Internet of Things 23 (2023) 100863

Contents lists available at ScienceDirect

Internet of Things

journal homepage: www.elsevier.com/locate/iot

IoT-enabled technologies for controlling COVID-19 Spread: A scientometric analysis using CiteSpace

Dheeraj Kumar [a,*], Sandeep Kumar Sood [b], Keshav Singh Rawat [c]

[a] Department of Computer Science & Informatics, Central University of Himachal Pradesh, Dharamshala, India
[b] Department of Computer Applications, National Institute of Technology Kurukshetra, Haryana, India
[c] Department of Computer Science & Information Technology, Central University of Haryana, Mahendergarh, India

ARTICLE INFO

Keywords:
ICT
COVID-19
Medical imaging
Social media
Artificial intelligence
Internet of Things

ABSTRACT

The COVID-19 outbreak has unleashed a cataclysmic impact on the daily existence of humanity, triggering a widespread upheaval in public health and wreaking havoc on the economies of affected nations. This lethal disease has emerged as a leading cause of substantial mortality and morbidity around the globe, and the emergence of new virus variants has confronted humanitarian society with formidable difficulties. In this tumultuous period, the Internet of Things (IoT) has played an indispensable role. IoT has offered various innovative solutions to curb the spread of the pandemic, providing a beacon of hope amidst the chaos. The current research delves into the literature on IoT-assisted COVID-19 research, utilizing a scientometric analysis to extensively examine the technological impact in the battle against the outbreak. It illuminates the multifaceted role of ICT in the ongoing pandemic by employing an array of empirical approaches such as publication patterns, citation structures, leading nations, literature co-citation network analysis, and knowledge mapping of scientific literature using the CiteSpace tool. Furthermore, the study uncovers the research frontiers, research hotspots, cluster analysis, and potential future directions in this knowledge domain, providing a visual narrative that inspires hope and a renewed commitment to our collective responsibility in the face of this global crisis.

1. Introduction

COVID-19 (C-19), the viral respiratory illness that originated in Wuhan, China, in December 2019, has left an indelible mark on the world [1]. It spread like wildfire across the globe, and the World Health Organization (WHO) declared it a pandemic in March 2020. This insidious disease has wrought tremendous loss in human lives, economic impact, and social upheaval. As of March 2023, over 470 million people had fallen prey to the contagion, resulting in the heartbreaking loss of more than 6 million lives. The pandemic has put an enormous strain on healthcare systems worldwide and left many nations with a severe shortage of medical supplies, hospital beds, and medical professionals. The pandemic's economic toll has been equally devastating with many businesses shutting down and people losing their jobs. Economies around the world have entered into recession and the pandemic has disrupted global supply chains.

The emergence of the C-19 pandemic has underscored the crucial role of IoT-enabled technologies in enhancing traditional healthcare systems to help control the viral spread. These technologies offer real-time data collection, remote monitoring, and early detection capabilities to enable more efficient and sustainable healthcare systems that prioritize patient outcomes and safety [2,3].

* Corresponding author.
E-mail addresses: sharmadheeraj2899@gmail.com (D. Kumar), san1198@gmail.com (S.K. Sood), keshav@cuh.ac.in (K.S. Rawat).

https://doi.org/10.1016/j.iot.2023.100863
Received 2 January 2023; Received in revised form 9 June 2023; Accepted 26 June 2023
Available online 1 July 2023

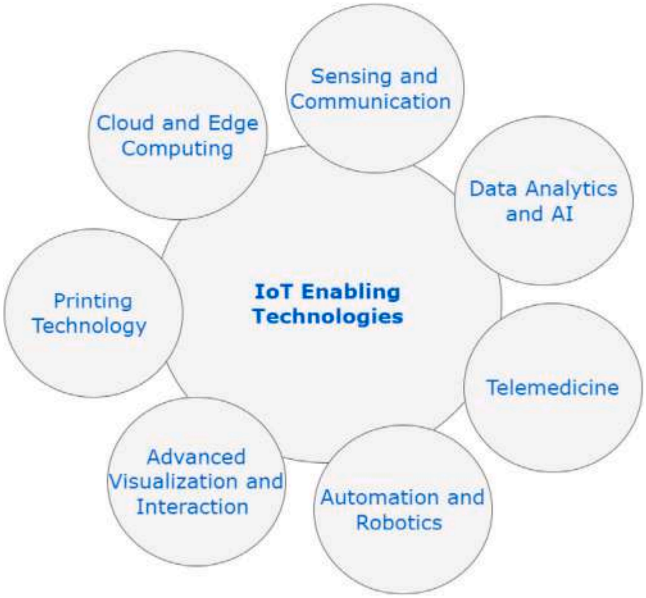

Fig. 1. IoT-enabling technologies.

IoT-enabled technologies, such as sensors, artificial intelligence (AI), communication technology, cloud and edge computing, and robotics have significant potential for controlling the spread of C-19. They have been employed to detect early symptoms of infection, facilitate remote consultations, track medical supplies, and automate tasks to minimize transmission risk.

It is imperative to underscore the pressing need for comprehensive research to assess the extant academic literature and design an IoT ecosystem that can bolster the capacity of conventional healthcare systems to combat the anticipated occurrence of future pandemics. Towards the objective, the current research undertakes a scientometric analysis of the literature on C-19 research that leverages IoT technologies, as shown in Fig. 1. Mainly, the research focuses on the role of IoT-enabling technologies during C-19 to control its prevalence and repercussions on humanitarian society.

1.1. Literature review

The current literature explores the recently published scholarly literature in the knowledge discipline. Liu et al. [4] provide a detailed review of the themes, methods, and geographic distribution of research on C-19 in social science. The study found a significant increase in research since the pandemic began, with public health, psychology, and sociology being the most common themes. Castiglione et al. [5] present an IoT-based model that leverages machine learning to identify and predict the severity of COVID-19 based on onset symptoms. The study employs IoT technology for real-time monitoring and offering a promising approach to control the spread of disease. Gunasekeran et al. [6] review smart health technologies to prevent C-19 and focusing on AI, telehealth, and related technologies. The authors identify various applications of these technologies, including predicting the infection spread, providing remote consultations, and monitoring symptoms [7,8]. Sood et al. [9] describe how AI and Industry 4.0 innovations transform healthcare by improving patient outcomes and reducing costs. The authors provide an overview of various AI approaches and their potential use cases in healthcare. It also covers the challenges and opportunities associated with the amalgamation of AI and Industry 4.0 technologies in healthcare. Javaid et al. [10] explore the IoT role in controlling the spread of C-19. The authors discuss various applications of the IoT. It includes wearable devices, smart home systems, and smart city systems. Moreover, it emphasizes the benefits of using the IoT in C-19 control. Ultimately, it encourages further research and development in this area. Sood et al. [11] examine the use of ICT in response to emerging viral infections and identify research themes and collaborations using a scientometric approach. It highlights the ICT importance in disease surveillance, outbreak prediction and management, and public health communication. Dong et al. [12] discuss the IoT applications in pandemic control and review various IoT platforms and their functionalities. It involves contact tracing, temperature monitoring, and symptom tracking. In addition, it covers the challenges and possibilities connected with the implementation of IoT platforms for C-19 prevention and control.

After a meticulous evaluation of the available literature, it is evident that the C-19 research domain has experienced a significant surge since the year 2020. Numerous studies have highlighted the potential of smart solutions in this area by harnessing digital technologies. However, a dearth of scientometric analysis has been observed regarding the extensive literature on IoT-assisted C-19 research. Thus, the proposed research endeavours to offer a complete analysis of the IoT-enabled technological research domains in C-19.

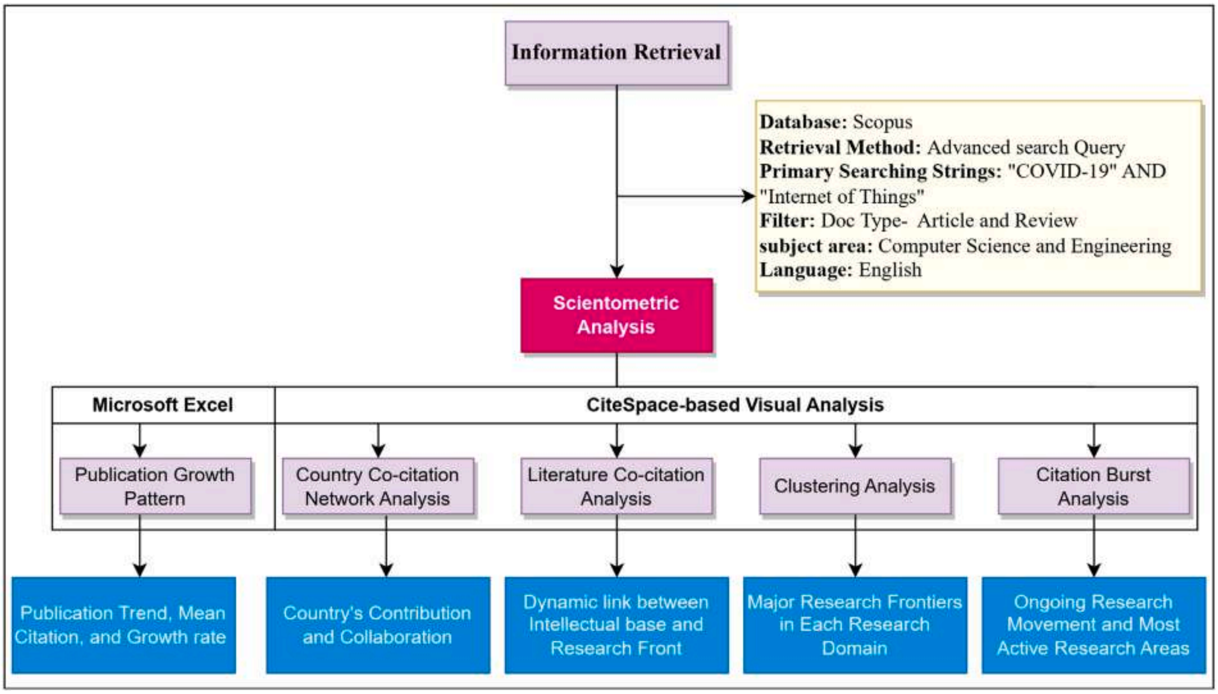

Fig. 2. Research design.

1.2. Objectives and contribution

The current research aims to offer a comprehensive and scientific exploration of the knowledge mapping of IoT-assisted C-19 research. The research employs rigorous analytical and visualization techniques to identify and understand various research domains, IoT trends, and developing paths in this field. The specific goals of this research are:

1. To identify the intellectual landscape of smart technologies in C-19 literature using co-citation analysis. It is a well-established methodology that enables the identification of important research themes and influential publications in a field.
2. To perform the strongest citation burst analysis to explore recent demanding research areas and to track the ongoing research movement. This technique is useful for identifying emerging areas of research that are gaining significant attention in the scientific community.
3. To analyze scientific publication growth, citation structure, and leading countries in the knowledge domain.
4. To identify various research dynamics such as collaborative technologies, research hotspots, and pivotal points in this research domain for the extraction of future research directions.

The document comprises four sections: Section 1 presents an introduction to the proposed problem and background information. Section 2, the methodology, describes the adopted approach and search strategy. Section 3, provides an analysis and results section, including publication pattern analysis, leading countries, domain-wise co-citation analysis, and burst references. Section 4, summarizes the results of the analysis and the conclusion of the study.

2. Methodology

The scientometric approach offers a quantitative analysis of academic literature and research outputs. It entails analyzing publication patterns, citations, collaboration, and other aspects of scholarly communication using various tools and methods. It can be used to examine the growth and evolution of a particular research discipline. It assists researchers in systematically analyzing large datasets of scientific literature in order to minimize the influence of subjective biases. It enables to identify emerging research areas and trends without being influenced by individual opinions or preferences.

CiteSpace, a software that visualizes and analyzes citation networks, is a popular instrument for scientometric analysis. This tool is particularly effective at identifying clusters of related research topics and visualizing the co-citation relationships between them [13]. The researchers noted that CiteSpace provided a nuanced view of the intellectual landscape and is better at identifying turning points and transitions in research topics [14]. CiteSpace has various customizable visualization options that allow researchers to explore their data in different ways. In the current paper, the CiteSpace tool has been used to perform literature co-citation analysis, country contribution analysis, and burst reference analysis for the exploration of scientific knowledge as shown in Fig. 2.

Table 1
Research documents in various IoT domains.

Sr. No.	Categories	Documents
1	AI & Data Analytics	1090
2	Advanced Visualization & Interaction	387
3	Automation & Robotics	610
4	Cloud and Edge computing	595
5	Printing Technology	257
6	Sensing & Communication	1022
7	Telemedicine	422

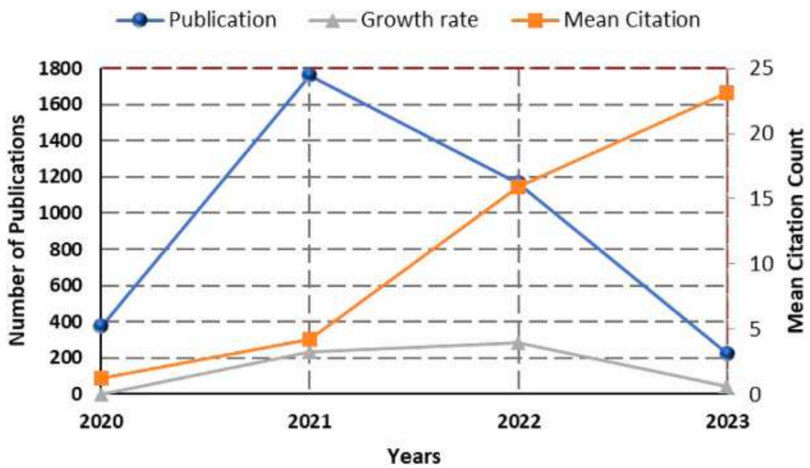

Fig. 3. Publication growth patten from 2020 to 2023.

The paper utilized the Scopus database to obtain a comprehensive dataset for analysis. Scopus is a reputable bibliographic database encompassing over 23,000 journals, conference proceedings, and book series across diverse scientific, medical, and social sciences fields. As an Elsevier-operated platform, Scopus provides extensive tools for researchers to explore, discover, and assess pertinent research articles and potential collaborators. The salient features of Scopus include its broad coverage and diverse metrics, such as author and institutional profiles, h-index, and citation counts.

In this study, the authors used the advanced query option to retrieve all relevant records from the database, utilizing “COVID-19” AND “IoT” as the primary search strings. To obtain a domain-wise dataset, the authors incorporated all related keywords of selected technological domains one by one using the “AND” operator with primary key terms. The authors employed the “AND NOT” operator to reduce dataset overlapping among the seven research domains. Moreover, the dataset was limited to subject area, document type, and language to obtain more relevant records, as demonstrated in Fig. 2. After applying inclusion/exclusion criteria and duplicates, this research has obtained an overall 3525 and domain-wise 4383 records, as presented in Table 1.

3. Results and discussion

3.1. Publications and citation structure analysis

The publication growth analysis examines the trends and patterns of publication output in a particular field or subject area over time. This analysis can provide insights into the development and progress of the research field and identify the area of emerging or declining research activity.

Table 1 shows the distribution of research publications across different technological disciplines of IoT. Upon analyzing each category separately, it is evident that AI & data analytics has the highest number of publications (1090), followed by sensing & communication technologies (1022), automation & robotics (610), and cloud and edge computing (595). On the other hand, printing technology (257) has the lowest number of publications (300), followed by advanced visualization & interaction (AVI) (387) and telemedicine (422) domains.

Fig. 3 shows an overall publication pattern in terms of publication numbers, growth rate, and mean citation count over the last four years. X-axis shows the year 2020 to 2023. The primary y-axis represents the scale of the number of publications, whereas the secondary Y-axis shows the mean citation count of the publication. The analysis observed that most publications were published in 2021. Researchers may have encountered numerous obstacles in their efforts to understand the virus and its impact on individuals and communities because the pandemic unfolded in 2020. Consequently, there were relatively few publications on the use of IoT

Table 2
Top-10 Leading Countries.

Sr. No.	Country	Centrality	n	TC	n (%)	TC (%)	MC	RCI
1	INDIA	0.13	901	8472	25.57	26.76	9.40	1.05
2	CHINA	0.1	510	5812	14.47	18.36	11.40	1.27
3	UNITED STATES	0.22	379	4719	10.75	14.90	12.45	1.39
4	SAUDI ARABIA	0.08	369	4237	10.47	13.38	11.48	1.28
5	UNITED KINGDOM	0.1	260	3740	7.38	11.81	14.38	1.60
6	PAKISTAN	0.07	183	2015	5.19	6.36	11.01	1.23
7	SOUTH KOREA	0	177	1517	5.02	4.79	8.57	0.95
8	AUSTRALIA	0.04	162	2465	4.60	7.79	15.22	1.69
9	ITALY	0.05	155	1470	4.40	4.64	9.48	1.06
10	MALAYSIA	0.1	152	1768	4.31	5.58	11.63	1.29

in C-19 research during this period. As the epidemic progressed, however, researchers began developing and using innovative IoT technologies to solve the obstacles posed by the virus.

The substantial increase in IoT-assisted C-19 research publications in 2021 reflects the increased use of IoT in C-19 research. Furthermore, with the global rollout of vaccines, researchers have used IoT technology to monitor vaccine distribution and effectiveness.

However, it also observed an increase in mean citation counts (15.95 to 23.14) despite the decrease in publication count in 2023 (227) compared to 2022 (1165). It indicates that researchers may be concentrating their efforts on more impactful studies that generate a higher number of citations. In addition, journals with a high impact and a high citation count can publish the most innovative and insightful research. As the field of C-19 research matures, there can be more opportunities to build upon existing research and produce more influential studies that lead to a rise in average citation counts.

3.2. Leading countries

The analysis seeks to identify leading countries in a particular research area to obtain valuable knowledge of the global landscape of research activities and to determine which countries contribute the most to a particular field.

Table 2 presents the top 10 nations that have demonstrated high activity in C-19 research and have made significant contributions in this field. It includes countries' numbers of published papers (n), total citation count (TC), total publication share (n%), mean citations per publication (MC), and relative citation score (RCS). The analysis shows that India has produced the highest share of publications (901, 25.57%), followed by China (510, 14.47%) and the United States (379, 10.75%) with TCs of 8472, 5812, and 4719, respectively. The high MC values for Australia (15.22), the United Kingdom (14.38), and the United States (12.45) indicate that these countries have produced high-quality research papers in this domain. The United States also gained the highest centrality value (0.22), which signifies the most collaborative and influential country in the country's collaboration network, followed by India (0.13). Similarly, the RCS value gauges the worldwide visibility and impact of a country's research status in the IoT-assisted C-19 field.

$$\text{RCS} = \frac{\text{Country's Citation Rate (TC\%)}}{\text{Country's Publication Rate (n\%)}}$$

A value of 1 for RCS indicates that a country's citation rate is on par with the global citation rate. If RCS exceeds 1, the country's citation rate is greater than the global citation rate, whereas an RCS lower than 1 denotes a citation rate below the global rate. Table 2 depicts South Korea as the only top nation with a lower RCS than the global citation rate. The remaining countries in the list have an RCS higher than the global citation rate indicating a higher citation rate.

3.3. Literature Co-citation analysis

Co-citation is the practice of citing two or more papers together in subsequent literature. It provides the intellectual landscape of science by revealing co-citation patterns over time which can shed light on the mechanisms of specialty development. Co-citation analysis is more reliable than citation-only analysis because it looks at more pertinent articles. This makes it an indispensable resource for comprehending the development of scientific disciplines [15].

Document co-citation analysis (DCA) is a method for identifying and analyzing the frequency with which two or more documents are cited together in scholarly works. It is commonly used to determine the intellectual structure of a scientific domain because it enables researchers to identify the most influential documents and topics. CiteSpace generates visual representations of the co-citation network for a given field. Additionally, the software can also cluster documents based on their co-citation patterns which allows researchers to identify important research topics and subfields within a larger discipline.

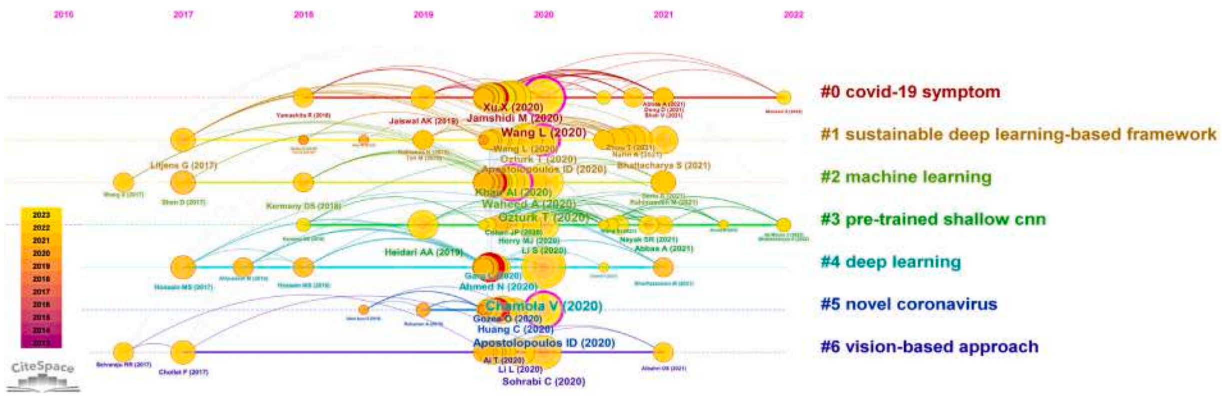

Fig. 4. DCA timeline view of AI & Data analytics.

Table 3
Cluster information of AI & Data analytics domain.

ID	Size	Silhouette	Label	Research topics
0	43	0.665	COVID-19 symptom	Deep learning, deep forest model, computerized tomography scan
1	42	0.771	Sustainable deep learning-based framework	Convolutional neural network, modern weapon, automatic architecture
2	41	0.873	Machine learning	AI model,multi-feature representation, C-19 risk stage evaluation
3	33	0.698	Pre-trained shallow cnn	Directional mutation, forest-bagging broad learning system, crow search algorithm
4	25	0.943	Deep learning	Blockchain-based solution, future pandemics, privacy perspective

3.3.1. DCA of AI & Data analytics domain

In the midst of the pandemic's turmoil and uncertainty, the power of AI & data analysis shines bright. This dynamic duo employs predictive modeling and machine learning (ML) techniques to examine massive datasets and reveal patterns and trends related to the disease. Furthermore, ML algorithms are utilized to develop more precise diagnostic tools and analyze medical images enabling healthcare professionals to make well-informed decisions. With the amalgamation of data analytics and AI, decision-making is enhanced in terms of speed and accuracy, ultimately leading to improved patient outcomes and societal welfare.

Fig. 4 illustrates the temporal DCA network of AI & data analytics, consisting of a complex network of 283 cited references and 1124 co-citation links, spanning six years from 2017 to 2022. CiteSpace employs a log-likelihood ratio (LLR) weighting algorithm to assign labels to the clusters, ensuring that each label encapsulates the essential concepts represented within the group. The reliability of the clusters is determined through the calculation of silhouette scores, which measure homogeneity and consistency. CiteSpace leverages different clustering algorithms such as k-means, hierarchical clustering, and Density-Based Spatial Clustering of Applications with Noise (DBSCAN) to compute the structural metrics of the co-citation network, including the silhouette score of each cluster [16]. The silhouette metric assists in estimating the uncertainty associated with determining the cluster's nature. It provides a numerical value spanning from −1 to 1 that reflects the level of uncertainty one must consider when interpreting the cluster. A value of 1 signifies a complete separation from other clusters which signifies a clear distinction. Additionally, clusters with a silhouette value in the range of 0.7 to 0.9 or higher are expected to facilitate cluster labeling and other aggregation tasks, making them more straightforward to interpret [13]. In the current study, the three largest clusters have scores above 0.6, indicating their dependability and proximity to the highest score of 1.00. Cluster #0, which pertains to C-19 symptoms, is the most sizable, encompassing 43 member references, comparatively most significant than other clusters. Conversely, cluster #6, owing to its smaller size, is the least significant in the network. Table 3 shows detailed information of clusters in terms of identifier (ID), silhouette score, cluster label, and major research topics in this knowledge domain. C-19 symptoms, sustainable deep learning-based framework, ML, pre-trained shallow CNN, and deep learning are the primary research front in the area. It is noted that the research focuses on the top largest and pertinent clusters based on the proposed research domain and CiteSpace analysis of the most active citers and clusters.

Cluster #0, titled "COVID-19 symptoms", involves research on detecting this viral infection using ML and deep learning techniques. The lifespan of the cluster is from 2018 to 2022. It signifies that substantial research has been happening in this domain, as shown in Fig. 4 with a solid line against cluster #0. The cluster's most cited and citing references signify a dynamic interrelation between its intellectual foundation and its prospective research fronts. In the cluster, the most citing paper [17] provides a comprehensive overview of the various AI/ML techniques used to combat C-19. It covers the applications of AI/ML, such as diagnosis, prediction, treatment, and control measures, and highlights the potential benefits, including faster diagnosis, personalized treatments, and better control measures. Similarly, the most cited article [18], developed an AI-based model that can accurately identify C-19 from chest X-ray images. The model uses a new deep learning algorithm called COVID-Net, developed over a massive dataset of chest X-ray images, including C-19 cases, non-C-19 pneumonia cases, and normal cases. The significance of COVID-Net lies in its ability to accurately classify C-19 cases from chest X-rays, even in cases where other pneumonia-like symptoms are present.

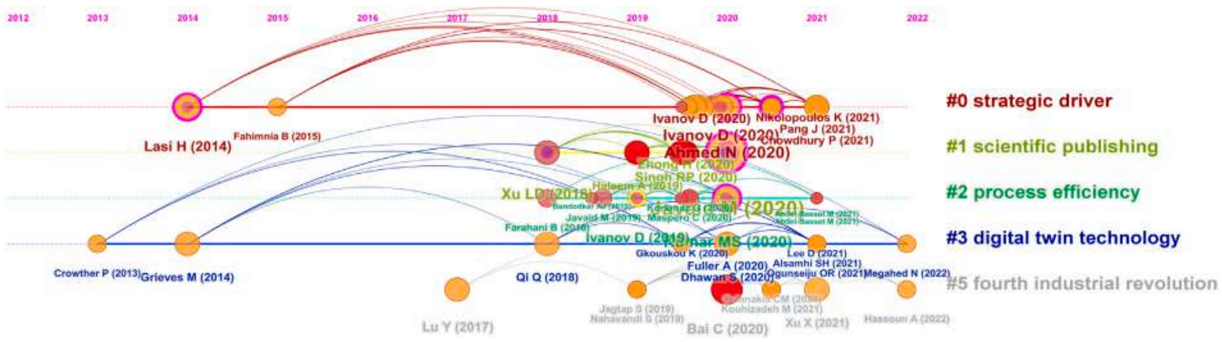

Fig. 5. DCA timeline view of AVI.

Table 4
Cluster information of advanced visualization & Interaction.

ID	Size	Silhouette	Label	Research topics
0	24	0.902	Strategic driver	Blockchain, digital twin, government support, supply chain
1	15	0.997	Scientific publishing	Medical field, conventional education system, remote monitoring system
2	14	0.854	Process efficiency	Treatment process, ensemble-based classifier, feature selection
3	14	0.979	Digital twin technology	Digital twins collaboration, smart personalized healthcare

This is important because chest X-ray imaging is widely available and cost-effective, especially in areas with limited access to other diagnostic tools such as RT-PCR tests.

Cluster #1, titled "sustainable deep learning-based framework" involves studies on the deep forest model and imaging technologies. The lifespan of this cluster is from 2017 to 2021. It suggests that before and after this lifespan, no substantial research has been conducted in this research domain. In the cluster, the most citing paper [17] presents a comprehensive analysis of 68 articles on the contributions of AI and data analytics towards addressing the C-19 pandemic. The study identified AI/ML-based tools and techniques that have been used for early detection and diagnosis, predictive modeling, and natural language processing for analyzing unstructured data sources. Similarly, the most cited article [19] focuses on using deep neural networks for the automated detection of C-19 cases using X-ray images. It suggests that deep neural networks can be used in detecting and diagnosing C-19, but further research is needed to evaluate their effectiveness in real-world clinical settings.

Cluster #2, titled "machine learning" involves studies on the multi features representation and privacy concerns with the utilization of digital technologies. The lifespan of this cluster is from 2017 to 2021. In the cluster, the most citing article [20] describes the potential of the IoT in fighting C-19 and future pandemics, focusing on security and privacy perspectives. It highlights the importance of IoT-based technologies, such as wearables, sensors, and smart devices, in monitoring the viral prevalence. The most cited article [21] focuses on the use of deep learning approaches in the diagnosis and treatment of C-19. It demonstrates the potential of AI-based techniques in analyzing medical images and patient data to assist in C-19 treatment. It explores the various deep-learning models developed for C-19 diagnosis and treatment, such as those for image segmentation, classification, and prediction.

3.3.2. DCA of advanced visualization & Interaction

AVI employs AR/VR and digital twin technologies to improve patient care and treatment. It emphasizes on creating interactive 3D models of patient anatomy and simulating surgical procedures using these technologies. More specifically, AR and VR can be used to simulate training scenarios for healthcare professionals and provide remote patient consultations, while digital twin technology can create virtual replicas of medical devices and equipment for maintenance and monitoring purposes. It can assist physicians in planning and practicing difficult surgical operations prior to performing them on patients, thereby minimizing the likelihood of problems and enhancing clinical outcomes. These virtual technologies can potentially improve healthcare delivery and patient outcomes during the C-19 pandemic and beyond.

Fig. 5 illustrates the temporal DCA network of AVI, consisting of a complex network of 160 cited references and 489 co-citation links, spanning seven years from 2013 to 2022. Notably, the three largest clusters have scores above 0.8, indicating their dependability and proximity to the highest score of 1.00. Cluster #0, which pertains to the strategic driver, is the most sizable, encompassing 24 member references, comparatively more significant than other network clusters. Conversely, cluster #5, owing to its smaller size, is the least significant in the network. Table 4 shows detailed information of clusters in terms of identifier (ID), silhouette score, cluster label, and major research topics. Strategic driver, scientific publishing, process efficiency, and digital twin technology are the major research fronts of the cluster.

Cluster #0, titled "strategic driver" involves studies on smart supply chain management and industry 4.0. The lifespan of this cluster is from 2014 to 2021. The most citing article [22] describes the supply chain disruptions caused by the C-19 epidemic and investigates prospective disruption control strategies. The paper highlights the pandemic impact on global supply chains and discusses the challenges that companies face in controlling supply chain disruptions. The most cited [23] describes using big data

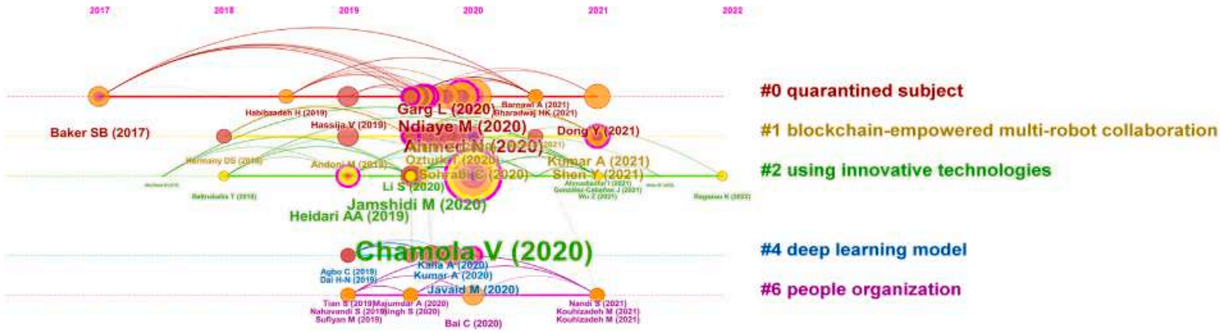

Fig. 6. DCA timeline view of Automation & Robotics.

Table 5
Cluster information of automation & Robotics.

ID	Size	Silhouette	Label	Research topics
0	38	0.841	Quarantined subject	Contemporary digital tool, transforming construction health
1	34	0.887	Blockchain-empowered multi-robot collaboration	IoT-based qms, care delivery
2	31	1	Innovative technologies	Deep visual social distancing monitoring, safety management
4	22	0.857	Deep learning model	Safe pedestrian navigation service, future pandemics, AI-based solution
6	16	0.956	People organization	Pandemic preparedness, fourth industrial revolution, key-route main path analysis

analytics and digital twin technology in the smart manufacturing domain. It provides an overview of the concept of a digital twin in product design, process optimization, and predictive maintenance applications. It highlights the challenges linked with technological implementation, such as data security, interoperability, and standardization.

Cluster #1, titled “scientific publishing” contains studies on digital twins. The lifespan of this cluster is from 2018 to 2020. The most citing article [24] describes the potential of digital twin technology in supporting the United Nations’ Sustainable Development Goals (SDGs). It provides an overview of digital twins and their capabilities, including real-time monitoring, data analytics, and predictive modeling. Digital twins can contribute to achieving the SDGs by improving the efficiency and effectiveness of various systems, such as energy, transportation, and healthcare. The top-cited article [25] discusses the advantages and limitations of online learning, including its flexibility, accessibility, scalability, and challenges of student engagement, equity, and technology infrastructure. The paper also comprehensively reviews the existing literature on online learning, including its pedagogical models, assessment strategies, and best practices.

Cluster #3, titled “digital twin technology” involves research on personalized healthcare and standardized interfaces. The lifespan of this cluster is from 2013 to 2022. The most citing article [26] examines the superfoods in the context of the C-19 pandemic. The author describes the popular notion that certain foods can enhance the immune system and help fight off infections and separates scientific evidence from myths and misconceptions. It critically reviews the current research on superfoods and highlights the need for more rigorous scientific studies to validate their health benefits. The most cited article [27] discusses the digital twin and its enabling technologies. It offers a comprehensive review of the various technologies that enable the creation and deployment of digital twins, including sensors, data analytics, IoT, and AI. It identifies various open research issues, such as improving the accuracy and reliability of digital twins, developing new use cases for digital twins, and advancing technologies.

3.3.3. DCA of automation & Robotics

The use of robots and automation technologies to assist in various healthcare activities. In the context of C-19, the technological domain has gained significant attention due to the need to reduce human-to-human contact and minimize the transmission risk. One of the key applications of this category is the use of disinfection robots to sanitize and disinfect hospital rooms, offices, and other public spaces. These robots use UV-C light or other disinfection technologies to kill viruses and bacteria. Additionally, Robotic Process Automation (RPA) has been used to automate administrative tasks, such as patient registration and scheduling, reducing the need for human interaction. The automation & robotics category has been instrumental in enhancing the safety of healthcare practices during the C-19 pandemic.

Fig. 6 illustrates the temporal DCA network of automation & robotics, consisting of a complex network of 231 cited references and 745 co-citation links, spanning six years from 2017 to 2022. Notably, the three largest clusters have scores above 0.8, indicating their dependability and proximity to the highest score of 1.00. Cluster #0, which pertains to the quarantined subject, is the most sizable, encompassing 38 member references, comparatively most significant than other clusters in the network. Conversely, cluster #6, owing to its smaller size, is the least significant in the network. Table 5 shows detailed information of clusters in terms of identifier (ID), silhouette score, cluster label, and major research topics in this knowledge domain. Quarantined subject, blockchain-empowered multi-robot collaboration, using innovative technologies, deep learning model, and people organization are the major research fronts of the cluster.

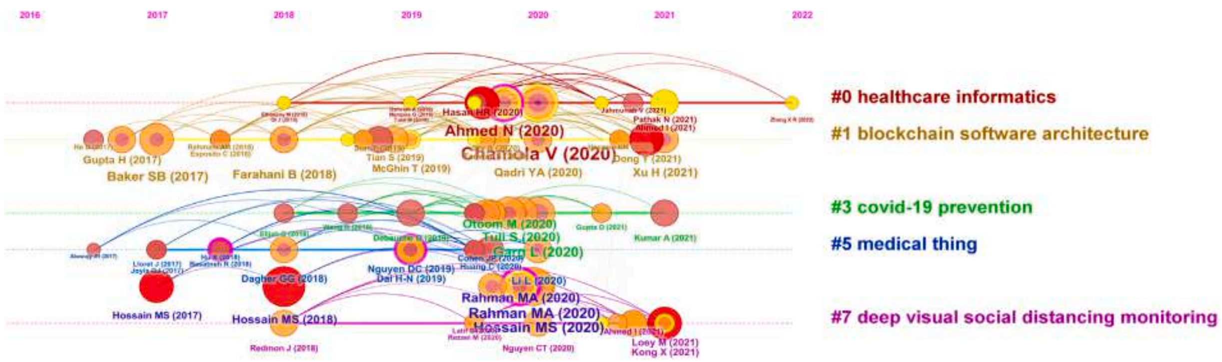

Fig. 7. DCA timeline view of cloud and edge computing.

Cluster #0, titled "quarantined subject" involves studies on digital tools and technologies. The lifespan of this cluster is from 2017 to 2021. The top citing article [28] examines the use of contemporary digital tools and technologies during the C-19 crisis and their impact on various aspects of the pandemic response, including healthcare delivery, remote work, education, and social interaction. It provides a comprehensive overview of the various digital technologies, including telemedicine, virtual reality, and AI, and their potential applications in addressing the challenges posed by the pandemic. The most cited article [29] provides a comprehensive survey of the use of IoT technology in response to the C-19 pandemic, including its contributions, challenges, and future evolution. It discusses various IoT applications and highlights the benefits and limitations of using IoT during the pandemic.

Cluster #1, titled "blockchain-empowered multi-robot collaboration" includes research on blockchain technology utilization in robotic applications. The lifespan of this cluster is from 2018 to 2021. The top citing article [30] provides a comprehensive review of the robotics technology used in the C-19 response. The author explores various applications of robotics technology such as disinfection robots, telepresence robots, and logistics robotic applications. The most cited article [31] describes the potential use of blockchain technology in the fight against C-19 which concentrates on the supply chain management area, contact tracing, and digital identity management. The author argues that blockchain technology could help to increase transparency, accountability, and security in these areas and it can lead to more effective pandemic response efforts.

Cluster #2, titled "using innovative technologies" involves studies on AI-based drones and social distancing monitoring. The lifespan of this cluster is from 2018 to 2022. The most citing article [32] presents a survey of blockchain and AI technologies in pandemic response efforts. The survey discusses different use cases of these technologies, including decentralized contact tracing apps and social media analysis for monitoring virus spread.

The most cited article [33] explores the potential effect of drone delivery on cost and sustainability. It highlights the benefits of using drones for delivery which include reducing delivery times, improving accessibility, and reducing carbon emissions. Through cost analysis, the study reveals the potential cost savings that can be achieved through drone delivery and discusses its potential environmental benefits.

3.3.4. DCA of cloud and edge computing

Cloud and edge computing are revolutionizing healthcare by allowing healthcare providers to access patient data from anywhere and at any time and enabling the analysis of large datasets of patient health data for predictive modeling and advanced analytics. Computing technology has significantly improved the quality and efficiency of patient care. In the fight against the C-19 pandemic, it has helped healthcare professionals to stay ahead of the curve in identifying and mitigating the viral spread. The contribution of cloud and edge computing in this area is in providing critical insights and transforming how diagnosing, treating, and preventing diseases.

Fig. 7 illustrates the temporal DCA network of cloud and edge computing, consisting of a complex network of 214 cited references and 681 co-citation links, spanning six years from 2017 to 2022. Notably, the three most significant clusters have scores above 0.7, indicating their dependability and proximity to the highest score of 1.00. Cluster #0, which pertains to healthcare informatics, is the most sizable, encompassing 31 member references, comparatively more significant than other network clusters. Conversely, cluster #7, owing to its smaller size, is the least significant in the network. Table 6 shows detailed information of clusters in terms of identifier (ID), silhouette score, cluster label, and major research topics in this knowledge domain. Healthcare informatics, blockchain software architecture, COVID-19 prevention, medical thing, and deep visual social distancing monitoring are the major research fronts of the cluster.

Cluster #0, titled "health informatics" involves studies on IoT deployment in smart spaces. The lifespan of this cluster is from 2018 to 2022. The most citing article [34] analyzes the impact of the C-19 pandemic on IoT technologies adoption across various domains, including healthcare and smart cities. The authors describe the challenges and opportunities for IoT adoption in these domains during and after the pandemic. The paper highlights the potential benefits of IoT in addressing challenges related to C-19, such as reducing the spread of the virus, optimizing resource utilization, and improving patient outcomes. The most cited article [35] provides a detailed review of the C-19 and the potential emerging technologies role, including IoT, AI, drones, 5G, and blockchain, in managing its impact. It discusses various use cases and applications of these technologies in addressing challenges related to C-19.

Table 6
Cluster information of cloud and edge computing.

ID	Size	Silhouette	Label	Research topics
0	31	0.933	Healthcare informatics	IoT gadget, smart quarantine environment privacy, Industrial IoT
1	28	0.789	Blockchain software architecture	Emerging biomedical applications, connected healthcare, big data framework
3	19	0.707	COVID-19 prevention	Scalable technology, mass video surveillance, wireless resource management
5	19	0.911	Medical thing	AI-based solution, wearable internet, wireless resource management
7	13	0.898	Deep visual social distancing monitoring	Edge deployment framework, facial detection method, detector-based intelligent face mask detection model

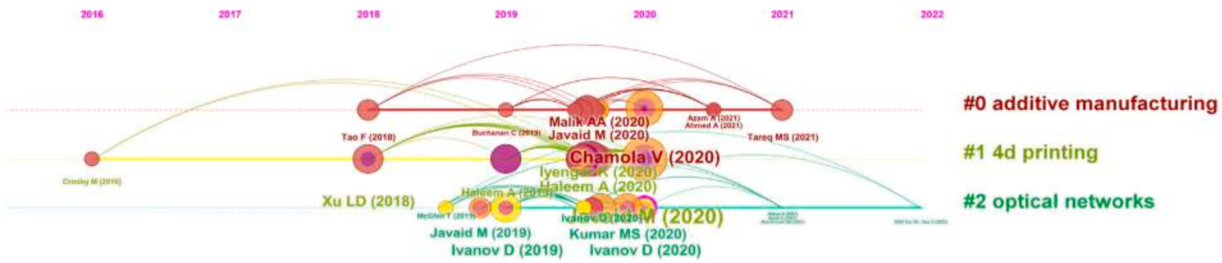

Fig. 8. DCA timeline view of printing technology.

Cluster #1, titled “blockchain software architecture” involves studies on blockchain-enabled connected healthcare systems. The lifespan of this cluster is from 2017 to 2021. The most citing article [36] proposes a fog and blockchain-based software architecture for global vaccination plan management. It highlights the need for an efficient and secure system for managing the distribution and administration of C-19 vaccines worldwide. It describes the different components of the proposed architecture, including the fog nodes, smart contracts, and decentralized applications. The most citing article [37] focuses on the IoT applications in the healthcare industry and how it can enable smart healthcare. The challenges faced by the healthcare industry, such as increasing healthcare costs, ageing populations, and the prevalence of chronic diseases.

Cluster #3, titled “COVID-19 prevention” involves studies on smart surveillance and detection system. The lifespan of this cluster is from 2018 to 2021. The most citing article [38] proposes a framework for detecting C-19 using transfer learning in the context of the Internet of Medical Health Things (IoMHT). The framework employs a ResNet50 CNN model to extract features from chest X-ray images and fine-tunes the model on a C-19 dataset. The authors present a system architecture for implementing the proposed framework, which can collect data from various sources and perform real-time analysis to detect C-19.

The most cited article [39] reveals that edge intelligence can significantly enhance the performance of 6G networks by providing real-time processing and decision-making capabilities at the network edge. This can enable the deployment of ultra-reliable low latency applications that require high reliability, low latency, and high bandwidth.

3.3.5. DCA of printing technology

Printing technology involves the use of 3D printing and RFID printing to create medical devices, prosthetics, and other healthcare-related products. These technologies are crucial to the IoT ecosystem. These technologies can be used to produce sensors and conductive inks for wearable devices that monitor vital signs, activity levels, and sleep patterns. This data can then be transmitted to healthcare providers in real time through IoT, improving patient outcomes. The technological research domain enables the creation of custom-made medical devices tailored to a patient’s specific needs. In the context of IoT-assisted C-19, it refers to using 3D printing and RFID printing technologies to manufacture medical devices and supplies in high demand during the pandemic. 3D printing has been utilized to create face shields, ventilator parts, and nasal swabs for testing, while RFID printing has been used for tracking and inventory management of critical medical supplies. The use of these printing technologies has helped to address the shortage of medical equipment and supplies during the C-19 pandemic.

Fig. 8 illustrates the temporal DCA network of printing technology, consisting of a complex network of 276 cited references and 845 co-citation links, spanning seven years from 2016 to 2022. Notably, the three largest clusters have scores above 0.9, indicating their dependability and proximity to the highest score of 1.00. Cluster #0, which pertains to additive manufacturing, is the most sizable, encompassing 30 member references, comparatively most significant than other clusters in the network. Conversely, cluster #2, owing to its smaller size, is the least significant in the network. Table 7 shows detailed information of clusters in terms of identifier (ID), silhouette score, cluster label, and major research topics in this knowledge domain. Additive manufacturing, 4d printing and optical networks are the primary research fronts of the cluster.

Cluster #0, titled “additive manufacturing” involves studies on 3D printing applications and scope in healthcare. The lifespan of this cluster is from 2018 to 2021. The most citing article [40] explores the evolution of 3D printing technology and its usability in sustainable energy generation during C-19. It discusses the 3D printing technology role in combating the C-19 pandemic, including the production of personal protective equipment (PPE), ventilator parts, and diagnostic tools. The most cited article [41] provides an overview of Industry 4.0 applications in fighting the C-19. It highlights the potential of technologies such as the IoT, AI, and

Table 7
Cluster information of printing technology.

ID	Size	Silhouette	Label	Research topics
0	30	0.969	Additive manufacturing	3d printing, emergency supplies, manufacturing engineering
1	30	0.974	4d printing	Smart materials, cloud computing, modern technologies applications, intelligent wearable mask
2	26	0.99	Optical networks	Quantum-secured blockchain, quantum computing, healthcare industry, supportive feature

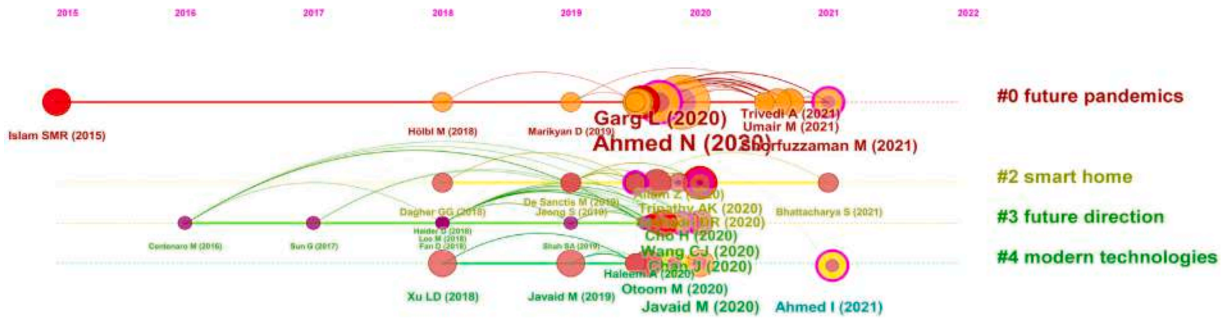

Fig. 9. DCA timeline view of sensing and communication.

Table 8
Cluster information of sensing and communication.

ID	Size	Silhouette	Label	Research topics
0	34	0.81	Future pandemics	Blockchain model, sustainable development, Medical thing
2	28	0.73	Smart home	Smart building, industrial IoT, IoT adoption
3	26	0.955	Future direction	COVID-19 contact, mobile device, multi-agent approach
4	19	0.953	Modern technologies	Cloud computing, radio technologies, nanomedicine technology

robotics in combating the pandemic. It presents a detailed analysis of the various applications of these technologies. It also discusses the Industry 4.0 technologies role in improving the supply chain management of medical devices and PPE [42].

Cluster #1, titled “4d printing” includes research studies on Medical 4.0 and emerging technologies. The lifespan of this cluster is from 2016 to 2020. The most citing article [43] provides a detailed analysis of the various components of Medical 4.0. It emphasizes the need for advanced healthcare technologies during pandemics and highlights how Medical 4.0 can aid in better decision-making and monitoring of the pandemic. The most cited article [44] presents an overview of AI applications in combating the C-19 pandemic. It underscores the collaborative efforts between healthcare professionals and AI experts to develop more effective strategies for pandemic management.

Cluster #2, titled “optical networks” involves studies on data analytics and risk evaluation. The lifespan of this cluster is from 2019 to 2022. The most citing article [45] describes the potential for innovative dentistry 4.0 applications during the C-19 period. The study explores the various Dentistry 4.0 technologies, including AI and 3D printing, and their potential role in providing remote dental consultations and designing personalized protective equipment for C-19-related oral health issues. The most cited article [46] discusses the potential benefits and risks of using digital data to combat the C-19 pandemic, including contact tracing, quarantine enforcement, and outbreak modeling. It highlights the importance of responsible data governance and ethics in implementing these digital solutions and advocates for transparency and user control over personal data.

3.3.6. DCA of sensing and communication

The sensing and communication category encompasses the technologies and devices that enable the collection and transmission of real-time data and information related to the patient’s health status, activities, and environment. Wearables, biosensors, and IoT-based sensing devices are used to gather data, which can then be transmitted to healthcare professionals for monitoring and analysis. Sensing and communication technologies aim to enhance patient outcomes by providing timely and accurate data to healthcare professionals for improved decision-making and personalized care.

Fig. 9 illustrates the temporal DCA network of sensing and communication technologies, consisting of a complex network of 224 cited references and 696 co-citation links, spanning six years from 2015 to 2021. Notably, the three largest clusters have scores above 0.7, indicating their dependability and proximity to the highest score of 1.00. Cluster #0, which pertains to future pandemics, is the most sizable, encompassing 34 member references, comparatively most significant than other clusters in the network. Conversely, cluster #4, owing to its smaller size, is the least significant in the network. Table 8 shows detailed information of clusters in terms of identifier (ID), silhouette score, cluster label, and major research topics in this knowledge domain. Future pandemics, smart home, future direction, and modern technologies are the major research fronts of the cluster.

Cluster #0, titled “future pandemics” involves studies on remote monitoring and medical things. The lifespan of this cluster is from 2015 to 2021. The most citing paper [34] examines the impact of C-19 on IoT adoption in healthcare, smart homes, and

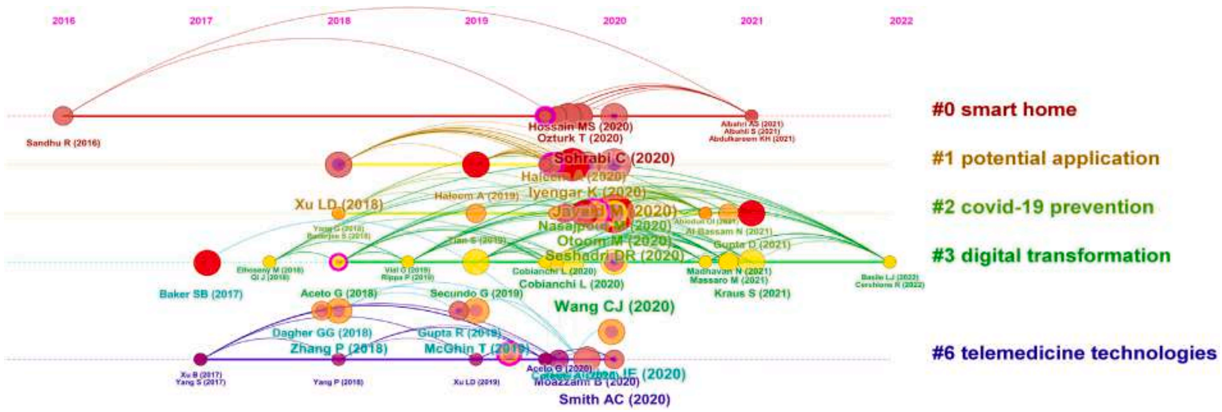

Fig. 10. DCA timeline view of telemedicine.

Table 9
Cluster information of telemedicine.

ID	Size	Silhouette	Label	Research topics
0	37	0.846	Smart home	Automating pandemic mitigation, blockchain technology application
1	33	0.982	Potential application	Nanomedicine technology, telemedicine technologies, cloud computing
2	33	0.986	COVID-19 prevention	Recent advance, domiciliary hospitalization, big data
3	24	0.989	Digital transformation	Healthcare industry, empirical analysis, sustainable C-19 healthcare
6	13	0.960	Telemedicine technologies	Health information technology, recent advance, digital social innovation

industrial fields. The pandemic has increased the use of IoT technology in healthcare for remote patient monitoring and contactless care. The most cited paper [47] emphasizes the need for wearable sensors to be used for C-19 patient monitoring and virtual assessments. This can help healthcare providers detect early signs of deterioration and enable timely intervention.

Cluster #2, titled “Smart home” involves studies on technological supports for diagnosis. The lifespan of this cluster is from 2018 to 2021. The most citing paper [48] underlines the importance of modern technologies in managing the C-19 pandemic. It emphasizes the digital technologies that have been instrumental in assisting with the development of vaccines and the analysis of vast quantities of data. The most cited article [49] proposes an early detection and monitoring system for C-19 cases based on IoT technology. The framework includes the utilization of various IoT devices like thermal cameras, wearable sensors, and mobile phones to gather crucial data about symptoms and exposure history.

Cluster #3, titled “future direction” contains studies on recent advances in sensing technologies. The lifespan of this cluster is from 2016 to 2020. The most citing paper [50] is a scientific review of non-contact sensing technologies for C-19. The prominence of these technologies lies in reducing the spread of the virus and protecting healthcare workers. It covers several non-contact sensing technologies, including thermal imaging, infrared thermometry, and radar. The most cited article [51] describes the development of IoT-based smart health monitoring systems. Mainly, it focuses on using IoT devices to collect health data. The collected data is then analyzed using ML algorithms to detect any anomalies in a person’s health status. These smart health monitoring systems can be useful for remote patient monitoring and reducing healthcare costs.

3.3.7. DCA of telemedicine

Telemedicine has been a critical tool in C-19 management, as it provides remote access to healthcare services, enabling patients to receive care without physically visiting a hospital or clinic. Telemedicine platforms allow healthcare providers to communicate with patients and provide consultations virtually. The utilization of chatbots has extended to delivering immediate responses and information pertaining to commonly asked C-19 questions. Meanwhile, patient portals that offer a secure virtual space have given patients access to their medical records, test results, and means to communicate with healthcare providers. By doing so, these technological innovations have been instrumental in minimizing infection risk and granting patients the convenience of receiving care from home.

Fig. 10 illustrates the temporal DCA network of telemedicine, consisting of a complex network of 242 cited references and 810 co-citation links, spanning seven years from 2016 to 2022. Notably, the three largest clusters have scores above 0.7, indicating their dependability and proximity to the highest score of 1.00. Cluster #0, which pertains to smart home, is the most sizable, encompassing 37 member references, comparatively most significant than other clusters in the network. Conversely, cluster #6, owing to its smaller size, is the least significant in the network. Table 9 shows detailed information of clusters in terms of identifier (ID), silhouette score, cluster label, and major research topics in this knowledge domain. Smart home, potential application, C-19 prevention, digital transformation, telemedicine technologies are the major research fronts of the cluster.

Cluster #0, titled “Smart home” involves studies on biosensors and smart spaces. The lifespan of this cluster is from 2016 to 2021. The most citing paper [52] discusses various biosensor technologies, including electrochemical, optical, and microfluidic biosensors, and highlights their potential use in identifying potential outbreaks and monitoring the virus's spread. It also emphasizes the need for further research to improve their sensitivity, selectivity, and accuracy for C-19 detection in wastewater. Similarly, the most cited article [53] provides a comprehensive overview of the pandemic's origins, transmission, clinical features, and the global response to its outbreak. It emphasizes the importance of early detection, prompt treatment, and effective public health measures.

Cluster #1, titled "potential application" involves the studies on telemedicine enabling technologies. The lifespan of this cluster is from 2018 to 2020. The top citing article [54] focuses on an empirical analysis of the digital transformation drivers in the healthcare field. It highlights the various factors contributing to digital technologies' adoption and implementation in healthcare, such as organizational and environmental factors, regulatory frameworks, and technological infrastructure. The top cited article [55] examines the potential of telemedicine in managing the C-19 pandemic. It discusses how telemedicine can help in reducing the spread of the virus by allowing patients to consult healthcare providers remotely. The author also highlights the potential benefits of telemedicine. Such as increased access to healthcare services, improved efficiency, and cost savings.

Cluster #3, titled "digital transformation" involves studies on telehealth and data security. The lifespan of this cluster is from 2017 to 2022. The top citing article [56] highlights the use of blockchain technology in enhancing the security and privacy of healthcare data and facilitating the sharing of data across different healthcare organizations. It discusses the implementation of a blockchain-based workflow for the telemedical laboratory which includes the use of smart contracts and secure data-sharing protocols [57]. The most cited article [58] describes the potential of telehealth in managing global emergencies, such as pandemics, natural disasters, and humanitarian crises. It highlights the benefits of telehealth, such as increased access to healthcare services, improved efficiency, and reduced risk of infection transmission.

3.4. Burst analysis

The strongest citation burst references analysis aims to identify highly influential research papers that have significantly impacted a particular field of study. Burst detection is a methodical technique used to identify substantial fluctuations within a given frequency function, particularly within a brief period of time. CiteSpace identifies the bursty references based on burst detection algorithm developed by Kleinberg in 2002. Mathematically, the burstiness of the reference can be calculated as follows:

$$Burstiness = \frac{\beta - \gamma}{\beta + \gamma}$$

where β indicates burst duration length which the reference receives a higher than average number of citations and γ represents the average time span between citations for the reference. In particular, a bursty behavior is indicated when a reference receives citations in rapid succession with shorter interarrival periods. In the current study, top-10 burst references have been identified using the CiteSpace tool. Fig. 11 shows the burst references along with their burst strength, burst duration (starting and ending year), and a graphical representation of the burst timeline of each selected reference with the blue and red lines. From which the blue timeline shows the ordinary growth of citations, whereas the red timeline indicates the burst growth of citations. As illustrated in Fig. 11, the following burst references are ranked by their burst strength value.

In light of the C-19 pandemic, a multitude of studies has emerged to identify the challenges and potential solutions in confronting this unprecedented public health crisis. Iyengar et al. [59] describe the significance of ventilators in combating the virus and the need for collaboration between healthcare providers, manufacturers, and government agencies to increase their production and availability. Meanwhile, Hernández-Orallo et al. [60] explore the effectiveness of smartphone contact tracing applications for controlling viral transmission and propose a model for evaluating their effectiveness in reducing the number of C-19 cases.

Similarly, Iyengar et al. [61] investigate the C-19 impact on the medical supply chain and solutions for fulfilling the urgent need for ventilators for C-19 patients. Singh et al. [62] explore the potential of the IoMT in orthopedic care during the C-19 pandemic. It discusses the various technologies that can be employed in IoMT, such as wearables, smart sensors, and remote monitoring systems. It highlights the benefits of IoMT in reducing the risk of viral transmission.

Loey et al. [63] propose a hybrid deep transfer learning model for face mask detection to enforce public health regulations and reduce the C-19 spread. Haleem et al. [64] explore the academic research domain with the C-19 effect. The author provides an overview of the various research areas impacted by the pandemic, such as epidemiology, public health, and healthcare delivery.

Furthermore, Gupta et al. [65] explore the potential of smart city infrastructures in enabling and enforcing social distancing measures during the C-19 pandemic. It discusses the various smart city technologies that can be employed in social distancing, such as surveillance cameras, drones, and IoT devices. Bahl et al. [66] highlight the potential of telemedicine technologies for improving patient experience. Kumar et al. [67] propose the use of drones in pandemic response for medical supply delivery, public sanitation, and social distancing monitoring, highlighting their potential to enhance public health surveillance and pandemic management. Lastly, Christaki [68] describes the potential of smart technologies for predicting and preventing viral infections. It analyzes various technological approaches, such as biosensors, mobile health applications, and computational modeling, and highlights their potential to enhance public health surveillance, pandemic response, and management.

3.5. Current limitations and future scope

In the pursuit of understanding the various domains of IoT-assisted technology in COVID-19 research, the research intends to shed light on current trends, hotspots, and frontiers for knowledge diffusion. Nevertheless, it is essential to acknowledge the limitations and challenges that must be surmounted in order to exploit the promise of smart technology in this field. Thus, the following key research areas require attention and plausible solutions.

Top 10 References with the Strongest Citation Bursts

References	Strength	Begin	End	2020 - 2023
Iyengar K, 2020, CHALLENGES AND SOLUTIONS IN MEETING UP THE URGENT REQUIREMENT OF VENTILATORS FOR COVID-19 PATIENTS @ DIABETES & METABOLIC SYNDROME, V14(4), P0	**4.31**	2020	2020	
Hernandez-Orallo E, 2020, EVALUATING HOW SMARTPHONE CONTACT TRACING TECHNOLOGY CAN REDUCE THE SPREAD OF INFECTIOUS DISEASES, V8, P0	**4.31**	2020	2020	
Iyengar KP, 2020, IMPACT OF THE CORONAVIRUS PANDEMIC ON THE SUPPLY CHAIN IN HEALTHCARE @ BRITISH JOURNAL OF HEALTHCARE MANAGEMENT, V26(6), P1-4	**4.31**	2020	2020	
Singh RP, 2020, INTERNET OF MEDICAL THINGS (IOMT) FOR ORTHOPAEDIC IN COVID-19 PANDEMIC, V11(4), P0	**3.76**	2020	2020	
Loey M, 2021, A HYBRID DEEP TRANSFER LEARNING MODEL WITH MACHINE LEARNING METHODS FOR FACE MASK DETECTION IN THE ERA OF THE COVID-19 PANDEMIC @ MEASUREMENT, V167, P0	**3.41**	2022	2023	
Haleem A, 2020, AREAS OF ACADEMIC RESEARCH WITH THE IMPACT OF COVID-19 @ THE AMERICAN JOURNAL OF EMERGENCY MEDICINE, V38(7), P0	**3.07**	2020	2020	
Gupta M, 2020, @ ENABLING AND ENFORCING SOCIAL DISTANCING MEASURES USING SMART CITY AND ITS INFRASTRUCTURES, V0, P0	**2.2**	2021	2021	
Bahl S, 2020, TELEMEDICINE TECHNOLOGIES FOR CONFRONTING COVID-19 PANDEMIC, V5(4), P0	**2.2**	2021	2021	
Kumar A, 2021, A DRONE-BASED NETWORKED SYSTEM AND METHODS FOR COMBATING CORONAVIRUS DISEASE (COVID-19) PANDEMIC @ FUTURE GENER COMPUT SYST, V115, P0	**2.2**	2021	2021	
Christaki E, 2015, NEW TECHNOLOGIES IN PREDICTING, PREVENTING AND CONTROLLING EMERGING INFECTIOUS DISEASES @ VIRULENCE, V6(6), P0	**1.84**	2020	2020	
Christaki E, 2015, NEW TECHNOLOGIES IN PREDICTING, PREVENTING AND CONTROLLING EMERGING INFECTIOUS DISEASES @ VIRULENCE, V6(6), P0	**1.84**	2020	2020	

Fig. 11. Top-10 strongest citation burst articles.

- **Improved data quality:** The quality and standardization of COVID-19 data across regions and countries need improvement. The development of common data standards and protocols for data collection and reporting could address this issue, leading to a more consistent and reliable dataset.
- **Personalized Medicine:** AI and data analytics can be leveraged to develop personalized medicine approaches to COVID-19 treatment and management. It includes developing AI-based diagnostic tools and using data analytics to identify subgroups of

patients who may respond differently to specific treatments. In addition, the use of 3D printing to create custom-made medical devices tailored to individual patient needs could further advance personalized medicine.

- **Ethical frameworks:** Ethical frameworks are necessary to guide the use of AI and data analytics in healthcare, given privacy, security, and bias concerns. By establishing ethical frameworks and guidelines, the responsible and ethical use of robots and automation technologies in healthcare can also be ensured.
- **Integration with IoT:** Integrating AI with IoT devices such as wearables and sensors could enhance the accuracy and usefulness of predictions and analyses. It could provide real-time data and insights into COVID-19 transmission and risk factors, leading to more precise and efficient strategies.
- **Increased adoption and cost reduction:** Increasing the adoption and implementation of AR/VR, digital twin, and robotics technologies in healthcare are necessary. It can be achieved through education and training programs while exploring cost-effective strategies such as open-source software and hardware.
- **Interoperability:** Developing interoperability standards is crucial for data sharing, healthcare coordination, and developing a unified healthcare system. Interoperability standards can promote more efficient and effective healthcare practices by facilitating communication and collaboration between healthcare providers.

4. Conclusion

The present paper endeavours to visually map IoT-enabling technologies in the context of C-19 research through a scientometric analysis of 4383 academic articles sourced from the Scopus database. The paper meticulously identifies seven crucial domains where IoT-assisted technology has proven effective and provides a comprehensive analysis of annual publication patterns, citation structures, leading nations, and literature co-citation network analysis, from the perspective of science and technology discipline.

The research thoroughly evaluates the effectiveness of IoT-enabled technologies in controlling the prevalence of C-19 and has discovered that these technologies have not only proven successful in combating the pandemic but have also improved traditional healthcare systems to manage the possibility of future outbreaks better. The cutting-edge findings of this study reveal that blockchain technology, deep learning techniques, and digital twin technology are the latest trends in C-19 research. These disruptive technologies are extensively employed with IoT to overcome the significant challenges posed by the virus. Moreover, proactive supply risk management strategies, decentralized contact tracing applications, smart social distancing, and quarantine have emerged as the current research hotspots in this domain. Additionally, smart city, remote consultations, personalized treatment, and robotic process automation are gaining substantial attention from the scientific community.

The research underscores the importance of collaboration, innovation, and technological advancement in the fight against the C-19 pandemic. While IoT, blockchain, digital twin, and AI technologies have enormous potential to significantly improve pandemic response efforts, their successful implementation requires the concerted efforts of various stakeholders. However, the study has also identified several challenges and limitations associated with the adoption of these technologies, such as data quality issues, limited data availability, ethical concerns, regulatory barriers, and the digital divide. Therefore, the research highlights the critical need for interdisciplinary collaborations among researchers, policymakers, and industry stakeholders to tackle the technical, social, and ethical challenges associated with IoT adoption in the post-pandemic world. It is imperative to take a systematic and scientific approach to maximize the benefits of IoT-enabled technologies while mitigating the risks associated with their adoption.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

References

[1] N. Chakravarty, T. Senthilnathan, S. Paiola, P. Gyani, S. Castillo Cario, E. Urena, A. Jeysankar, P. Jeysankar, J. Ignatius Irudayam, S. Natesan Subramanian, et al., Neurological pathophysiology of SARS-CoV-2 and pandemic potential RNA viruses: a comparative analysis, FEBS Lett. 595 (23) (2021) 2854–2871.
[2] S. Sareen, S.K. Sood, S.K. Gupta, Secure internet of things-based cloud framework to control zika virus outbreak, Int. J. Technol. Assess. Health Care 33 (1) (2017) 11–18.
[3] K. Prateek, N.K. Ojha, F. Altaf, S. Maity, Quantum secured 6G technology-based applications in internet of everything, Telecommun. Syst. 82 (2) (2023) 315–344.
[4] Y.-L. Liu, W.-J. Yuan, S.-H. Zhu, The state of social science research on COVID-19, Scientometrics (2022) 1–15.
[5] A. Castiglione, M. Umer, S. Sadiq, M.S. Obaidat, P. Vijayakumar, The role of internet of things to control the outbreak of COVID-19 pandemic, IEEE Internet Things J. 8 (21) (2021) 16072–16082.
[6] D.V. Gunasekeran, R.M.W.W. Tseng, Y.-C. Tham, T.Y. Wong, Applications of digital health for public health responses to COVID-19: a systematic scoping review of artificial intelligence, telehealth and related technologies, NPJ Digit. Med. 4 (1) (2021) 40.
[7] M. Bhatia, S. Kaur, S.K. Sood, V. Behal, Internet of things-inspired healthcare system for urine-based diabetes prediction, Artif. Intell. Med. 107 (2020) 101913.
[8] R. Sandhu, S.K. Sood, G. Kaur, An intelligent system for predicting and preventing MERS-CoV infection outbreak, J. Supercomput. 72 (2016) 3033–3056.
[9] S.K. Sood, K.S. Rawat, D. Kumar, A visual review of artificial intelligence and industry 4.0 in healthcare, Comput. Electr. Eng. 101 (2022) 107948.

[10] M. Javaid, I.H. Khan, Internet of things (IoT) enabled healthcare helps to take the challenges of COVID-19 pandemic, J. Oral Biol. Craniofac. Res. 11 (2) (2021) 209–214.
[11] S.K. Sood, K.S. Rawat, D. Kumar, Analytical mapping of information and communication technology in emerging infectious diseases using CiteSpace, Telemat. Inform. (2022) 101796.
[12] Y. Dong, Y.-D. Yao, IoT platform for COVID-19 prevention and control: A survey, IEEE Access 9 (2021) 49929–49941.
[13] C. Chen, F. Ibekwe-SanJuan, J. Hou, The structure and dynamics of cocitation clusters: A multiple-perspective cocitation analysis, J. Am. Soc. Inf. Sci. Technol. 61 (7) (2010) 1386–1409.
[14] L. Leydesdorff, K. Welbers, The semantic mapping of words and co-words in contexts, J. Informetr. 5 (3) (2011) 469–475.
[15] Y. Fang, J. Yin, B. Wu, Climate change and tourism: A scientometric analysis using CiteSpace, J. Sustain. Tour. 26 (1) (2018) 108–126.
[16] M. Mei, A Framework for the Discovery and Tracking of Ideas in Longitudinal Text Corpora (Ph.D. thesis), University of Cincinnati, 2022.
[17] O. Dogan, S. Tiwari, M. Jabbar, S. Guggari, A systematic review on AI/ML approaches against COVID-19 outbreak, Complex Intell. Syst. 7 (2021) 2655–2678.
[18] L. Wang, Z.Q. Lin, A. Wong, Covid-net: A tailored deep convolutional neural network design for detection of covid-19 cases from chest x-ray images, Sci. Rep. 10 (1) (2020) 1–12.
[19] T. Ozturk, M. Talo, E.A. Yildirim, U.B. Baloglu, O. Yildirim, U.R. Acharya, Automated detection of COVID-19 cases using deep neural networks with X-ray images, Comput. Biol. Med. 121 (2020) 103792.
[20] M.A. Ferrag, L. Shu, K.-K.R. Choo, Fighting COVID-19 and future pandemics with the internet of things: Security and privacy perspectives, IEEE/CAA J. Autom. Sin. 8 (9) (2021) 1477–1499.
[21] M. Jamshidi, A. Lalbakhsh, J. Talla, Z. Peroutka, F. Hadjilooei, P. Lalbakhsh, M. Jamshidi, L. La Spada, M. Mirmozafari, M. Dehghani, et al., Artificial intelligence and COVID-19: deep learning approaches for diagnosis and treatment, IEEE Access 8 (2020) 109581–109595.
[22] J. Moosavi, A.M. Fathollahi-Fard, M.A. Dulebenets, Supply chain disruption during the COVID-19 pandemic: Recognizing potential disruption management strategies, Int. J. Disaster Risk Reduct. (2022) 102983.
[23] Q. Qi, F. Tao, Digital twin and big data towards smart manufacturing and industry 4.0: 360 degree comparison, IEEE Access 6 (2018) 3585–3593.
[24] H. Hassani, X. Huang, S. MacFeely, Enabling digital twins to support the UN SDGs, Big Data Cogn. Comput. 6 (4) (2022) 115.
[25] S. Dhawan, Online learning: A panacea in the time of COVID-19 crisis, J. Educ. Technol. Syst. 49 (1) (2020) 5–22.
[26] A. Hassoun, R. Harastani, S. Jagtap, H. Trollman, G. Garcia-Garcia, N.M. Awad, O. Zannou, C.M. Galanakis, G. Goksen, G.A. Nayik, et al., Truths and myths about superfoods in the era of the COVID-19 pandemic, Crit. Rev. Food Sci. Nutr. (2022) 1–18.
[27] A. Fuller, Z. Fan, C. Day, C. Barlow, Digital twin: Enabling technologies, challenges and open research, IEEE Access 8 (2020) 108952–108971.
[28] M. Subramanian, K. Shanmuga Vadivel, W.A. Hatamleh, A.A. Alnuaim, M. Abdelhady, S. VE, The role of contemporary digital tools and technologies in Covid-19 crisis: An exploratory analysis, Expert Syst. 39 (6) (2022) e12834.
[29] M. Ndiaye, S.S. Oyewobi, A.M. Abu-Mahfouz, G.P. Hancke, A.M. Kurien, K. Djouani, IoT in the wake of COVID-19: A survey on contributions, challenges and evolution, IEEE Access 8 (2020) 186821–186839.
[30] M. Javaid, A. Haleem, A. Vaish, R. Vaishya, K.P. Iyengar, Robotics applications in COVID-19: A review, J. Ind. Integr. Manage. 5 (04) (2020) 441–451.
[31] A. Kalla, T. Hewa, R.A. Mishra, M. Ylianttila, M. Liyanage, The role of blockchain to fight against COVID-19, IEEE Eng. Manage. Rev. 48 (3) (2020) 85–96.
[32] D.C. Nguyen, M. Ding, P.N. Pathirana, A. Seneviratne, Blockchain and AI-based solutions to combat coronavirus (COVID-19)-like epidemics: A survey, IEEE Access 9 (2021) 95730–95753.
[33] W.-C. Chiang, Y. Li, J. Shang, T.L. Urban, Impact of drone delivery on sustainability and cost: Realizing the UAV potential through vehicle routing optimization, Appl. Energy 242 (2019) 1164–1175.
[34] M. Umair, M.A. Cheema, O. Cheema, H. Li, H. Lu, Impact of COVID-19 on IoT adoption in healthcare, smart homes, smart buildings, smart cities, transportation and industrial IoT, Sensors 21 (11) (2021) 3838.
[35] V. Chamola, V. Hassija, V. Gupta, M. Guizani, A comprehensive review of the COVID-19 pandemic and the role of IoT, drones, AI, blockchain, and 5G in managing its impact, IEEE Access 8 (2020) 90225–90265.
[36] H.J.D.M. Costa, C.A. Da Costa, R.D.R. Righi, R.S. Antunes, J.F.D.P. Santana, V.R.Q. Leithardt, A fog and blockchain software architecture for a global scale vaccination strategy, IEEE Access 10 (2022) 44290–44304.
[37] S.B. Baker, W. Xiang, I. Atkinson, Internet of things for smart healthcare: Technologies, challenges, and opportunities, IEEE Access 5 (2017) 26521–26544.
[38] M.V. Madhavan, A. Khamparia, D. Gupta, S. Pande, P. Tiwari, M.S. Hossain, Res-CovNet: an internet of medical health things driven COVID-19 framework using transfer learning, Neural Comput. Appl. (2021) 1–14.
[39] R. Gupta, D. Reebadiya, S. Tanwar, 6G-enabled edge intelligence for ultra-reliable low latency applications: Vision and mission, Comput. Stand. Interfaces 77 (2021) 103521.
[40] Y. Wang, A. Ahmed, A. Azam, D. Bing, Z. Shan, Z. Zhang, M.K. Tariq, J. Sultana, R.T. Mushtaq, A. Mehboob, et al., Applications of additive manufacturing (AM) in sustainable energy generation and battle against COVID-19 pandemic: The knowledge evolution of 3D printing, J. Manuf. Syst. 60 (2021) 709–733.
[41] M. Javaid, A. Haleem, R. Vaishya, S. Bahl, R. Suman, A. Vaish, Industry 4.0 technologies and their applications in fighting COVID-19 pandemic, Diabetes Metab. Syndr.: Clin. Res. Rev. 14 (4) (2020) 419–422.
[42] N. Kaur, S.K. Sood, Cognitive decision making in smart industry, Comput. Ind. 74 (2015) 151–161.
[43] A. Haleem, M. Javaid, Medical 4.0 and its role in healthcare during COVID-19 pandemic: A review, J. Ind. Integr. Manage. 5 (04) (2020) 531–545.
[44] R. Vaishya, M. Javaid, I.H. Khan, A. Haleem, Artificial intelligence (AI) applications for COVID-19 pandemic, Diabetes Metab. Syndr.: Clin. Res. Rev. 14 (4) (2020) 337–339.
[45] M. Javaid, A. Haleem, R.P. Singh, R. Suman, Dentistry 4.0 technologies applications for dentistry during COVID-19 pandemic, Sustain. Oper. Comput. 2 (2021) 87–96.
[46] M. Ienca, E. Vayena, On the responsible use of digital data to tackle the COVID-19 pandemic, Nat. Med. 26 (4) (2020) 463–464.
[47] D.R. Seshadri, E.V. Davies, E.R. Harlow, J.J. Hsu, S.C. Knighton, T.A. Walker, J.E. Voos, C.K. Drummond, Wearable sensors for COVID-19: a call to action to harness our digital infrastructure for remote patient monitoring and virtual assessments, Front. Digit. Health (2020) 8.
[48] R. Vaishya, M. Javaid, I.H. Khan, A. Vaish, K.P. Iyengar, Significant role of modern technologies for COVID-19 pandemic, J. Ind. Integr. Manage. 6 (02) (2021) 147–159.
[49] M. Otoom, N. Otoum, M.A. Alzubaidi, Y. Etoom, R. Banihani, An IoT-based framework for early identification and monitoring of COVID-19 cases, Biomed. Signal Process. Control 62 (2020) 102149.
[50] W. Taylor, Q.H. Abbasi, K. Dashtipour, S. Ansari, S.A. Shah, A. Khalid, M.A. Imran, A review of the state of the art in non-contact sensing for COVID-19, Sensors 20 (19) (2020) 5665.
[51] A. Rahaman, M.M. Islam, M.R. Islam, M.S. Sadi, S. Nooruddin, Developing IoT based smart health monitoring systems: A review, Rev. d'Intell. Artif. 33 (6) (2019) 435–440.
[52] C.C. Azubuike, F. Couceiro, S.C. Robson, M.Z. Piccinni, J.E. Watts, J.B. Williams, A.J. Callaghan, T.P. Howard, Developing biosensors for SARS-CoV-2 wastewater-based epidemiology: A systematic review of trends, limitations and future perspectives, Sustainability 14 (24) (2022) 16761.
[53] C. Sohrabi, Z. Alsafi, N. O'neill, M. Khan, A. Kerwan, A. Al-Jabir, C. Iosifidis, R. Agha, World health organization declares global emergency: A review of the 2019 novel coronavirus (COVID-19), Int. J. Surg. 76 (2020) 71–76.

[54] N. Raimo, I. De Turi, F. Albergo, F. Vitolla, The drivers of the digital transformation in the healthcare industry: An empirical analysis in Italian hospitals, Technovation 121 (2023) 102558.
[55] B. Moazzami, N. Razavi-Khorasani, A.D. Moghadam, E. Farokhi, N. Rezaei, COVID-19 and telemedicine: Immediate action required for maintaining healthcare providers well-being, J. Clin. Virol. 126 (2020) 104345.
[56] A. Celesti, A. Ruggeri, M. Fazio, A. Galletta, M. Villari, A. Romano, Blockchain-based healthcare workflow for tele-medical laboratory in federated hospital IoT clouds, Sensors 20 (9) (2020) 2590.
[57] M. Bhatia, S.K. Sood, Internet of things based activity surveillance of defence personnel, J. Ambient Intell. Humaniz. Comput. 9 (2018) 2061–2076.
[58] A.C. Smith, E. Thomas, C.L. Snoswell, H. Haydon, A. Mehrotra, J. Clemensen, L.J. Caffery, Telehealth for global emergencies: Implications for coronavirus disease 2019 (COVID-19), J. Telemed. Telecare 26 (5) (2020) 309–313.
[59] K. Iyengar, S. Bahl, R. Vaishya, A. Vaish, Challenges and solutions in meeting up the urgent requirement of ventilators for COVID-19 patients, Diabetes Metab. Syndr.: Clin. Res. Rev. 14 (4) (2020) 499–501.
[60] E. Hernández-Orallo, P. Manzoni, C.T. Calafate, J.-C. Cano, Evaluating how smartphone contact tracing technology can reduce the spread of infectious diseases: The case of COVID-19, IEEE Access 8 (2020) 99083–99097.
[61] K.P. Iyengar, R. Vaishya, S. Bahl, A. Vaish, Impact of the coronavirus pandemic on the supply chain in healthcare, Br. J. Healthc. Manage. 26 (6) (2020) 1–4.
[62] R.P. Singh, M. Javaid, A. Haleem, R. Vaishya, S. Ali, Internet of medical things (IoMT) for orthopaedic in COVID-19 pandemic: Roles, challenges, and applications, J. Clin. Orthop. Trauma 11 (4) (2020) 713–717.
[63] M. Loey, G. Manogaran, M.H.N. Taha, N.E.M. Khalifa, A hybrid deep transfer learning model with machine learning methods for face mask detection in the era of the COVID-19 pandemic, Measurement 167 (2021) 108288.
[64] A. Haleem, M. Javaid, R. Vaishya, S. Deshmukh, Areas of academic research with the impact of COVID-19, Am. J. Emerg. Med. 38 (7) (2020) 1524–1526.
[65] M. Gupta, M. Abdelsalam, S. Mittal, Enabling and enforcing social distancing measures using smart city and its infrastructures: a COVID-19 use case, 2020, arXiv preprint arXiv:2004.09246.
[66] S. Bahl, R.P. Singh, M. Javaid, I.H. Khan, R. Vaishya, R. Suman, Telemedicine technologies for confronting COVID-19 pandemic: a review, J. Ind. Integr. Manage. 5 (04) (2020) 547–561.
[67] A. Kumar, K. Sharma, H. Singh, S.G. Naugriya, S.S. Gill, R. Buyya, A drone-based networked system and methods for combating coronavirus disease (COVID-19) pandemic, Future Gener. Comput. Syst. 115 (2021) 1–19.
[68] E. Christaki, New technologies in predicting, preventing and controlling emerging infectious diseases, Virulence 6 (6) (2015) 558–565.