Revista Brasileira de Inovação
ISSN 2178-2822
DOI: https://doi.org/10.20396/rbi.v22i00.8668109

ARTICLE

Applications of artificial intelligence to combat COVID-19: a technology prospection based on patents

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RECEIVED: 13 JANUARY 2022 REVISED VERSION: 19 SEPTEMBER 2023 ACCEPTED: 15 OCTOBER 2023

ABSTRACT

The COVID-19 pandemic and the consequent growth of scientific and technological research to fight it presents challenges for researchers who need to monitor the knowledge produced on this theme. Among these support technologies are Artificial Intelligence (AI) and its applications. This article presents a technology prospection to describe the technology landscape of AI applications in the fight against COVID-19. The study analyzed 350 patent families, which were organized into technology categories. The findings demonstrated a prevalence of patent filings from India, China, and the United States. Collaboration between countries and innovation organizations was not evident, unlike what was observed in academic collaborations in previous studies. There was a predominance of technologies in the areas of computing and medicine, that is, ICTs adapted for the treatment or processing of medical data with focus on identification, triage, diagnosis, and prediction of new outbreaks of the epidemic.

KEYWORDS | COVID-19; Artificial intelligence; Technology prospection

1. Introduction

In December 31, 2019, the World Health Organization (WHO) was warned about several cases of pneumonia in the city of Wuhan, province of Hubei, in the People's Republic of China. It was a novel coronavirus strain, which had not been previously identified in humans.

Soon after the WHO declared the COVID-19 pandemic, it signaled that Artificial Intelligence (AI) could be an important technology to manage the crisis caused by the Sars-Cov-2 virus (WORLD HEALTH ORGANIZATION, 2020).

The concept of AI was created in 1995 by John McCarthy, who defines it as: "Science and engineering of making intelligent machines, especially intelligent computer programs" (MCCARTHY, 2007). The AI is broadly used in medicine and it includes two branches: virtual and physical. The virtual branch comprises information as intelligent treatments related to the register of information for decision-making in treatments; the physical branch is represented by robots, which help in the support to patients and the performance of surgeries. There have been advances in the facilitation of use through solutions that utilize natural languages and algorithms, which use the knowledge acquired by means of the very use of solutions (HAMET; TREMBLAY, 2017). The technological evolution enables the increase of its availability and use by health professionals.

In this article, the concept of Artificial Intelligence encompasses Machine Learning (ML), which has Deep Learning (DL) as a more specific capability, and the artificial neural networks constitute the backbone of their algorithms. For Adadi et al. (2022), DL and ML methods are dominating the AI scenario dedicated to combating the coronavirus. According to Abd-Alrazaq et al. (2020), AI techniques used in the fight against COVID-19 often utilize models and DL algorithms related to artificial neural networks.

In this context, World Health Organization (2020) publicized six principles to ensure that AI works in the public interest of all countries, which are: protect human autonomy; promote human wellbeing and safety and the public interest; ensure transparency, explicability, and intelligibility; promote responsibility and accountability; ensure inclusion and equity; and promote AI that is responsive and sustainable. Such principles seek to limit the risks and maximize opportunities intrinsic to the use of AI, besides contributing to the regulation and governance of AI application in the health area.

The emergence of COVID-19 pandemic presented and still presents challenges for researchers and organizations on the monitoring of knowledge produced in several areas of knowledge necessary for the development of efficient solutions to mitigate the problem.

Recent studies have demonstrated that AI is a promising technology employable in various sectors, such as process industries, agriculture, banking, computing and health (WIRTZ et al., 2019; LIU et al., 2019; ABDULJABBAR et al., 2019). This technology is also applied in several fields in the health area, presenting timely, trustworthy and efficient outcomes, sometimes surpassing humans in conducting specific tasks (COECKELBERGH, 2010; NADARZYNSKI et al., 2019; WAHL et al., 2018). Despite its deficiencies, AI has the possibility to potentiate the efforts of humans, who otherwise would be overburdened with the high number of patients (CHEN; SEE, 2020).

Chang et al. (2021) state that AI technology is being gradually directed from the laboratory to clinical and public health applications, as in the cases of early warning of epidemics outbreaks and intelligent analysis of large medical data.

Among the various AI applications in the fight against COVID-19 pandemic, one can highlight the identification, triage and diagnosis of the virus, reuse or repurposing of drugs, and prediction of new surges of COVID-19 (AHUJA; REDDY; MARQUES, 2020; BECK et al., 2020; MOHANTY et al., 2020; MONSHI; POON; CHUNG, 2020; SIPIOR, 2020; VAISHYA et al., 2020). Technologies based on AI improve the detection of the virus, presenting higher precision and efficiency, besides enabling more effective treatment (ALBAHRI et al., 2020; SWAPNAREKHA et al., 2020; SUFIAN et al., 2020).

The vast international literature produced due to the pandemic attracted the attention of the scientific community in the search of methods based on trustworthy data, in order to discover useful knowledge that responds to specific research issues. Examples of such issues are: investigate the reaction of scientific communities to the COVID-19 crisis (ZHANG et al., 2020); identify international collaboration patterns (FRY et al., 2020; GRAMMES et al., 2020; YANG et al., 2020); and outline the profile of researches related to COVID-19 from a scientometric perspective (ABD-ALRAZAQ et al., 2020; COLAVIZZA et al., 2020; DOANVO et al. 2020; LALMUANAWMA; HUSSAIN; CHHAKCHHUAK, 2020; PICCIALLI et al., 2021; TAYARANI; MOHAMMAD, 2021).

Abd-Alrazaq et al. (2020) verified that in the context of COVID-19, AI has been used for five purposes: diagnosis, treatment, and discovery of vaccines, epidemiologic modeling, tasks related to the patient's outcome, and infodemiology.

However, Bullock et al. (2020) and Lalmuanawma et al. (2020) pointed that few of the solutions identified in literature reviews presented operational maturity. Hence, it is important to define a research and study trajectory of AI applications, as to understand how this technology can contribute in the short term and in combating future pandemics.

In Brazil, specifically regarding the use of AI, some studies have sought to present answers to possible applications, based on bibliographical review (FREITAS et al., 2020).

In addition to these studies and as far as we know in an unprecedented way, the present study seeks to answer the following research questions, drawing on a patentometric investigation, i.e., on the state-of-the-art techniques through patents:

- Does the research related to the use of AI to combat COVID-19 constitute one or several communities of research and technology innovation? How are the main players connected (organizationally and individually)?
- What patterns of collaboration between countries determine the transfer of knowledge and technology?

- What types of application are being developed? How can they be grouped?
- How did the temporal evolution occur in the production of AI technologies applied to the fight against COVID-19?

As suggested by Porter et al. (2020), the answers to these questions are initially grouped into four basic questions related to the development of AI applied to solutions for COVID-19: Who? Where? When? What?

The aim of this research was to describe the technology panorama of AI applications in the combat against COVID-19.

Among the literature on COVID-19, few studies have analyzed the relevance of AI and the patents that can provide useful information about the area. This study offers an overview of recent patents that deal with aspects of identification, triage and diagnosis of the virus, reuse or repositioning of drugs, and prediction of new COVID-19 surges.

The outcomes of this research may be useful for governmental authorities and other entities interested in the role of intellectual property rights, especially patents, as means of protection or access to the developed technologies.

2. Methodology

The methodology adopted for this prospection study was characterized as descriptive, with quantitative and qualitative analyses using a patentometric approach, drawing on available data from patents filed with several intellectual property offices. These are covered by the Questel Orbit Intelligence platform, used in this research due to its geographic coverage, comprising publications of almost a hundred countries and patent authorities (EPO, WIPO, ARIPO, etc.).

The database of the sample was developed using as search expression: (ARTIFICIAL INTELLIGENCE OR MACHINE LEARNING OR DEEP LEARNING OR NEURAL NETWORK)/TI/AB/CLMS AND (COVID_19 OR CORONA_VIRUS OR 2019_NCOV OR SARS_COV_2 OR “MERS-COV” OR “SEVERE ACUTE RESPIRATORY SYNDROME”

OR “MIDDLE EAST RESPIRATORY SYNDROME”)/TI/AB/CLMS) AND ((PDA =2019-12-01:2021-12-31)). Data were collected in December 2021. The only fields used were “Title – TI”, “Abstract – AB” and “Claims - CLMS” in order to capture with greater specificity the technologies and their applications, as defended by Milanez et al. (2017). The search terms were compiled drawing on the literature review of studies on the same theme based on scientometrics – e.g., Naudé (2020); Gunasekeran et al. (2021); Tayarani and Mohammad (2021); Piccialli et al. (2021); Wang et al. (2021); Khan et al. (2021) – with the purpose of broadening the range of outcomes with relevant technologies.

In order to describe a technological sector (or a set of technologies), patentometrics uses several data found on the patent documents, specifically on the fields defined by the INID (acronym for Internationally agreed Numbers for the Identification of Data) codes, which identify all data comprised on the cover sheet. Because they are explicitly found on the patent document, data obtained from the direct analysis of INID codes are named primary indicators (SPEZIALI; NASCIMENTO, 2020). The indicators used in this research were as follows:

2.1 When?

- Temporal series (TS): assessment of worldwide filings of patent families through time. The first year of filing is the most indicated for this use, because it refers to the closest date to the creation of the technology.

2.2 Where?

- Technology Centers (TC): uses data of the office where the oldest filing occurred. This analysis is related to the place of origin of the technology.
- Protection Market (PM): assessment of potential PM, made through the analysis of countries where the total filings of patents occurred (including the children patents, i.e., all patents belonging to the same family).

- Analysis of Triadic Patents (ATP): a triadic patent is defined by the Organization for Economic Co-operation and Development (OECD) as a set of patents simultaneously registered at the three major patent offices – Japan Patent Office (JPO), European Patent Office (EPO) and United States Patent and Trademark Office (USPTO).

2.3 Who?

- Most active applicants (top10, top5, top3, etc.) of the technology or sector under analysis.

2.4 What?

- Technical Areas (TA): The IPC and CPC codes, acronyms that stand for International Patent Classification and Cooperative Patent Classification, respectively, are the main classification tools according to the fields to which the filings are associated. In this sense, besides the analysis of classification, this study also conducted the analysis per technological domain. The Questel Orbit Intelligence groups the codes of Industrial Property in 35 fields of technology. The categorization per technological domain are groups according to the IPC of the analyzed group of patents.

3. Results and discussion

There were 350 patents found with the search argument used. The analyses that follow are concentrated on the analytical categories presented in the methodology section (When? Where? Who? What?) and seek answers to the research questions presented in the introduction of the article.

3.1 Basic analyses

3.1.1 When?

This section seeks an answer to the question: how was the temporal evolution of the AI technologies applied in the combat against COVID-19? The research identified 350 patent families, according to the distribution of years, as presented on Chart 1.

Initially, it is important to justify why the sample shows patents filed before the emergence of COVID-19 pandemic. These are applications submitted to the USPTO, where it is allowed to have a "continuation", i.e., a new request that enables additional claims based on the same description and priority date of a previous pending application. This type of resource is a flexible and useful tool to promote several business objectives, such as to claim the protection of improvements developed after the previous application of a filing.

Another important point is that due to the time lapse between the filing and the publication of a patent, it is quite usual that the count of published patents presents a decrease in the last two years of a temporal series. On the other hand, the pandemic might have served as a reason for applicants to request the voluntary anticipated publication of patent applications involving technologies related to diagnosis, prevention and treatment of COVID-19.

CHART 1
Patent families

1st year of filing	Patent families
2017	1
2018	1
2019	2
2020	159
2021	187
Total	**350**

Source: Authors elaboration drawing on Questel Orbit Intelligence (2022).

The anticipated publication can facilitate collaborations, partnerships or joint ventures, negotiations and competitive advantages to the various interested parties.

Therefore, it is possible that researches conducted in the future with the same search argument might show different results, because the panorama of patents is dynamic due to the movements of full publication of patents, legal disputes, and analyses of requests, among other reasons.

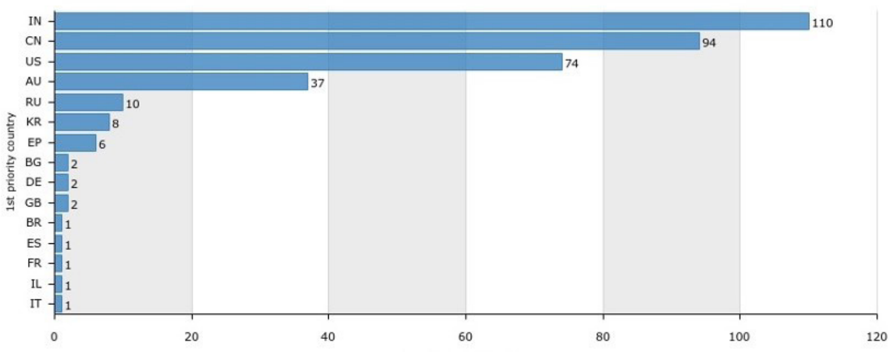
3.1.2 Where?

This section presents possible answers to the question of patterns of collaboration between countries and their influence in knowledge and technology transfer.

The analysis of TCs is related to the place of origin of the technologies. Figure 1 shows that a small number of countries were identified in the sample as producers of AI technology with solutions for COVID-19.

The quantitative analysis shows that the leading countries in the production of technologies are India (IN) with 110 patent families, China (CN) with 94, United States (US) with 74, and Australia (AU) with 37.

FIGURE 1
Patent families per 1st priority year.



Source: Questel Orbit Intelligence (2022).

The other countries in the sample have a maximum of 10 patent families. In the case of Brazil, for instance, the only patent to be highlighted is "Spectral profile for the diagnosis of COVID-19, its use, method, system and COVID-19 diagnosis platform", filed jointly by ImunoScan Engenharia Molecular and Federal University of Uberlandia (UFU).

Although the number of AI patents of Indian ownership is small in comparison with AI research production, India is among the 10 main countries producers of AI patents that experienced a high increase of filings of this type of patent since 2012, boosting a fast growth of inventions related to this technology. This is a significant conquest, considering that India had no AI patent before 2002.

The four major categories of AI patents in India are personal devices, computing, businesses, telecommunications, and life sciences, which represent 70% of AI patents in the country, and indicate that the Indian inventors are concentrates in AI applications in traditionally strong areas.

According to Chahal et al. (2021), India has evolved in AI patenting in the past two decades. The first reason is that the country has updated its patent system and, additionally, because the firms started to realize the benefits of using patents in order to protect their innovations. Moreover, the unrestricted support from the government and venture capital funds are some of the factors that explain this dynamics (RAIBAGI, 2023).

India still has a long trajectory ahead to reach China and the US, presently the prevailing sources of AI patents in a broad sense.

Another necessary analysis refers to the PMs, i.e., in which countries are the patent rights active (pending or granted).

This analysis can be performed drawing on the fields of patent families or International Patent Documentation (INPADOC). It is known that the main objective of a patent is to prevent a competitor from using a technology without the previous authorization of its holder. Thus, a given technology is filed in places considered as a market where competition must be prevented (SPEZIALI; NASCIMENTO, 2020).

Chart 2 presents the MPs. It shows the predominance of patents filed in India (IN), corresponding to 31.43% of the total, China (CN) corresponding to 26.86%, United States (US) corresponding to 21.14% and Australia (AU) corresponding to 11.52%, besides those under the Patent Cooperation Treaty (PCT), administered by the World Intellectual Property Organization (WIPO), filed at the EPO, corresponding to 20.57%.

Several studies have verified that there was a correlation between the number of confirmed cases of, and obits from, COVID-19 per region and the production of scientific research. According to Piccialli et al. (2021), Iran, Turkey, Egypt, USA, China, India, Italy and United Kingdom are among the ten countries presenting the highest number of peer-reviewed articles addressing the application of AI technologies for COVID-19 issues.

A relation is likely to be found also between PMs and countries with higher incidence of cases of COVID-19 (Table 1). These countries are the United States, India, Brazil, United Kingdom and Russia, as demonstrated on Figure 2.

It is observed that, although Brazil is ranked second in the number of cases worldwide, it occupies the 11th position on the list of countries with the highest number of technologies that seek protection.

CHART 2
Patent protection markets (PM)

#	COUNTRY / REGION	No. of PATENTS	#	COUNTRY / REGION	No. of PATENTS
1	IN – INDIA	109	**8**	KOR - Korea	6
2	CN – CHINA	93	**9**	DE - Germany	3
3	WIPO - PCT	57	**10**	BG - Bulgaria	2
4	US - USA	56	**11**	BR - Brazil	2
5	EP - Europe	47	**12**	FR - France	2
6	AU - Australia	40	**13**	CA - Canada	1
7	RU - Russia	10	**14**	ES - Spain	1
			15	TW - Taiwan	1

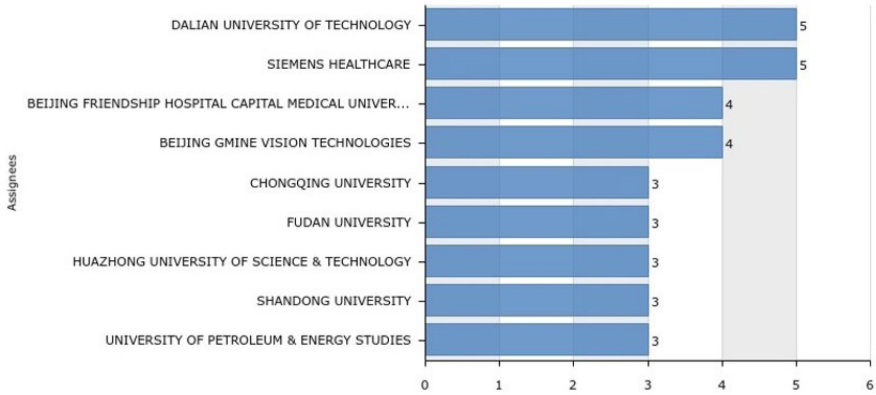
Source: Authors elaboration drawing on Questel Orbit Intelligence (2022).

TABLE 1
COVID-19 cases per country

	COUNTRY	DEATHS	CASES		COUNTRY	DEATHS	CASES
1	**United States**	1,111,678	102,614,774	11	**Indonesia**	160,838	6,731,304
2	**Brazil**	697,439	36,878,774	12	**Iran**	144,764	7,564,881
3	**India**	530,745	44,684,768	13	**Colombia**	142,244	6,355,135
4	**Russia**	387,364	21,695,239	14	**Argentina**	130,437	10,040,329
5	**Mexico**	332,479	7,390,230	15	**Ukraine**	119,018	5,682,693
6	**Peru**	219,205	4,482,629	16	**Poland**	118,748	6,383,225
7	**United Kingdom**	216,887	24,293,752	17	**Spain**	118,712	13,740,531
8	**Italy**	187,272	25,488,166	18	**South Africa**	102,595	4,057,211
9	**Germany**	166,292	37,842,223	19	**Turkey**	101,492	17,042,722
10	**France**	164,496	39,583,176	20	**China**	87,468	2,023,904

Source: Our World in Data (2023).

FIGURE 2
Major applicants.



Source: Questel Orbit Intelligence (2022).

This aspect points to the lack of interest from innovators to protect their innovations in the Brazilian market, signalizing that it does not configure a potential market for commercialization, import or production of such technologies. On the other hand, it does signalize the possibility of free exploitation of those technologies in the country.

The position of Brazil in terms of patents is even lower. Considering global data on patent filing in December 2022 database, Brazil was in the 25th position in 2021, with 6,902 filed patents. The first country in this raking is China, with over one and a half million patents, followed by the US, Japan, South Korea and Germany, all with over one hundred thousand filings. In computational technologies, the same countries are in the leading positions and Brazil has the 29th position, with 118 filings (WORLD INTELLECTUAL PROPERTY ORGANIZATION, 2023).

Although China is at the top of the PM list, the officially registered number of cases and deaths of COVID-19 is considerably lower than the numbers in Brazil. However, the COVID-19 pandemic highlighted the strong dependence of western countries in relation to equipment and medical inputs produced in China (RAPCIEWICZ; BURESH, 2020) and this fact might partially explain the market protection in that country.

Finally, there was no identification of triadic patent families. Because of the high investment required to make simultaneous filings at the three main international offices (USPTO, EPO, JPO), this is not a common procedure, unless there is an actual interest in exploring the technology (SPEZIALI; NASCIMENTO, 2020). This might be an indicator of the low innovation potential of several patents of the sample.

3.1.3 Who?

Does the research related to the use of AI to combat COVID-19 constitute one or several communities of technology research and innovation? What is the connection like between the main players (organizationally and individually)? In order to answer these questions, this section analyses the main participants (organizations and inventors) of the sample under study.

Figure 2 presents the 10 most frequent applicants/holders in the sample (with three or more patent families).

The predominance of academic institutions (universities) is noticeable, especially in China. This is congruent with the findings of other studies on the same theme. In a review conducted by Abd-Alrazaq et al. (2020), Chinese institutions published half of the analyzed works. As SARS-CoV-2 virus originated in China and affected the country during the first three months of the pandemic, it had the majority of available data related to COVID-19 and this led it to pioneer the researches on the theme.

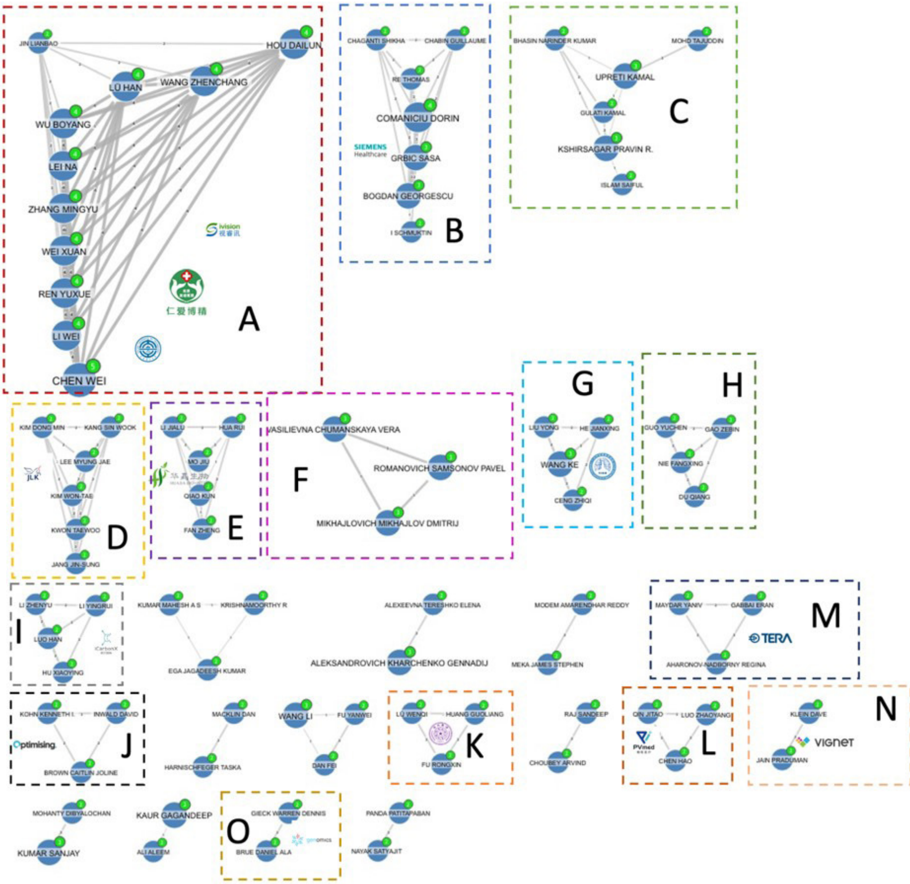
Furthermore, this finding can provide a perspective on the global dimension of research on the pandemic. Piccialli et al. (2021) state that the extensive knowledge of AI methodologies in the USA, on the one hand, and the availability of data in China, the country that experienced the first surge of the pandemic, on the other hand, can explain the central role of these two countries in the scientific production worldwide.

Thus, the direct impact of the pandemic boosts scientific research with AI methodologies applied in situations related to COVID-19, and there is a strengthening of the collaboration between countries because of the shared interests in finding efficient strategies to curb the crisis in many different fields (PICCIALLI et al., 2021). However, it is important to analyze whether this pattern of collaboration found in research (production of scientific papers) is also found in technology development (production of patents), which is the focus of this study.

In order to provide part of the answer to this question, Figure 3 shows the interactions between inventors (co-inventions) and the researchers of the thematic area. This type of graph highlights the main inventors linked to the teams.

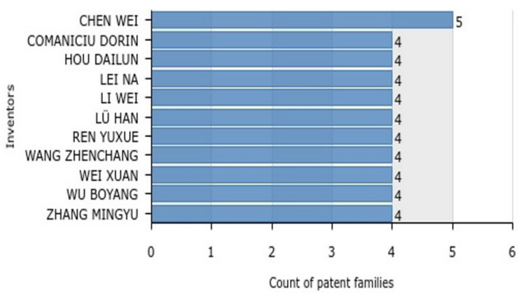
Figure 4 illustrates the networks of co-inventions of the sample. The groups signalized with colored dashed lines and marked with letters (A to O) are those with institutional interactions (group B, e.g., represents inventors of Siemens Healthcare present in the sample). The blue circles represent the inventors and the size indicates the number of respective patents, signalized by the numbers inside the green circles next to the blue ones. The connections between inventors indicate the amount of partnerships (patents with co-ownership). The other relationships (not signalized as groups) are of patents filed by natural persons and it was not possible to verify the inventors' professional link.

FIGURE 3
Interactions between inventors.



Source: Authors elaboration drawing on Questel Orbit Intelligence (2022).

FIGURE 4
Inventors with more filed patents.



Source: Questel Orbit Intelligence (2022) Platform.

It can be verified that most of the interactions occur among research groups within universities or firms, signalizing inner P&D (Planning and Development), with limited interinstitutional collaboration.

Figure 4 shows that the inventor with the greatest number of patents is Wei Chen, having five patent families with Chinese priority. There are interactions with all the other Chinese inventors with more than four patents – represented by group A on Figure 3. Because the Chinese patents are translated by the platform and due to the similarly of names and surnames, it was not possible to verify precisely the institutional link of each inventor. The issue of disambiguation of Chinese names has been pointed as one of the greatest challenges for bibliometric and patentometric studies (YIN; MOTOHASHI; DANG, 2020).

The non-Chinese inventor with the greatest number of filed patents in the sample is Dorin Comaniciu, a Romanian-American computer scientist. He is the Senior Vice-President of Artificial Intelligence and Digital Innovation at Siemens Healthcare, and can be seen on group B on Figure 4.

The international collaboration for the development of technologies was not found in the sample; this is different from the findings of collaboration in academic research, according to Grammes et al. (2020) and Yang et al. (2020). These studies verified a correlation between the confirmed cases, or obits, of COVID-19 per region and the production of scientific research.

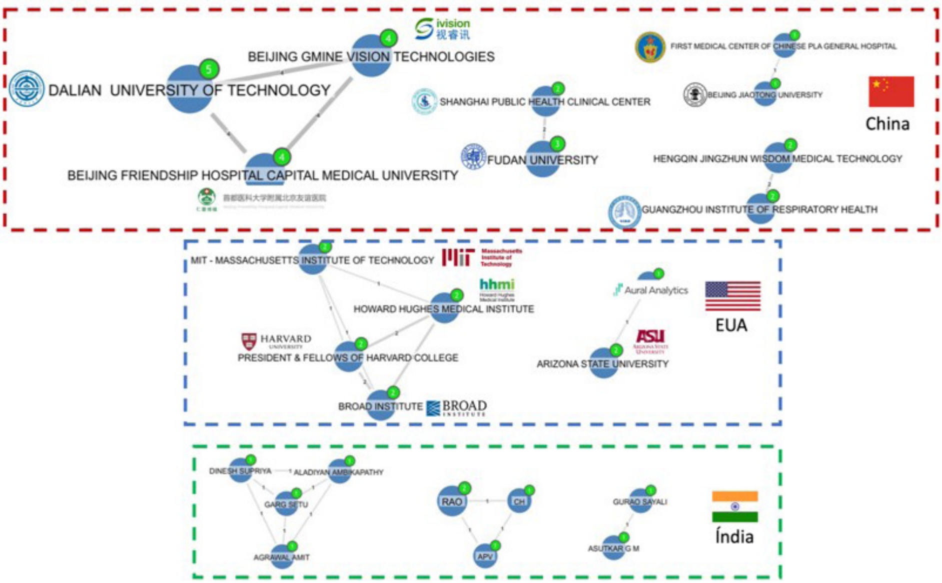
According to Grammes et al. (2020), the United States had more active researchers in collaborative efforts, sharing a significant number of manuscript authorships with the United Kingdom, China e Italy.

Additionally, Yang et al. (2020) also verified that the United States were the most frequent collaborative partners of China, followed by the United Kingdom. According to these authors, besides the cooperation with the United States, China also collaborated with Germany, United Kingdom, Italy, Colombia, Canada and Japan. The United States cooperated in researches with Japan, Canada, United Kingdom, Italy, Australia and France.

In sum, although each process implies different dynamics of collaboration and knowledge protection, thus the comparison is limited, it is known that many countries had collaborative relations during the phases of research or funding, whereas there was little cooperation regarding the materialization of patent ownership and this seems to indicate that the technological research on COVID-19 was still conducted within each country. This can be further observed on Figure 5, presenting the co-ownerships found in the sample.

In Figure 5, the groups signalized by rectangular dashed lines represent the countries of origin of the patent owner institutions. The blue circles indicate the organizations with the respective amount of patents, which are indicated inside the green circles next to them. The digits on the connection lines indicate the number of common patents between institutions. Figure 5 evinces the type of collaboration between different types of organizations, highlighting the role of universities and research centers.

FIGURE 5
Co-ownerships found in the sample.



Source: Authors elaboration drawing on Questel Orbit Intelligence (2022).

The origin of the collaboration between different organizations does not have as a frequent reason the sharing of patents. When analyzing the relations between European universities, in the sphere of collaborative projects, few of them originated from patents developed by one of the partners (CAVIGGIOLI et al., 2023). The collaboration between organizations, especially between companies and universities, is something desirable. Among the results found in the ample research on AI, it is also identified the development of AI open innovations, aiming to facilitate the diffusion of knowledge and the broadness of its utilization. The results of the research make explicit a low level of collaboration (WORLD INTELLECTUAL PROPERTY ORGANIZATION, 2019). The research shows that before the start of COVID-19 pandemic the collaboration between different organizations in AI was low.

Although it is not possible to state that there was no external collaboration of other kind or during stages of previous researches (e.g., bench research), it is verified that the few existing collaborations (represented by co-ownership of patents) are restricted to organizations within the same country.

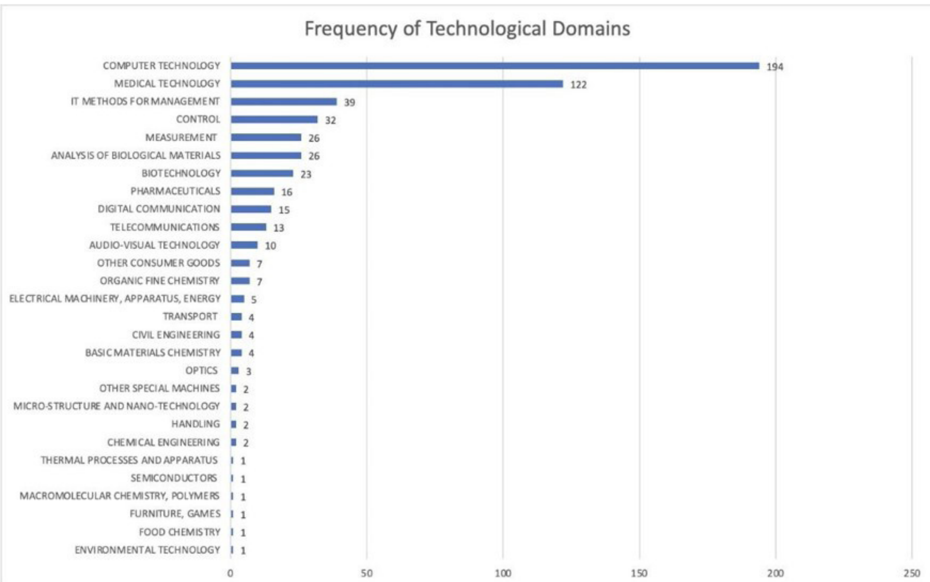
To exemplify the collaboration outside the universe of patents, one can mention some experiences, such as the Chinese technology giant Baidu, in partnership with the Oregon State University and the University of Rochester, which published its prediction algorithm Linearfold, in February 2020, to speed up the discoveries about the structure of the secondary ribonucleic acid (RNA) of a virus and provide scientists with additional data on how viruses are spread. On the other hand, DeepMind, a subsidiary of the corporate matrix of Google, Alphabet, also shared its predictions of coronavirus protein structures with its system AlphaFold AI. IBM, Amazon, Google and Microsoft also provided computational capacity of their servers to US authorities, to process very large data sets in epidemiology, bioinformatics and molecular modelling (EUROPE, 2020).

3.1.4 What?

From the analysis of the predominant technological domains in the sample, the following list of terms frequency was obtained, as shown on Figure 6.

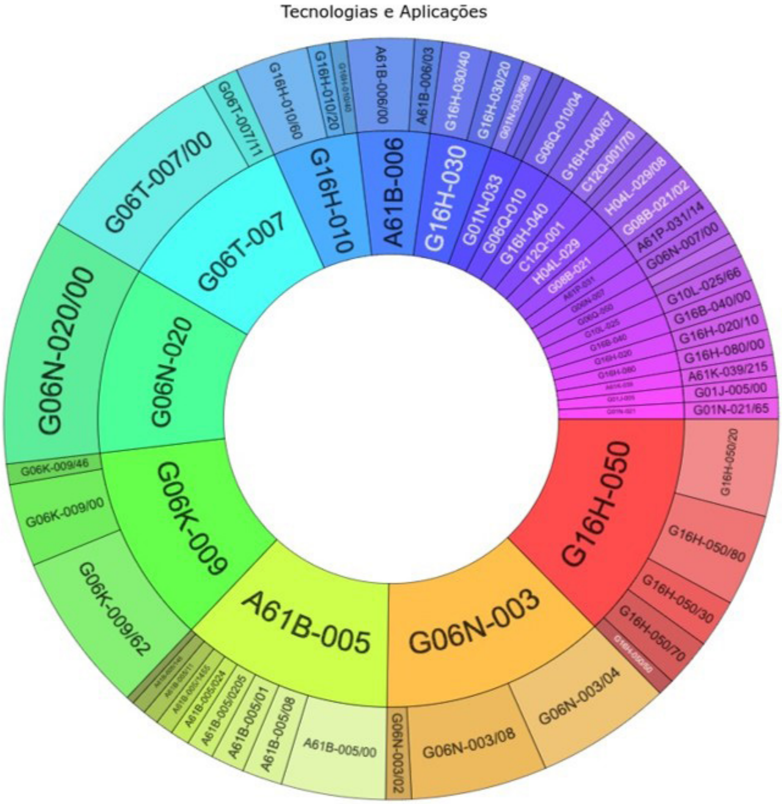
Therefore, the predominance of technology applications in the areas of computing (194 occurrences) and medical (122 occurrences) became evident. However, in order to answer how the technologies can be grouped (and how they can be related), an analysis of the Technical Areas (TA) was conducted using the Cooperative Patent Classification (CPC) codes. The CPC is the classification system developed jointly by EPO and USPTO, and it has around 200 thousand groups. With the CPC code, once the group to which the patent application belongs has been identified, it becomes easier to identify other patent filings related to the same purpose. Figure 7 presents an overview of the technologies and applications of the sample.

FIGURE 6
Frequency of technological domains of patents in the sample.



Source: Questel Orbit Intelligence (2022) Platform.

FIGURE 7
Technologies and Applications of the Sample.



Source: Questel Orbit Intelligence (2022) Platform.

The analysis found a predominance of subclasses CPC G16H (107 patents), G06N (69 patents), A61B (59 patents), G06K (42 patents) and G06T (36 patents). Due to the hierarchised organization of the patent classification system, it is necessary to perform a more detailed analysis to decipher the predominant CPC codes.

The CPC G16H-050 represents 30.57% of the sample's technologies (107 patent families). This classification covers the Information and Computer Technologies (ICTs) especially adapted for monitoring, detection or modeling of epidemics or pandemics. It also covers all issues related to medical and clinical diagnoses, health or diagnostic decisions, processing of diagnostic data and processing of data for diagnostic support.

In addition, all algorithms or methods for medical and clinical decisions, and those related to health or wellbeing and that support such decisions. Furthermore, all types of scoring, calculation of rates, risks or values related to health, and body, physiological and psychological parameters.

More specifically, stands out the CPC G16H-050/2, representing 18% of the technologies, with 63 classified patents. This group refers to ICTs especially adapted for medical diagnosis or computer-aided diagnosis, e.g., based on specialized medical systems. It covers all AI or heuristics used to support, assist or automatize the diagnosis or data analysis for diagnostic purposes. In addition, it encompasses the computer-assisted medical decision-making. In this sense, Tayarani and Mohammad (2021) conducted a review on the applications of AI to assist medical professionals in decision-making, e.g., algorithms developed for automatic identification of patients' clinical characteristics in order to predict who tends to develop severe symptoms.

Also worthy of note is the CPC G16H-050/80, representing 15.43% of the technologies, with 54 classified patent families. It covers the ICTs used to monitor, detect or model epidemics or pandemics, e.g., for warnings about Influenza, Ebola, HIV or even bioterrorism. It also encompasses medical data mining for the detection of unusual health patterns in geographical regions or population groups. In this sense, Abd-Alrazaq et al. (2020) highlight that research on AI with this purpose can help to predict the development of the pandemic (e.g., number of confirmed, recovered, deaths, suspected, asymptomatic and critical cases, and the finishing time of the pandemic).

Other technologies were classified in the group CPC A61B-005, representing 17.71%, with 62 patents. This category includes devices, instruments, implements or processes exclusively intended to evaluate, examine, measure, monitor, study or test specific characteristics and aspects of living or dead bodies, human and animals, for medical purposes. In particular, stands out the application for measurement for purposes of diagnosis and identification of persons (A61B-005/00), e.g., by automatized measurement of body temperature in checkpoints at airports, train stations and other places in the cities PICCIALLI *et al.*, 2021).

The CPC G06N includes computing systems not based on traditional mathematical models. Specifically, the G06N-003, representing 17,71% with 62 patents, comprises systems in which computation is based on biological models (brain, intelligence, consciousness, genetic reproduction) or uses physical material from biological origin (biomolecules, DNA, biological neurons, etc.) to perform computation, whose calculation can be digital, analogical or chemical. This classification is specific for neural networks, because in computing science (and related fields) the artificial neural networks are computational models inspired by an animal's central nervous systems and are capable of performing machine learning and recognition of patterns.

Another predominant CPC in the sample is G06K-009, representing 14.57%, with 51 patents. It is related to the reading of data from graphs and covers the processes of patterns recognition by means of electronic devices. Several studies point that medical images are broadly used as entry parameter for ML and DL models (KHAN et al., 2021; ADADI; LAHMER; NASIRI, 2022; TAYARANI e MOHAMMAD, 2021). According to these authors, medical imaging will become increasingly more important, especially where access to RT-PCR tests is scarce or unavailable due to the lack of resources. In addition, imaging responds to more formal procedures and is less dependent on the operator's experience.

The fact that COVID-19 effects are visible on medical imaging and exams enables the monitoring of its severity and progression. The result of the RT-PCR test, on the other hand, does not reveal the magnitude or the stage of the disease. Medical images (tomography and X-ray) perform an important role in the treatment and control of COVID-19 and were recognized as the most sensitive modalities of imaging for the recognition of abnormalities due to the high sensibility and easy access (KHAN et al., 2021).

It was verified that, in practice, these technologies can be used by different governments to combat COVID-19 (and other epidemics), including (CHEN et al., 2022):

- Diagnosis: AI algorithms can help to identify symptoms and predict the evolution of the disease in patients with COVID-19, helping health professionals to provide a more precise treatment. Some governments have used COVID-19 triage systems based on AI at airports and other entry spots to identify potential COVID-19 cases;
- Epidemics monitoring: AI technologies, as natural language processing, can help to monitor and analyze large data amounts, including public health data, to identify tendencies and predict the propagation of the disease. This can help governments in improving decision making on the implementation of control measures of the pandemic;
- Health resources managing: AI technologies can help in the management of health resources distribution, such as hospital beds, personal protection equipment and medicaments, to ensure that they reach the most needed locations. Some governments have used AI based solutions to help in the management of distribution of medical supplies during the pandemic;
- Contact tracing: Some governments have used AI based technologies to trace contacts of persons who tested positive for COVID-19, helping to contain the spread of the disease;
- Development of treatments and vaccines: AI algorithms can help to identify promising compounds and molecules for the development of treatments and vaccine against COVID-19. Some governments have invested in research programs based on AI to speed the development of treatments and vaccines.

Kumar and Sharma (2020) conducted a survey on AI applications through different governments. India used robots and drones for food supply, medicaments delivery, software and population management by means of AI sensors. Singapore compiled data measured by mobile phones and geo-localization to monitor the population for social distancing. China used AI for mass surveillance; also, intelligent devices were used for temperature tracing to identify the infection from COVID-19, such as 'intelligent' helmets capable of signaling individuals with high body temperature and devices with face recognition utilized to detect the use of masks.

The same authors highlighted that Israel used AI resources to alert people about social distancing, he use of masks and geo-localization tracing. South Korea used AI applications for social distancing, especially at busy places, such as public transport, shopping centers, by means of data collection and data providing to governmental agents. The government of Taiwan provided mobile phones to infected patients and traced their geo-localization to provide information to the police to tracing their movements and social distancing.

In Italy, a smartphone application developed to trace the trips history of an individual infected with the virus was used to alert those with whom the person had contact. Finally, the US government, in collaboration with AI companies, collected aggregate and anonymous data in mobile phones to avoid the virus propagation (KUMAR; SHARMA, 2020).

4. Conclusion

AI is a promising technology and is widely used in various sectors, including in health care. The aim of this article was to describe the technology panorama of the applications of AI in the fight against COVID-19 pandemic.

The first step was to demonstrate the temporal evolution of technology production through the filing of patents. It was observed that, although in general there is a gap in patents data due to the difference of 18 months between the application for a patent and its publication (invention confidentiality period), in the context of Covid-19 there were several requests to anticipate the publication. This indicates the urgency to make available the technologies developed, due to the global demand and to commercial strategies of anticipated negotiation of technologies.

The next step was to analyze the patterns of international collaboration for the development of solutions. From the analysis of the TPCs, it was observed that there was a small number of countries identified in the sample as producers of AI technology with solutions for COVID-19 and those were basically the same PM.

In terms of quantity, the leading countries of technology production are India, China, United States and Australia. It was verified that there is little, almost inexistent, cooperation regarding patent ownership and that the countries keep their isolation when conducting the development of AI technologies for COVID-19. Thus, the analysis did not identify international collaboration.

Another aspect of the discussion was the identification of communities of technology research and innovation on the use of AI in the combat against COVID-19 and the analysis pointed to the predominance of academic institutions (universities), especially Chinese. No collaboration for the development of technologies was found in the sample. This indicates that, although the organizations might have collaborative relations in research and funding (this can be seen from articles published in scientific journals), there is little cooperation regarding the materialization of patent ownership and the research on COVID-19 is still conducted by P&D inner teams, in contrast to the tendencies of adoption of open innovation strategy.

Finally, the study verified the predominance of technologies in the areas of computing and medicine. More specifically, health informatics, i.e., Information and Communication Technology (ICT) adapted the treatment or processing of medical or health data; computational arrangements based on specific computational models; technologies of diagnosis, surgery or identification to be used in medical procedures, and reading of data from graphs and processing of imaging data. All of these applications were found in previous studies that conducted systematic reviews or used bibliometric techniques to analyze scientific publications.

This study draws on the consideration that the world health system needs new technology support systems, such as Artificial Intelligence (AI), Internet of Things (IoT) and machine learning devices that help to diagnose, analyze, assist and prevent new diseases that spread throughout the world. It was verified that AI technologies were introduced the improvement of the management of patients, to enable real-time monitoring of their clinical condition and update patients data.

On its turn, this reflects on the improvement of treatment outcomes, by prioritizing patients and the diagnostic process, assisting health professionals and providing productive solutions.

Moreover, AI is configuring as an important tool to help with the construction of a coordinated response to COVID-19 pandemic. Its multiple uses also exemplify the limits of what can be presently achieved by this technology.

In view of this scenario, it is impossible to ignore the role of Intellectual Property Rights (IPRs). On the one hand, it is stated that companies need protection to direct their financial and technical resources for the development of new solutions. On the other hand, it should be taken into consideration that public resources are strongly allocated to support research and that, in a critical situation as one of a pandemic, the IPRs may hamper the dissemination and access to technologies.

Finally, by the end of the crisis, there should be the possibility of an evaluation of the adopted emergency measures, with the purpose of identifying the benefits and the problems encountered with the use of digital tools and AI. In particular, the temporary measures of mass population control and monitoring by this technology should not be trivialized nor become permanent.

In line with this thought, norms regarding data protection, as the General Data Protection Law (LGPD) in Brazil, should be fully applied in all circumstances: use of biometric data, geopositioning, facial recognition or use of health data. The use of emergency measures should be conducted in full consultation with data protection authorities and respect the dignity and privacy of users. The different aspects (positive and negative) of the various types of surveillance operations should be considered.

In sum, the main results of the research regarding the use of AI in the fight against COVID-19 are:

- There were 350 families of patents identified related to the use of artificial intelligence in the fight against COVID-19.
- Most of the patents were filed by companies and institutions in India, China and the United States.

- No significant collaboration was found between governments and innovative organizations.
- The main areas of artificial intelligence application focus on identification, triage, diagnosis and prediction of new epidemics outbreaks.

The limitations of this research should be pointed out. First, due to practical issues, the research was restricted to patents in English (or translated to English by automatized processes on the Questel Orbit Intelligence platform). Therefore, it is likely that patents written in other languages, such as Portuguese, were not included in the sample. The search expression used in the research did not include terms related to specific models or algorithms, such as Support Vector Machine (SVM), Linear Regression, Logistic Regression, Decision Tree, etc. Thus, it is likely that it did not include some patents that used these terms on the title, abstracts or claims, instead of the terms used in this study (AI, ML and DL).

The conclusions of this research are based mainly on patents pending on analysis, with the probability that they will not be granted for lack of some requirement (novelty, inventive activity and industrial applicability).

Although this research has quantitatively analyzed around 350 patent families, their quality was not evaluated, because this was not included in the scope of the study. Therefore, further analyses are needed to assess the quality of the sample's patents, especially in terms of patents effectively granted by the different patent authorities.

Many important players and technologies may have been left out of the sample for not having directly specified the application for COVID-19 in the patent claims, i.e., the technologies might have been protected for a broader scope, therefore there is no mention to the search terms used to compose the sample. It is also noteworthy that several technologies are not subject to protection through patent, such as software.

Having considered all these factors, it is believed that this paper will help researchers, research and development institutes, health organizations and public policies managers with new insights on how AI can control the COVID-19 pandemic and conduct researches and additional studies to mitigate the present pandemic and future ones.

Acknowledgements

To FAPEAM – This work was developed with the support of the Government of the State of Amazonas through the Research Support Foundation of the State of Amazonas.

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Conflict of interest: The authors declare that there is no conflict of interest.

Source of funding: This article is the result of a Research and Development Project (R&D) of Fundação de Amparo à Pesquisa do Estado do Amazonas (FAPEAM) [Research Support Foundation of the State of Amazonas], performed together with Universidade Federal do Amazonas (UFAM) [Federal University of Amazonas], through EDITAL N. 006/2020 - PCTI-EMERGESAÚDE/AM - CHAMADA II – ÁREAS PRIORITÁRIAS [Call for Proposals – Priority Areas], under the title Soluções para Uso de Inteligência Artificial e Tecnologias Digitais para Referenciamento de Pacientes [Solutions for Artificial Intelligence and Digital Technologies Use for Patients Referral].