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A review: Data visualization for COVID-19

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Abstract:

As COVID-19 raged across the globe, it seriously disrupted social health security, daily work, and the rest of the people, which aroused great panic among all classes. These facts extensively affected the regional circulation and economic growth of the epidemic area. Data visualization, an advanced technology, can help humans understand epidemic transmission trends, identify high-risk areas of outbreak, and evaluate prevention and control policies. Previous essays immediately established databases to organize and build datasets. Other researchers built new visualization models to analyze the causes of virus transmission and pointed out the low efficiency of the existing COVID-19 system response. Although various research and data visualization methods have been used on COVID-19, there has not been a comprehensive, systematic essay that covers the entire span of COVID-19 and its data visualization usage. Therefore, this paper will provide a new systematic and comprehensive perspective to explore the analysis of data visualization to solve COVID-19 data challenges and provide research methods and applications for COVID-19. To be specific, this paper first introduces the characteristics and challenges of COVID-19 epidemic data people may face during the data visualization process, which includes data complexity problems, data timeliness problems, data regional problems, and data quality problems. Then, this paper discusses data visualization methods used by predecessors in previous research. After that, this paper describes the urgent data visualization analysis requirements of COVID-19, including regional differences in virus spread, the influence of temperature on the virus, transmission trends, and death rates for different genders and ages, etc. Finally, this paper reviews applications of data visualization in COVID-19 analysis, followed by earlier-stage prevention, mid-term containment, and later-term reduction of impact. This paper provides an important reference for further research and application of data visualization technology in COVID-19 prevention and control, which brings new ideas for strengthening future epidemic surveillance and data visualization for global epidemic prevention and control.

Keywords: Prevention, Policies, Data visualization, COVID-19, Epidemic

1. Introduction

In December 2019, a novel coronavirus began to spread in countries around the world, and the World Health Organization (WHO) officially named it COVID-19. Due to the speed and spread of the epidemic, COVID-19 has rapidly captured the attention of health organizations. Analysis of COVID-19 data plays a crucial role in understanding and predicting trends to advise on COVID-19 prevention. Firstly, data analysis can help governments and health agencies understand the spread of the epidemic, including the number of cases, the speed of transmission, geographical distribution, etc. So that targeted prevention and control measures can be taken to contain the virus. Secondly, data analysis can help to predict the course of the outbreak and prepare medical resources in advance. Thirdly, through in-depth analysis of epidemic data, potential risk factors and transmission routes can be found to provide a scientific basis for COVID-19 prevention and control work. However, the results of data analysis may not be intuitive enough to be understood by the public.

Data visualization technology is a kind of technology using charts, maps, graphics, and other visual methods to present data analysis results in an intuitive, easy-to-understand way. This method can help people better understand the relationship, trend, and pattern of data that is hard to describe by data analysis. In the data collection phase, data visualization can help people better understand the source, size, and structure of data. These activities can not be done by data analysis due to a lack of context understanding of data. In the data processing phase, data visualization can help people understand the characteristics and distribution of data, and how data interact with each other. Finally, in the data analysis phase, data visualization can help people find correlations, trends, and anomalies between data, and extract valid information.

Previous studies used data visualization methods to analyze the relationship between several influencing factors and the epidemic, which partly addresses the problem of diversity of data resources by performing data mining methods from official reports, social media messages, medical reports, and research papers to reduce data inconsistency and incompleteness [1]. Others also analyzed data visualization methods in a single stage of COVID-19 development, which makes it difficult to extract effective information due to data complexity [2]. More researchers focused on designing new data visualization tools for COVID-19 data analysis [3] that may have timeliness issues as the update of COVID-19 data is very fast, which is in urgent need of real-time data correction [4]. Besides, researchers also conducted data visualization modeling for the development trend of COVID-19 to validate and optimize the newly built model [5]. However, there is a lack of correlation between these studies and a lack of systematic literature to summarize these works, which cannot strengthen the overall prevention and control of COVID-19.

In this study, it will conduct a systematic review of the COVID-19 situation and data visualization. Firstly, this paper will introduce the concept of data visualization and highlight its advantages that may solve fatal flaws in COVID-19 data analysis. Then, this paper will review existing essays from the period in which data visualization is used for COVID-19 analysis, which is divided into pre-epidemic, mid-epidemic, and post-epidemic periods. In the second part of the paper, the thesis will analyze the characteristics of COVID-19 datasets and the challenges of visualizing these data. This paper first describes the possible features of COVID-19 data. Then, it will discuss several data visualization methods that enable researchers to deal with data issues which include data complexity, data timeliness, data quality, and data source diversity aspects. However, researchers still need more advanced data visualization methods to solve more and more problems due to COVID-19 spreading. This paper will also talk about the specific needs of data visualization, which includes data update speed and model building. By analyzing these facts, people can have an overview of data visualization during the COVID-19 lifespan and realize data visualization techniques have more potential to solve COVID-19 problems. In the third part, this paper will focus on the application of data visualization in COVID-19 analysis. This paper first discusses the usage of data visualization in the earlier stages of COVID-19, which mainly focuses on early prevention and control. Then it will discuss its usage in the middle stage, which will include tracking and analysis of COVID-19 transmission trends, turnover and demand prediction of medical resources, marking the worst-affected areas, and isolating and blocking the transmission of the epidemic. Then, some successful epidemic protection policies discovered by data visualization due to their effectiveness will be highlighted. Finally, the paper will describe the influence of public opinion on COVID-19 during the later stage of COVID-19. In all, this paper discusses data visualization applications in both time and space aspects to describe the data visualization usage during the whole COVID-19 lifespan.

2. Characteristics of COVID-19 data sets and challenges in using data visualization

2.1 The features of COVID-19 data and datasets

The COVID-19 data and datasets have multiple characteristics that reflect the complexity and challenges of outbreak data and affect COVID-19 surveillance, analysis, and response. Data complexity problem: COVID-19 datasets contain various types of data, such as the number of infections, the number of deaths, the number of recoveries, the positive rate of detection, and the utilization of medical resources [6]. These data reflect different aspects of the COVID-19 and provide comprehensive information for decision-making [1]. Data timeliness problem: Because COVID-19 data is dynamic, the data will be updated and changed over time. To cope with new case reports, cures, and deaths that appear daily, the database needs to be updated to reflect the latest outbreak situation [7]. Data regional problem: COVID-19 datasets are regional, and the COVID-19 situation in different regions may vary greatly [8]. Therefore, COVID-19 data need to be collected and analyzed by geographical location so that corresponding prevention and control measures can be taken in different regions [9]. Data quality problem: The quality of COVID-19 data is uncertain due to the possibility of missing or misreporting during data collection. Measures need to be taken to ensure the accuracy and integrity of the data while identifying and dealing with outliers and error information in the data [10]. Diversity of data sources problem: COVID-19 data can come from multiple sources, including government departments, healthcare institutions, laboratories, social media, etc. Data diversity makes data collection more extensive. However, it also increases the complexity of data integration and cleaning [2].

2.2 Data visualization methods to address the complexity of COVID-19 data

In the early stage of COVID-19, many big data visualization tools were used in the medical industry to deal with the suppression of excessive data on the medical system

when they were undergoing the data collection process [3]. In Indiana, USA, a new dashboard was created to cope with the increasing amount of data, which also expanded state-wide health information datasets to address the inadequate information infrastructure [7]. To solve the problem of the complexity of COVID-19 data, data visualization technologies were used to understand the relationship between case-related characteristics through visualization and visual analysis of real COVID-19 epidemiological data sequences. Besides, data visualization can also weaken the impact of complexity caused by excessive data [11]. In addition, data visualization can optimize the dashboard by aggregating analysis to create a multi-layer network to analyze the impact of demographic data on COVID-19 data [6]. To deal with complex COVID-19 data, data visualization technology can also break the traditional two-dimensional visualization data model and use three-dimensional visualization technology to enable the public to have a deeper understanding of the epidemic trend [5].

2.3 Data visualization methods for timeliness of COVID-19 data

In the initial data processing stage of COVID-19, time-sensitive data played an important role in curbing the spread of the epidemic, accurately grasping the epidemic situation, formulating reasonable epidemic prevention and control regulations, and improving the efficiency of COVID-19 data processing [12]. Public health information systems were capable of capturing data on confirmed COVID-19 cases, but the need for real-time access and data visualization remained unmet during the COVID-19 phase [7]. To address this issue, some countries are using COVID-19 trackers built on HTML and JavaScript to obtain real-time visualizations of the outbreak within the country in real-time [13]. Other countries establish an abstraction layer for epidemic data to enhance the conceptual and data-driven information of data visualization, to understand the real-time COVID-19 situation [4]. In the later stage of COVID-19, some countries used real-time API data to build visual websites targeting COVID-19 [14].

2.4 Data visualization methods to address quality issues of COVID-19 data

In the phase of COVID-19 data collection, some European countries set up a large number of points of interest to collect spatiotemporal data about COVID-19, to compare independent data sources for data visualization to reduce the quality problems of COVID-19 data, enhance the credibility of data, and select data outliers [15]. In the phase of COVID-19 data processing, to reduce outliers, data missing, duplicate data, data inconsistency, sample bias, and data errors, technologies such as data cleaning and pre-processing visualization, temporal data visualization, multidimensional data visualization, and interactive visualization could be used to analyze COVID-19 data more comprehensively and intuitively. These methods were responsible for identifying potential problems and rules to provide scientific basis and decision support for COVID-19 response [10]. Some countries have developed curve-fitting algorithms based on past data for using stand-alone applications to mitigate the impact of outliers on future trend analysis of outbreaks [10]. Others have focused on web-based statistical tests and community detection algorithms to find similarities in COVID-19 data. Therefore, the results were mapped in the figure with data visualization technology to judge the authenticity of the COVID-19 data and find the problems existing in the datasets [16].

2.5 Data visualization methods to address diversity issues of COVID-19 data sources

The diversity of data sources was mainly a challenge and difficulty in the phase of COVID-19 data collection, which may lead to other problems such as data consistency and accuracy, data missing and lagging, data reliability and trust, and data integration in the subsequent phase of data processing and data analysis. To solve these problems, a large number of one-stop COVID-19 information platforms based on visualization technology have been used for COVID-19 publicity and analysis in various countries [10]. In developing countries such as the Philippines, the Sustainable Development Solutions Network, an official dashboard based on the aggregation of official medical institutions and industries, was used to curb the transmission of false COVID-19 news, thereby expanding the development of integrated, interactive COVID-19 news in the country [10]. While in the middle and later stages of the epidemic, the United States, led by Western developed countries, used a large number of datasets in the past three years to analyze the containment effect of vaccination on COVID-19 and combined with data visualization technology to identify the correlation between the distribution of vaccination and other influencing factors [17].

3. Applications of data visualization in COVID-19 analysis

3.1 Introduction

This paper will discuss the applications of data visualization usage in the early, middle, and later stages of COVID-19. Then it will estimate data visualization usage in chronological order, including early prevention and control, spread status tracking, medical resource and de-

mand analysis, critically endangered epidemic area analysis, prevention policies evaluation, and public opinion analysis. Besides, the thesis will also compare data visualization usage in different countries to analyze regional impact.

3.2 Early prevention and control

In the early stages of COVID-19, the prevention and control of COVID-19 can avoid the explosion of medical disasters in large cities such as New York and Wuhan. Technologies such as real-time COVID-19 maps, graph and trend analysis, heat map and hot spot analysis, model prediction, and early warning systems based on data visualization technology have become particularly important [15]. Among them, there are some unique data visualization applications: Some studies conducted a visual analysis of the epidemic attack in New York City based on the virtual environment, and used the combination of COVID-19 infection cases and postal code region datasets to build a virtual reality application for the COVID-19 broadcast in New York by geographical distribution map, to achieve the purpose of studying the epidemic spread simulation in mega-city. Formulate plans to contain the transmission of COVID-19 and understand the trend of COVID-19 spreading [18]. For the entire country, the early prevention and control of an outbreak can effectively integrate forces into the guidelines for combating an unprecedented (new) outbreak. In the early stage of COVID-19, Indonesia used visualization technology to map and describe the current situation and establish an analytical model for COVID-19, which helped to raise public awareness of COVID-19 prevention and enhance the urgency and importance of COVID-19 data [19].

3.3 Tracking and analyzing the spread of COVID-19

In the middle raging stage of COVID-19, the continuous tracking and analysis of COVID-19 can effectively predict its transmission law, which can provide real-time intelligence and warnings to the public combined with data visualization technology, provide the theoretical basis for the government to make decisions, and set standards and benchmarks for evaluating intervention measures.

At that time of the middling COVID-19 stage, there was a front-end page on COVID-19 data. Through the COVID-19 web page, a combination of maps and visual graphics was used to realize map visualization of COVID-19 data, which played an important role in improving individual awareness of self-protection and preventing the spread of COVID-19 [20]. Besides, some early staged COVID-19 application-related ideas can also be implemented in the middle of COVID-19 with the support of a large database. For example, based on the COVID-19 data collected from the network server by real-time visualization and analysis technology, the existing data values in the past are used to predict the future development trend of COVID-19, and the visualized data is input into the application to enable ordinary users to obtain COVID-19 related data analysis [10]. In addition to mobile apps, interactive data-driven dashboards have evolved into tools for analyzing epidemic spreading trends, some based on Python templates that can predict epidemic trends for the coming week and load new datasets into Web servers. It has comprehensive advantages over other data visualization methods in terms of performance speed, page size, and number of HTTP requests [21].

3.4 Medical resource turnover and demand forecast

In the middle stage of COVID-19, the application of data visualization in the turnover of medical resources and demand prediction can improve the utilization efficiency of medical resources and strengthen the response-ability to COVID-19. During this period, COVID-19 caused massive pressure on national medical facilities and personnel. Through the combination of data visualization technology and data analysis technology, the study can explore how COVID-19 spread over time in Nigeria, where medical resources are relatively scarce [22]. While in countries with abundant medical resources, data visualization utilizes continent-wide health information exchange-derived datasets to assess regional hospitalization, emergency medical care rates, and health resource utilization, to better plan the demand allocation priority of medical resources and ensure the COVID-19 containment situation in states and regions [7]. In Fig.1, the chart shows the SEIR model for people with COVID-19. In this figure, S represents to susceptible person, E represents to latent infected person, I represents to infected person, and R represents to removed person.

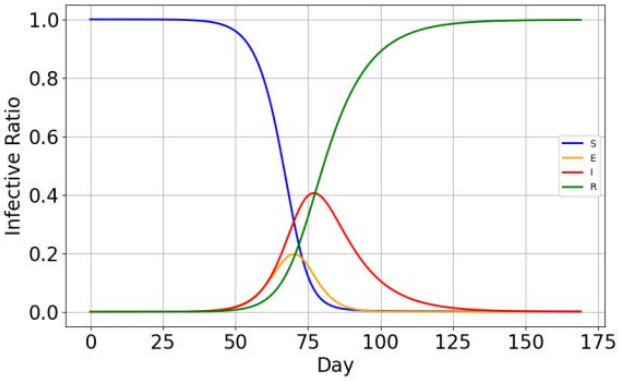

Fig.1 SEIR model for the number of infected people

3.5 Mark the worst-hit areas and isolate and block the transmission of COVID-19

In the middle stage of COVID-19, stopping the spread of COVID-19, isolating the hard-hit areas, and interrupting people-to-people exchanges play an important role in reducing the impact of COVID-19. Data visualization technology can mark and remind people of their geographical location and the medical situation they may face, strengthening the individual subjective initiative to avoid infection. At this time, interactive dashboards were invented to track the pattern and trend of COVID-19 in Sudan, and possible insights from the dashboards and visual analysis were obtained to make informed decisions for the spread of COVID-19 in Sudan, thus blocking COVID-19 in Sudan and providing a theoretical basis for timely reducing the flow of local people [23]. While in the western developed countries, research on the movement of people and the spread of COVID-19 has also been strongly disseminated. The deployment of community-based infrastructure and data visualization interactive web applications through visualization tools for mobility surveillance to combat the spread of COVID-19 and research interactive tools to visualize resident overcrowding in POI in real-time, thereby pointing out the broad impact of mid-outbreak mobility on pandemic transmission, provide a theoretical basis for home isolation policy [15].

3.6 Effectiveness of COVID-19 prevention policies

In the middle stage of COVID-19, visual analytics can assess the effectiveness of outbreak preparedness policies through policy implementation, vaccination, and the impact of COVID-19 on other industries, and provide data to support policymakers to adapt and improve existing policies for other COVID-19 challenges. Through big-data analysis and data visualization technology analysis, COVID-19 has the biggest impact on China transportation, chemical, mining, and non-banking financial industries, but its impact on agriculture, forestry, animal husbandry, and fishery, national defense and military, banking, food and beverage industries, which are most closely related to daily life, is less, which fully demonstrates the effectiveness of China COVID-19 prevention policies on public health protection [24]. Other studies conducted a side-by-side analysis of the COVID-19 situation in multiple countries, intuitively demonstrated the development and changes of the medical situation in different countries and regions through crawler and spatio-temporal visualization techniques, and dug out the spatio-temporal change rules, thus predicting the effectiveness of COVID-19 prevention policies [8]. Additionally, the time-span-based visual analysis of gross domestic product (GDP) can demonstrate the magnitude of a country impact on COVID-19, thus demonstrating the influence of national COVID-19 prevention and control regulations on the spread of the virus, and concluding that the negative COVID-19 influence has gradually weakened over time, proving the effectiveness of China COVID-19 prevention and control policy [9]. In the later stage of COVID-19, the promotion and vaccination of COVID-19 vaccines can also serve as the theoretical basis for the effectiveness of national COVID-19 prevention and control. In Malaysia during the vaccine roll-out phase, a dashboard based on data visualization technology was used to extract analysis results from the Ministry of Health on the COVID-19 tracker, its effectiveness, and acceptance of booster shots to demonstrate the effectiveness of the policy to promote booster shots for the COVID-19 [25]. Research can also focus on the distribution of mortality and vaccination by comparing the distribution of mortality and vaccination by state and exploring the correlation between various other factors such as race, political party, region, and age, using data visualization techniques to analyze the promotion and implementation of vaccination policies in the United States. Thus, the effectiveness of state COVID-19 prevention policies can be judged by the above method [26].

3.7 Public opinion influence and detection of epidemic

In the later stage of COVID-19, data visualization is of great significance in the influence of public opinion and detection of the COVID-19 virus, which can promote the transmission of information and the formation of consensus, improve the scientific and accurate response to the COVID-19, and thus enhance the cognition and understanding of the virus. At the same time, data visualization can also help governments and policymakers better communicate information and strengthen public support and cooperation for COVID-19 prevention and control. In developed countries, introducing data visualizations of how dashboards are produced can ease tensions between designers and the public involved in these processes. These conflicts are often caused by disagreements between public needs and existing policies [27]. Data visualization techniques are also capable of studying the relationship between the degree of trust in predictive visualization and the form of visualization and developing practical guidelines on how predictive visualization affects trust, including recommendations to determine the scope of prediction to balance the trade-off between trust and task performance, to judge the public opinion impact of COVID-19 [28].

4. Conclusion

During the COVID-19 era, data visualization plays a vital role as a powerful tool. Through the visual presentation and analysis of data, data visualization helps us better understand the spread of COVID-19, changes in trends, and the impact on different regions and populations. Firstly, this paper discusses data issues including the complexity, timeliness, quality, and source region of the COVID-19 data and data visualization methods to solve them. Then, the paper discusses data visualization applications usage in a spatiotemporal way. Through in-depth research on the application and response of data visualization in the COVID-19 outbreak, this study can provide work and historical experience for the early prevention and control of similar public health events in the future. In addition, this study also helps to promote the development of data visualization technology, improve its application level in the field of public health, and provide research direction for emerging data visualization models and technologies. By systematically summarizing and analyzing relevant research results, this study can provide references for policymakers, researchers, and the public, promote the application and development of data visualization in epidemic response, and ultimately contribute to COVID-19 control and public health protection.

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