and voice.

Detection of COVID-19 by the sensor

After the COVID-19 epidemic, infrared temperature scanners are often used in public places to check whether people have high fever symptoms. However, this technology requires front-line personnel to scan. To limit the contact between front-line employees and potential patients of COVID-19, some hospitals, airports, and medical centers have adopted AI-based multi-sensor technology cameras. These cameras can observe people, identify people with high body temperature and their faces, and track their movements. The AI system can even classify the symptoms of COVID-19.

An app is used to collect the smartwatch and activity tracker data that includes travel history, temperature measurements, and symptoms. The longitudinal, personal sensor data can help identify subtle changes that may indicate an infection of COVID-19 (Quer et al., 2020). A smartphone app called Biovitals Sentinel collects physiological parameters of the body by wearable biosensors, which include skin temperature, respiratory rate, pulse rate, and so on and then analyzes them (Wong et al. 2020). A solar smart security system based on solar-powered IoT is proposed to detect the temperature of people with no direct contacts and upload the data to the server (Das et al. 2021). As an example, daily temperature screening of the University of California is proved feasible and effective in the public university (Facente et al., 2021). ARTA-1 (Airlangga Robotic Triage Assistant version 1) is used to collect the data of the suspect's vital conditions and send it to the designated caregiver (Hidayat et al., 2021).

Detection of COVID-19 by medical image

Artificial intelligence technology has great potential in improving image-based medical diagnosis. The researchers found that using AI supporting tools to analyze the results of computed tomography (CT) and X-ray can provide more timely medical diagnoses for the current detection of COVID-19, which can save the evaluation and diagnosis time of radiologists.

Using chest X-ray images to detect COVID-19 patients accurately was presented in Tuncer et al. n.d Firstly, residual method example local binary pattern (ResExLBP) is used to abstract feature. Then the feature is selected by iterative relief (IRF). Finally, five classifiers are employed to identify the virus features, such as decision tree (DT), linear discriminant (LD), support vector machine (SVM), K-nearest neighbor (KNN), and subspace discriminant (SD). Xception and ResNet50V2 have been concatenated and trained by X-ray images to classify normal, pneumonia, and COVID-19 (Mr and Aa 2020). By combining the feature of the CT image with the Q-deformation entropy manual feature, LSTM (long- and short-term memory) method is used to classify the combined feature and identify the COVID-19 (Hasan et al., 2020). To avoid the task-specific data and achieve better performance of detection method, the popular deep learning frameworks are compared to abstract the most accurate feature. Then several machine learning classifiers are used to classify the COVID-19 case (Kassania et al., 2021), where CT and X-ray images are employed. The result shows DenseNet121 feature extraction with Bagging Tree classifier achieved the best performance. A hybrid machine learning method that combined ANFIS (adaptive network-based fuzzy inference system) with MLP-ICA (multi-layered perceptron-imperialist competitive algorithm) was proposed in Pinter et al. (2020), which can predict the time series and mortality of infected individuals.

Detection of COVID-19 by voice

Voice detection is one of the simplest techniques that can be used to identify potential COVID-19 patients. When there is a serious lack of detection tools, the voice detection platform can act as a screening measure to determine the personnel to be tested.

In Ponomarchuk et al. (2021), an app is developed by combining a signal processing method with a modified deep learning network to detect cough and classify. The

Department of Computer Science and Technology of the University of Cambridge proposed a voice model based on machine learning for detecting COVID-19 automatically by app software (Han et al. 2021). AI4COVID-19 app records for 2-s coughs of the subject and then analyzes the cough sample by AI running in the cloud, and the preliminary diagnostic result will be returned in 1 min (Imran et al. 2020). COVID-19 identification method based on intelligent speech analysis is being developed (Shimon et al. 2021), which can automatically classify the health status of patients by an audio and symptom model.

Disease surveillance

Collecting a large amount of COVID-19 data and establishing a database can help improve AI technology and effectively analyze the dynamic distribution and influencing factors of viruses, which can predict the harm of viruses and promote the positive development of vaccines, drugs, and preventive measures.

Gunasekeran et al. provide a systematic scoping review for artificial intelligence, telehealth, and related technologies which were used for digital health for population-level public health responses to the COVID-19 pandemic. Although a large number of reports investigate the application of AI and big data analysis, the weaknesses of research design limit generalizability and translation, highlighting the need for more real-world investigation. There is also little description about the application of the internet of things, a digital communication platform, digital solutions for data management, and digital structure screening, representing the gap and opportunity of digital public health (Gunasekeran et al., 2021). A B5G framework is proposed to detect COVID-19 with low latency, high-bandwidth, besides developing a surveillance system to monitor social distancing, body temperature, and mask-wearing (Hossain et al., 2020). An e-health platform can provide remote monitoring and assistance for patients with COVID-19 (Mouine et al., 2021), which has an AI module for sending alerts to the server after analyzing the acquired data. To continuously monitor the situation of wearing masks in public space, an application of CCTV surveillance systems with the trade-off between the level of AI performance and privacy preservation is developed, which is scalable and automatable (Kühl et al., 2020).

Risk prediction

The risk of infection usually depends on a variety of factors, including age, travel history, hygiene habits, current health status, past health status, and family history. Direct mathematical modeling of these factors will not produce rich results. However, combining a comprehensive analysis of these factors and AI technology can make a more accurate and reliable prediction of personal risk status.

In Gupta et al. n.d, by analyzing the data of Indian states and Union Territories, the proposed framework can predict the number of cured and deaths with a regression model, whose performance is decided by PR (polynomial regression), RF (forest regression), and decision tree regression. Research data (6 hospitals) of the Italian Multi-Center have been used to predict future severe cases by state-of-the-art learning approaches, including handcrafted approach, hybrid approach, and end-to-end deep learning approach (Soda et al. 2020). By training SARS data on 2003, migration data before and after January 23, and the recent COVID-19 data (at that time) to predict the epidemic (Yang et al. 2020), where the susceptible exposed-infected-removed (SEIR) is modified, LSTM (a recurrent neural network) is used to process and predict the series and count of new infections.

Therapeutic research

One of the main reasons why SARS-CoV-2 is difficult to treat is that the lack of existing research and treatment schemes of the virus. However, analyzing the current cases of COVID-19 and the existing research on related pneumonia diseases by AI can prove that AI is a useful technology to accelerate the drug development process. Some organizations and research laboratories have used AI to identify potential treatments for COVID-19. Moreover, AI technology can help evaluate the efficacy and value of existing drugs.

Drug development

Machine learning (ML) is a subset of AI, whose effectiveness in the drug development process in an emergency has been proved in the past period. During the Ebola epidemic, the Bayesian ML model was used to speed up the development of molecular inhibitors against the virus. Similarly, ML-assisted virtual screening and scoring technologies are adopted to speed up the discovery of virus inhibitors against the H7N9 virus. Given the current pandemic, ML models can help accelerate the process of developing drugs that can be used to treat COVID-19.

Reuse of existing drugs/compounds

Gero, artificial intelligence-driven drug discovery and drug reuse platform, has helped identify several existing drugs, including a drug called afatinib (for the treatment of non-small cell lung cancer) that may be used to treat COVID-19.

For predicting drug-target interaction (DTI) between viral proteins and existing drugs, various ML technologies have also been used to identify candidate drugs. Some scholars have established a deep learning deep convolution neural network (DFCNN) system, which can recognize the interaction between antigen and antibody with high accuracy. Therefore, using AI can not only identify effective treatment schemes but also help analyze their expected effects.

Virus modeling and analysis

The key to developing COVID-19 treatment is to understand the virus itself. Because viruses cannot reproduce themselves, they rely on host cells to make copies of their DNA. Therefore, viruses usually bind themselves to host receptors through the locking and key mechanisms to infect host cells. Most inhibitor-based drugs work by blocking receptors in target cells. Therefore, the design of effective inhibitors requires scientists to model the binding mechanism between viruses and host cells. Machine learning happens to be one of the most useful tools in scientists' arsenal for building such models.

In the past, ML models trained with protein data had been proved to successfully predict the protein–protein interaction (PPI) between H1N1 virus and human cells, thus eliminating the need for modeling the whole virus-host interaction. Machine learning can also be used to model various protein folding mechanisms used by viruses to maintain themselves. For example, it is very important to understand the three-dimensional structure of the protein by using a deep learning algorithm to predict protein structure from protein amino acid sequence, because the function of protein is closely related to its structure.

In the current COVID-19 health crisis, DeepMind (the AI company of Google) has used its Alphafold system to predict the structure of SARS-CoV-2-related proteins. These predictions can help scientists better understand the whole virus structure and develop a new drug to treat COVID-19. However, DeepMind indicates that these predictions have not been verified experimentally.

Implement isolation measures

Many countries and regions around the world are using AI to implement social alienation and locking measures, including China, India, the USA, and Britain. In the world, Baidu is one of the largest companies of AI and the internet, which has developed an infrared thermal imager with the computer vision (CV) function to scan public places. These cameras can not only identify people with a high body temperature but also identify residents who do not follow the locking measures by using the built-in face recognition system. A similar CV camera system has been deployed in Oxford, England, to monitor whether people follow social alienation measures.

Conclusion

This paper introduces the bibliometric analysis results and findings of articles on AI applied in COVID-19 from January 2020 to July 2021. The study highlights the main research concerns and issues among scholars; identifies the trends of the article and citation counts, major publication sources, subjects, countries, and institutions; and outlines relationships of academic collaboration. With the vigorous development of academic products, the field of AI applied in COVID-19 is more and more active and promising.

The study concerning AI applied in COVID-19 has great significance. First, it helps researchers, decision-makers, and practitioners better understand the tendency of AI applied in COVID-19 through the knowledge graph. Second, it can assist scholars, especially novices in this field, to understand the research results of productive institutions and countries, share their research results, cooperate, and identify important participants from whom to learn. Third, it helps scholars master the sources of publications in this field and provides suggestions for the published sources of works submitted by scholars. Most importantly, the results of term/keyword and topic analysis improve researchers' understanding of the research focus in this field.

It is conceivable that artificial intelligence can play an important role in mitigating the impact of the COVID-19 pandemic. However, the artificial intelligence system is still in the preparatory stage at present. Several challenges and limitations that hinder the application of AI in COVID-19 impact management are as follows:

- To produce reliable and accurate results, AI models need a lot of training data. However, due to the unprecedented nature of the pandemic and the lack of historical data for training AI models, the construction of AI models is inefficient.
- On the one hand, the lack of open data seriously hinders the performance of the AI model. On the other hand, noisy data and abnormal data also bring challenges to the effective use of AI technology. The failure of the Google Flu Trends project reveals the fact that a large amount of dirty data may drown the AI algorithm and inhibit its operation.
- Another limitation of artificial intelligence systems, especially machine learning models, is their inherent assumption that all possible accidents are the same as those shown in the trained data set under any given situation.
- The use of AI technology for crowd surveillance is regarded by many as an invasion of privacy. Although people have realized that public health issues are more

important than data privacy, the private traps for using AI still frighten the public. Even after the COVID-19 pandemic, the government may continue to monitor it.

- Another limitation of AI is its dependence on human knowledge. Human expertise plays an important role in guiding the implementation of AI technology and in the fight against the COVID-19 pandemic. Although the application of AI technology faces many challenges, its contribution to coping with the COVID-19 pandemic cannot be ignored. In recent years, AI technology has made amazing progress in NLP, ML, deep learning, data analysis, and other fields, which shows the potential of AI in assisting the COVID-19 pandemic management system. It should be noted that the future trend of science and technology will lead to the integration of multiple technologies. The application of a single technology cannot give full play to the maximum value, and blockchain and 5G technology are expected to become the most promising connectivity technologies.

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