G-CoV.2: A Computational System for Geolocation of Patients Diagnosed with COVID-19

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***Abstract*—Coronavirus disease 2019 (COVID-19) is a respiratory infection caused by the Severe Acute Respiratory Syndrome Coronavirus (SARS-CoV-2). In the current scenario of COVID-19, more than 6 million people have died worldwide, and near seven hundred thousand only in Brazil alone. The objective this work is designer a database using MySQL to develop a system for geolocating COVID-19 affected individuals and their close contacts. Patient addresses registered in the laboratory database were used to search for coordinate (latitude and longitude) using the OpenStreetMap Application Programming Interface. The user interface was developed in PHP using HTML, JavaScript, CSS, and AJAX. A dashboard displaying the geolocation information of selected patients was presented on the screen for public health agents. A system called G-CoV.2 was developed. The makers produced by G-CoV.2 had 100% accuracy when manually compared with the same patient address records. G-CoV.2 can be used as a computational system to aid health managers in identifying regions with the most people infected by COVID-19 or other pathological processes. The submitted work can meet the third goal of sustainable development of the United Nations for Latin America, ensuring a healthy life and thus promoting well-being for all people, at all ages. One of the ways is through the monitoring of COVID-19 and other pathologies as a preventive measure, applying the system developed G-CoV.2 that was the subject of the writing of the article, which may reduce the mortality rate at all ages, with the premise of ending epidemics of serious and communicable diseases, directing health managers to increase investment in health in critical areas, as well as creating actions in favor of prevention and promotion of the population's health.**

Link to graphical and video abstracts, and to code: https://latamt.ieeer9.org/index.php/transactions/article/view/8604

***Index Terms*—Coronaviruses, Geographic information systems, Pandemics, Pathology.**

I. Introduction

Coronavirus disease 2019 (COVID-19) is an infectious respiratory disease caused by the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) [1]. The identification of positive cases and their contacts is essential for monitoring the pandemic process and planning Public Health actions to limit the spread of viremia in the population.

Common symptoms associated with COVID-19 include fever (83-98%), cough (59-82%), shortness of breath (19-55%), and muscle pain (11-44%), with most individuals (>85%) recovering well (Huang *et al.*, 2020) [2]. However, the pneumonia caused by COVID-19 has a wide spectrum of severity and progression. Some individuals (~3-29%) may require admission to Intensive Care Units (ICUs), long-term use of mechanical ventilators, high-cost specialized care, and high mortality (5.4%) is a common outcome according to Tu *et al.* (2020) [3] and Wang *et al.* (2020) [4]. Additionally, there is a possibility that a fully recovered infected individual may be re-infected, suggesting that immune protection will not always be available or perennial, adding complexity to the pathological process [5].

Globally, consolidated strategies for managing the COVID-19 pandemic are centred on social distancing to varying degrees (lockdown, horizontal and vertical isolation). Social distancing promotes the "flattening" of the spread curve of the virus [6]. This process is fundamental and effective for better management of patient care in the Unified Health System (SUS: Sistema Único de Saúde, Portuguese), avoiding the collapse of the system by the overuse of ICU beds, their equipment (mechanical respirators), medicines, and especially health professionals and necessary Personal Protective Equipment (PPE) [7]. Therefore, a computer system that identifies the locations of those affected can optimize public agents' effective actions.

Long or post-COVID is the condition whereby affected individuals do not recover for several weeks or months after the onset of symptoms suggestive of COVID-19. In a study carried out in 2022, approximately 50.2% of the individuals had the so-called long COVID syndrome with 23 symptoms, the main ones being related to fatigue (35.6%), persistent cough (34.0%), dyspnea (26.5%), loss of smell/taste (20.1%), frequent headaches (17.3%), mental disorders (20.7%), changes in blood pressure (7.4%), and thrombosis (6.2%) of the individuals [8].

The challenges in diagnosing long COVID boil down to 4 important points: (1) Patients who have had a history of typical symptoms of acute COVID-19 with a positive RT-PCR result, presenting with long-lasting symptoms: the diagnosis of long COVID is straightforward. (2) Patients with acute symptoms of COVID-19 with negative RT-PCR results, presenting with long symptoms: these cases represent a real challenge in clinical practice. (3) A significant proportion of patients with COVID-19 are asymptomatic, and the development of long symptoms in these patients increases diagnostic confusion. (4) There is a variation in the duration of acute symptoms among patients, adding to the difficulties in differentiating between long COVID-19 and acute COVID-19 patients [9].

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This project aims to provide a computational tool to help the Public Health Manager of SUS of the municipalities, states, or the country to identify important sites of infected people and ensure remote monitoring of those affected. It uses patient records from the SUS health entity databases, clarifying that notifying those infected by the virus is mandatory. To mitigate privacy risks with the proposed system, it is important to note that researchers cannot access the names or identifying elements of the individuals involved. The project complies with Guideline 22–Data collected online and digital tools in health research. These guidelines were developed by the Council for International Organizations of Medical Sciences (CIOMS) in collaboration with the World Health Organization (WHO). The proposed project includes security and privacy controls (CIOMS, 2018, p. 178) [10].

II. Methods

We conducted the study in the city of Curitiba, the capital of the state of Paraná, Brazil, in partnership with the researchers, the Municipal Laboratory of Curitiba (LMC: Laboratório Municipal de Curitiba, Portuguese), and the Clinics Hospital of the Federal University of Paraná (HC: Hospital de Clínicas da Universidade Federal do Paraná, Portuguese).

A. Ethical Aspects

We performed all procedures in accordance with the recommendations of the Ethics Committee for Research on Human Beings. The Ethics Committees of the Clinics Hospital of the Federal University of Paraná (CAAE: 43948621.7.3001.0096) and Curitiba Municipal Laboratory (CAAE: 43948621.7.3002.0101) approved this project.

B. Study Location

The developed system was the result of research conducted in Curitiba, the capital of Paraná, one of the three states in Brazil's Southern Region. Curitiba has an estimated population of 1,773,733, with 253 Unified Health System facilities and a Human Development Index (HDI) of 0.823 [11].

The Clinics Hospital (HC), a federal public teaching hospital, is a reference for medical hospital care in Curitiba, Paraná. As a supplementary body of the Federal University of Paraná, the HC aims to serve teaching, research, and extension programs in health sciences and provide health care to the community. It is the largest public hospital in Paraná and the third-largest university hospital in Brazil. It is a reference in several areas of health care, performing all its services free of charge, fully financed by the Unified Health System (SUS), and provides care only to medium- and severe-risk cases [12].

The Curitiba Municipal Laboratory (LMC) is a tertiary public institution with automated equipment for the analysis of laboratory tests, with a large physical area managed by Curitiba City Hall. The LMC has 111 sample collection centers distributed throughout Curitiba [13].

C. Collected Data

The laboratory test results to detect COVID-19, totalling 5,218 records, in the attended patients, without duplicity or homonymy, were exported from the database of the Curitiba Municipal Laboratory (n=2,495) and Clinical Hospital (n=2,723) through the Laboratory Information System.

We obtained raw data in text form separated by semicolons in a Comma-Separated Values (CSV) file format. At the Federal University of Paraná Clinics Hospital, the data were extracted using Structured Query Language (SQL) commands in DB2 (Database Management System from *IBM*), generating a CSV file. They were collected from May 2020 to May 2022. At the LMC, the *One Step COVID-2019 Test (IgG/IgM)* immunochromatographic reagent (manufactured by *Guangzhou Wondfo Biotech Co*. and imported by *Celer Biotecnologia S/A*) was used for the rapid, qualitative detection of IgG/IgM antibodies against Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) using whole blood, serum, or human plasma samples.

At the HC, different laboratory tests for IgG/IgM detection have been employed, including a rapid test for antibodies, which identifies antibodies against the virus, and diagnostic testing using RT-PCR, considered the gold standard test for detecting COVID-19.

D. Data Processing

The results of the laboratory tests extracted from the databases of the institutions studied were processed using computational tools. We removed redundant and incompatible data. We merged records of laboratory test results of both health institutions. We performed this process with the following computational tools: a Stream Editor, known as SED, to edit the files; CAT command to copy the contents of each file and join them into a single target file; regular expression feature to search string sets; and the AWK language for the selection of specific records in the searched files. These tools are native to the GNU/LINUX Operating System [14].

Data processing involved generating a single CSV file using the Python programming language in the Jupyter Notebook computing environment and the Pandas and Matplotlib libraries [15] to perform data processing and analysis.

III. Results

We used the MySQL Relational Database Management System to create a database for the developed system. MySQL was chosen because it has the characteristics of portability, compatibility with the PHP Programming Language, excellent performance, stability, and it is a Free Software. The processed data were imported into a database model for the system following the concept of database design using the data and entity relationships proposed by Chen (1976) [16].

The developed model included relationships among the entity data, and we created four types of entities for the proposed system: USER, PATHOLOGY, ADDRESS, and TEST. The Entity-Relationship Diagram in Fig. 1 shows the connection between the data to generate the geolocation of COVID-19-positive patients.

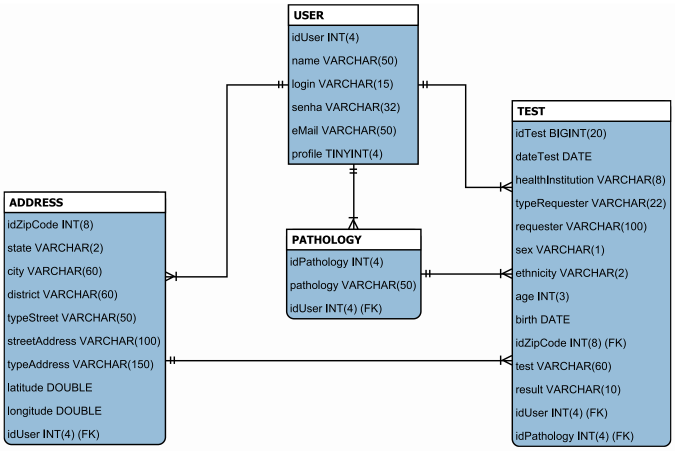


Fig. 1. Entity-Relationship Diagram of the developed system database.

The first element in the tables identifies each piece of the stored information (USER, PATHOLOGY, ADDRESS, and TEST). The table's relationship is determined by linking each identifier element with the one with the same name in the related table through a Foreign Key (FK), with lines structured by Chen (1976). The term *VARCHAR* refers to the data type of a column in a database that can contain letters and numbers. *DATE* is a simple date stored in the pattern 'YYYY-MM-DD' (Century and Year-Month-Day). *DOUBLE* is a rational number stored in a 64-bit floating point system. *INT* is an integer stored in 16 bits. *BIGINT* returns a large integer (binary integer with 63-bit accuracy). *TINYINT* stores integer values that fall within the range of -128 to 127. This type requires one byte of space (eight bits). The numbers in parentheses represent the limits of the maximum storage column size.

We obtained patient addresses by searching for coordinates (latitude and longitude) associated with the Postal Address Code (similar to the ZIP Code). The table containing the Postal Address Code is associated with latitude/longitude indicators (according to Table ADDRESS in Fig. 1); to implement the geolocation functionality, we used the OpenStreetMap Application Programming Interface (API), which allows for the manipulation of points on the map and the delimitation of regions [17].

A system named G-CoV.2 (**G**eolocation for **CoV**id **2**) was developed to identify positive patients in a specific city region. The number 2, as part of the composition of the system's name, was based on SARS-CoV-2 having the context of the pandemic [18]. The system is available twenty-four hours a day and seven days a week on a server (computer) of the Federal University of Paraná with public access connectivity and adequate performance (response time); that is, the time it takes for information to be processed on the server in response to the user's screen.

We developed the user interface of the system using the PHP programming language with HyperText Markup Language (HTML), JavaScript, Cascading Style Sheets (CSS), and **A**synchronous **J**avaScript **A**nd **X**ML (AJAX) [19]. The PHP programming language was chosen to carry out insert, delete, update, and select transactions with the database created in MySQL. To develop systems for the Internet, HTML, JavaScript, and CSS technologies were chosen to create interfaces (screens) to be used by system users. AJAX technology has the characteristic of improving performance and agility for the user interface by reducing the volume of data transmitted between the server computer and the client computer. A responsive web version (adaptable and flexible for all computer screens) was developed and can be accessed at https://cpdm.ufpr.br/g-cov-2.

When accessing the main page (typing the address above into a browser to open web pages) and clicking on the system icon, the user is directed to the home screen of the system to connect through the Username and Password or to register to gain access. After validation, of the username and password, will display the access options to G-CoV.2 System, including user management, data import and export, line, column, histogram charts, statistics, information, and the Geolocation of COVID-19 Positive Patients. To download the CSV file with the data used in the system, you must register in the system, log in, choose the Manage option and click Export Data.

The process involved selecting and exporting tests for COVID-19-positive patients from the HC and LMC Databases. Subsequently, we imported the data into the G-CoV.2 database and it became possible to perform geolocation of individuals on the map presented by accessing the system.

Fig. 2 shows the main phases of developing the proposed system.

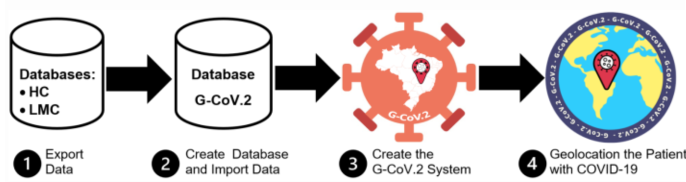


Fig. 2. Phases of system creation. (1) A database with COVID-19 results from two health institutions (HC end LMC) are exported. (2) The G-CoV.2 database with the COVID-19 results report was created, from which data were imported. (3) A developed system G-CoV.2, accesses the COVID database for COVID-19 positive results and processes the information. (4) The geolocation of positive COVID-19 is shown on a screen structured as a map, with pins (markers) of different colours according to COVID-19 severity (red, severe, or blue, mild to moderate).

It was necessary to create twenty-one files (scripts) using the PHP programming language with HTML, JavaScript, and one file for the standardization of the screens using Cascading Style Sheets (CSS) and creating a database with four tables where the information used in the system was stored to develop the G-CoV.2 computer system. G-CoV.2 System is a software registered in the Brazilian National Institute of Industrial Property under BR512023000732-3 [20], linked to the Federal University of Paraná, Brazil.

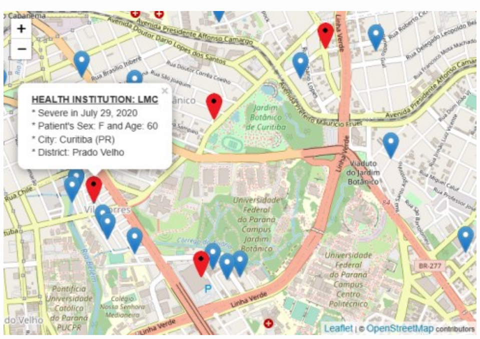
The developed system provides access to a login and password, ensuring security control. Additionally, the software can provide information regarding anthropometric data (age and sex) and COVID-19 positivity and assist health managers in decision-making. Sensitive patient data, such as name, telephone number, and identifiers directly reported to the individual, are not part of the database.

Analysing the studied database (n=5,218) from HC and LMC, positive results for COVID-19 from 4,249 individuals were from the city of Curitiba, and 921 from other cities in the state of Paraná, and 48 in the other states of Brazil. In the database, only 47 (1.1%; 47/4,249) incorrect Zip Code records were identified in patients from the city of Curitiba, these did not allow for geolocation.

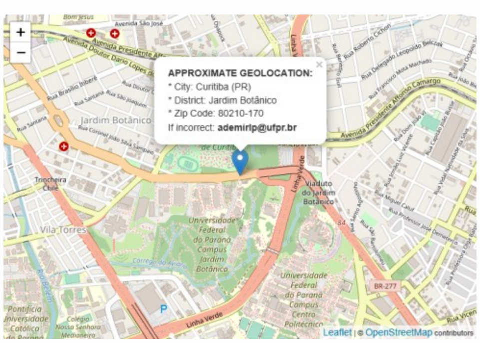
In the alpha and beta phases of the system development, we conducted preliminary tests with more than 100 patient records representing all areas of Curitiba City. The geolocation of patients with COVID-19 through the "pins" (geographical position indicators) or markers produced by the G-CoV.2 System had 100% assertiveness when manually compared to the same patient address records. We performed preliminary tests on patients with the Zip Code in Curitiba, where the two health institutions were located.

The developed system displays the geolocation of patients with COVID-19 with information on age, sex, district, health institution, date of test results provided, and severity (severe or mild-to-moderate), maintaining the confidentiality of sensitive patient data (such as name and identity registration) to enable monitoring and decision-making by health institutions based on reliable and real-time information.

After connecting to the system, the user can view the geolocation of positive COVID-19 individuals by selecting the geolocation option and then G-CoV.2 when displaying the map, as shown in Fig. 3 (a). The system offers a ZIP Code query to verify the integrity of geolocation information (latitude and longitude) registered in the ADDRESS table in the system database. To perform the check, select the geolocation option from the G-CoV.2 menu and then choose the Check Zip Code option. Enter the Zip Code numbers and click Check. Fig. 3 (b) displays a map with the approximate geolocation containing the city, state, district, and Zip Code.



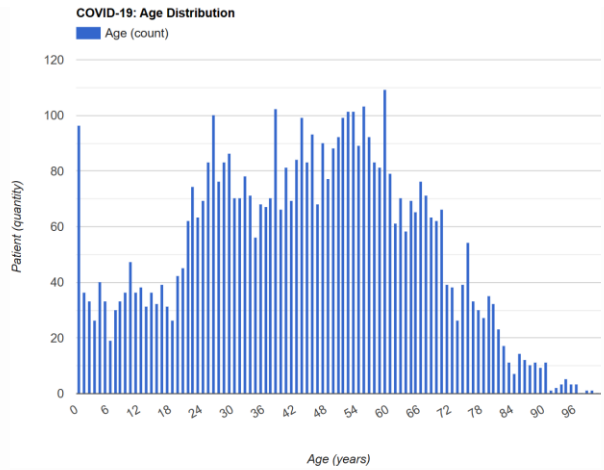
(a)



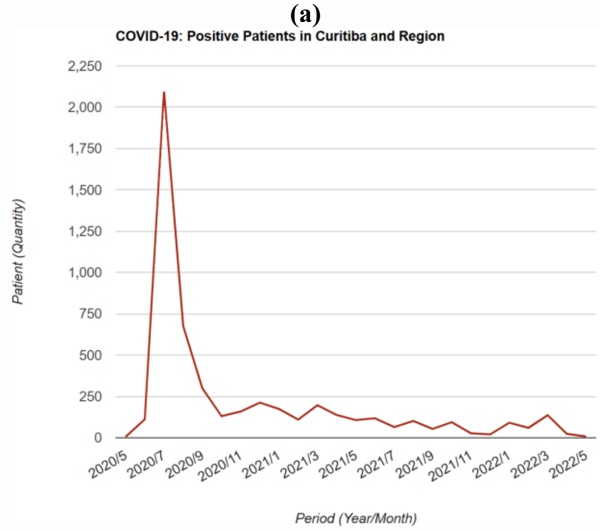
(b)

Fig. 3. Geolocation with G-CoV.2 System. (a) G-CoV.2 displays details of a COVID-19 patient's location. Select the desired marker to view everyone's data. The blue marker shows individuals with mild to moderate COVID-19, and the red marker for Severe COVID-19. (b) Map with the Universidade Federal do Paraná – Campus Jardim geolocation Botânico after checking the Zip Code entered by the user. For both maps above, clicking the "+" icon will enlarge the map displaying information more closely. Clicking on the "-" icon will decrease the map but enlarge the region to display more information.

Fig. 4 shows a histogram of the ages and the positivity of COVID-19 cases. The histogram represents a normal distribution of the age of patients in the period, identifying that with the greatest contagion. The line graph represents positive COVID-19 individuals, showing the peak period of cases in the region studied.



(a)



(b)

Fig. 4. Graphical Data Information with the G-CoV.2 System. Histogram of the Age Distribution of COVID-19-positive subjects. (b) Evolution of Positivity by year and month of COVID-19 Positive Patients in Curitiba and Region.

G-CoV.2 offers charting (as above) and reporting options for viewing the data used in the database and descriptive statistics about COVID-19-positive individuals.

The G-CoV.2 System is prepared to inform the geolocation of individuals with other pathological processes, such as COVID-19, Long COVID, Diabetes mellitus, obesity, hypertension, sexually transmitted infections (STIs), and tuberculosis which can be visualized on a map, including graphs and statistics. (Fig. 5).

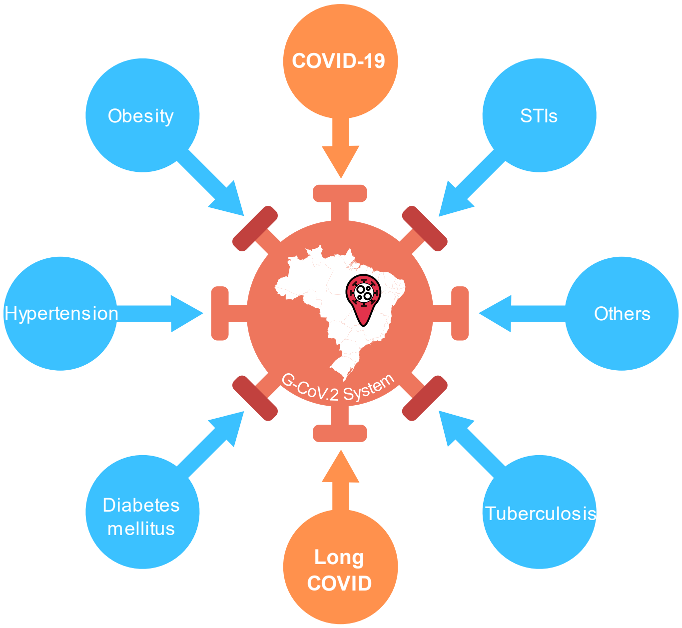


Fig. 5. Geolocation of other pathologies. The G-CoV.2 System, with appropriate minor adjustments, can geolocate patients with different pathological processes, especially those with an epidemic/pandemic bias.

STIs, Sexually Transmitted Infections: syphilis, gonorrhea, chlamydia, trichomoniasis, hepatitis B, herpes simplex virus (HSV), Human Immunodeficiency Virus (HIV), lymphogranuloma venereum, monkeypox, *Shigella sonnei*, *Neisseria meningitidis*, Ebola, Zika, and Human PapillomaVirus (HPV).

Others: Alzheimer, vaccination coverage, leprosy, cancer, dyslipidemia, stroke, and other pandemic or endemic processes such as Avian Influenza A (H5N1).

The health institution that wishes to use it may contact the authors through the Inform menu in the system to register and understand the procedures necessary to enter the geolocation data of patients for the desired pathology of their institution. The procedure should be performed using only the System Administrator user account.

IV. Discussion

The COVID-19 pandemic presents new challenges for governments, businesses, health agencies, and individuals worldwide. Geolocation is a valuable tool for understanding people's movements because its technology can pinpoint an individual's location from an Internet-connected device. Geolocation data used to combat the spread of COVID-19 may contain sensitive information regarding a person's identity, location, behavior, and health.

The G-CoV.2 System provides data that can be effectively used for decision-making by local health managers, helping to combat the pandemic in a timely and region-specific manner. This approach makes it possible to perceive the weaknesses and needs of the local population and enables the allocation of resources in the most rational way in each case, contributing to the proper functioning of the SUS and the country's economy.

Similar efforts to gather relevant data on the spread of the pandemic and its effects have been reported. One example is the Autonomous Community of Catalonia, in northeast Spain, which is considered a pole of development and reference in digital health in the country and has developed several digital initiatives to confront COVID-19. One of the technologies developed was the application for self-assessment of the symptoms of the disease, called Stop Covid Cat (https://www.intelligentcitieschallenge.eu/stop-covid19-cat), which has the geolocation function creating a heat map with the most affected areas [21]. In the G-CoV.2 Systems and the markers of positive COVID-19 individuals in a region are displayed on the map, allowing the user to navigate in any area of Brazil and decrease or increase the desired region for a better view.

In Poland, an app was developed for people diagnosed with COVID-19 and their contacts. The police used it to detect possible quarantine violations. Police authorities contacted all individuals registered in the application daily to request geolocation. In addition to location data, the user was asked to take a selfie. Adherence to the study was voluntary [22]. The system developed in this work, G-CoV.2, keeps confidential, sensitive individual data according to the General Data Protection Law (GDPL). The GDPL even allows the use of individualized personal data in exceptional situations such as "protection of life", "execution of public policies provided for by law" and "for health protection", which would include the pandemic situation [23]. It is important to discuss alternative contact tracing solutions that take advantage of the geolocation information already available owned by BigTech companies. These corporations possess high penetration rates in most countries that adopt mobile contact tracing apps. However, these companies must offer sufficient privacy guarantees to protect the identity of infected individuals [24].

Another study conducted in Romania had objectives similar to those proposed in the present study. Through the identification of reliable sources of information and statistical data, such as the Ministry of Health, National Institute of Public Health, Strategic Communication Group, and National Institute of Statistics, the study proposed to analyse indicators or variables of the percentage of older people, population without medical care, people with heart diseases and respiratory problems, households with no water distribution network, medical teams, hospitals dedicated to treating patients with COVID-19, PCR testing laboratories, and vaccinated individuals. The index mapping of the different levels of vulnerability to COVID-19 aimed at visualizing areas with vulnerable populations and the communication problem between different institutional and administrative levels of healthcare and their local and professional communities [25].

Table I summarizes other systems for geolocation with technologies other than G-CoV.2.

TABLE I
Related Works of Geolocation Systems for COVID-19

Country	Technology	Application	Reference
Indonesia	Android	Geographical information system	[26]

EUA	Mobile-phone-deployable	Real-time systems	[27]
India	MatLab	Global position system	[28]
Bangladesh	Mobile phone	Geolocation data	[29]
India	Web application	Geolocation	[30]

Different technological approaches to identify those affected by COVID-19 are also described, applying Bluetooth, Google/Apple, GPS, data mining, Geolocation, QR Code technologies [31], [32], [33].

In a systematic review, Kondylakis and collaborators evaluated multiple applications for mobile systems, with an emphasis on contact, home monitoring and decision making for COVID-19 patient management [34].

The search for interactions between the G-CoV.2 System and other already established applications can offer improved benefits for those affected by pandemic processes, expanding the benefits of the proposed system.

The G-CoV.2 System can classify the patient's COVID-19 result as Severe (critical) and Mild to Moderate (non-severe). According to the WHO classification of positive cases, we identified cases as mild to moderate, severe, or critical [35]. Severe COVID-19 was associated with the patient's situation for both health institutions, admitted to an Intensive Care Unit, and non-severe cases where the patient was seen in an outpatient clinic. The work published by Wu and McGoogan (2020) identified that not all individuals infected with COVID-19 require admission to Intensive Care Units, but approximately 15% have a severe form of the disease [36]. In our study, we identified 1,198 (37%) severe cases of COVID-19 and 77% of mild-to-moderate cases. On the G-CoV.2 map, patients with severe and non-severe COVID-19 are indicated with the red and blue marker, respectively.

In May 2023, the World Health Organization recognized the end of the COVID-19 pandemic is a global emergency (https://www.cdc.gov/coronavirus/2019-ncov/your-health/end-of-phe.html). It is important to note that positive cases of COVID-19 continue to be identified worldwide.

One possible new pandemic is the outbreak alert of the highly pathogenic avian influenza A(H5N1) virus in seals from New England, United States, indicating that monitoring of wild shorebirds and marine mammals will be critical to determine the pandemic potential of influenza A viruses [37]. The G-CoV.2 System has the potential to be applied in this process as well as in other future pandemics and epidemics outbreaks.

Additionally, in the oncological context, it is relevant for patient management to know the distribution (geolocation) of cases in states and cities, identifying distances from reference centers for the treatment of pathological processes. G-CoV.2, with minor adaptations, can be applied in this case.

Finally, anyone who is infected with COVID-19 can experience Long COVID. The long or post-COVID period includes new, returning, or ongoing health problems that people experience after being infected with the COVID-19 virus. Most people with COVID-19 get better within a few days to a few weeks after infection; therefore, Long COVID could first be identified at four weeks. Most people experience symptoms days after first learning they have COVID-19, but some do not know when they are infected [9], [38]. Special attention is needed for patients with Long COVID, due to the multitude of the symptoms and associated complications. The G-CoV.2 System can be an additional tool for public managers in optimizing resources in the care of this group.

V. Conclusion

The developed system (G-CoV.2) has the potential to support managers in Brazil's Unified Health System as a useful and flexible tool for managing the COVID-19 pandemic through specific geographic coverage of a region or city.

This project offers the possibility that, with appropriate adjustments, the G-CoV.2 System could be easily used in other pathologies requiring preventive actions and several procedures from SUS.

In summary the G-CoV.2 System offers the geolocation of those affected by COVID-19, with graphs and descriptive statistics for data analysis, maintains the anonymity of individuals, is user-friendly, and has the potential to monitor and help decision-making by health institutions based on reliable and real-time information.

In future studies, we intend to implement the G-CoV.2 System for the follow-up of long-term COVID (or Post-COVID) patients and their contacts. We also intend to improve the system using machine learning, a data analysis method that is an offshoot of artificial intelligence within the context of computer science [39], to predict the severity of COVID-19 based on training-classified data to identify patterns and assist in decision-making for health managers.

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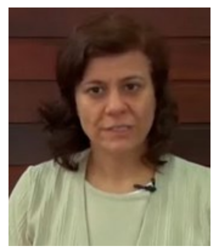

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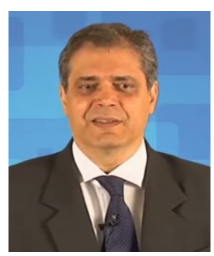

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