A GIS Application for the Hospitalization of COVID-19 Patients

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Abstract. During the COVID-19 pandemic period, it is often necessary to hospitalize a patient positive for the virus and in serious health conditions in suitable hospitals. The difficulty in managing these emergencies arises from the fact that it is often not possible to know which is the nearest hospital with beds available for hospitalization of the COVID-19 patients. In this work, we present a GIS application based on a relational database that allows to determine an optimal path for the patient transport from a starting point to the nearest hospital with free places for hospitalization. The developed application reduces the patient's transport time, decreasing the exposure time of the medical staff in the ambulance in contact with the positive patient. The application was developed in the urban area of Catania where hospitals gather a large pool of users and therefore it is essential to have a system that in real-time provides the available beds and thus optimize the distribution of COVID-19 positive patients who need an admission to a hospital.

Keywords: Covid-19 · Spatial database · Desktop GIS · WebGis

1 Introduction

Almost two years have passed since Chinese authorities identified a deadly new coronavirus strain, SARS-CoV-2 (January 7, 2020), causing more than 100,000 people infected and thousands of deaths. The whole world scientific community has realized that the pandemic problem would soon affect the whole world.

This important and dangerous virus must be fought by everyone and with all the weapons at the disposal of science with research activities involving all sectors from medicine, geography, engineering, etc. [1–9]. Obviously, many works are affecting the research activities of medicine that must deal with the virus biologically, even with its changes and variants.

New information technologies have provided valid tools for studying and fighting the virus. Among all, certainly the GIS technology has been widely used because it is a valid tool to decision support systems. Indeed, GIS technology is used in various fields providing valid applications, ranging from energy management, risk management, mobile robotics, socio-economic studies, land planning and more.

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Several GIS applications have been developed to manage the COVID-19 pandemic phenomenon thanks also to the ability to manage big data. In this way, the GIS technology has been used in identifying the spatial transmission of the epidemic, in spatial prevention and control of the epidemic, in spatial allocation of resources, and in spatial detection of social sentiment, among other things [10]. South Korea has given the best example in controlling COVID-19 outbreak thorough GIS applications, in order to identify, track and monitor the infected people, and the places that each detected patient had visited before being certified as positive to the virus [11, 12]. Many studies have also involved the development of GIS applications for socio-economic analysis in order to understand how the socio-economic aspect can contribute to the spread of the virus. For example, from a socio-economic analysis carried out on the territory of Iran with GIS technology, it was found that the reduction of population concentration in some urban land uses is one way to prevent and reduce the spread of COVID-19 disease. The results obtained using the GIS application have shown that the central and the eastern regions of Tehran are more at risk and public transportation stations and pharmacies were the most correlated with the location of COVID-19 patients in Tehran [13]. Finally, several studies have been addressed to understand the spatiotemporal dynamics of COVID-19 to define decision-making processes, planning and community action to mitigate and clarify the extent and impact of the pandemic [14–16].

In this work, a GIS application was developed that allows reducing the patient's hospitalization time by providing the optimal path according to the COVID-19 beds available in hospitals. The application is characterized by an architecture where the data are collected and structured within a spatial RDBMS (Relational Database Management System) and linked to a GIS platform. We tested the GIS by using the city of Catania (Sicily, Italy) as test case.

2 The GIS Application

The transport of a positive COVID-19 patient to a hospital must be carried out as quickly as possible both to avoid worsening the patient's health conditions and to reduce the time exposure of the transporters. To reduce the patient's travel time, it is necessary to know the nearest hospital with free covid beds and the shortest route to reach them. To these purposes, we developed a GIS platform to manage the transport of a COVID-19 patient using a database containing a road graph structured in arcs and nodes and a vector layer containing the hospitals capable of managing COVID-19 positive patients. The GIS application, which can be implemented in the WEBGIS version, allows to choose a starting point and automatically provides the fastest route to the nearest hospital with free beds. The automatic calculation of the starting path in the GIS environment is performed using the network analysis tools, which is able to consider different variables, including the road interruptions or the traffic conditions, if available as vector or raster data.

The relational database has been implemented in a Relational Database Management Systems (RDBMS) extern to the GIS platform [2], in which the trigger functions have been implemented to automatically discard hospitals that have run out of beds and therefore will not be used as possible destinations for the patient.

Using this hardware architecture and the dedicated RDBMS software, it is possible to avoid problems of data redundancy and inconsistency, problems of competition for access to data by multiple simultaneous users, loss of data integrity, security problems, and problems of efficiency from the point of view of data search and updating.

The hardware architecture is characterized by a server where the RDBMS and the spatial database are located, while all GIS applications (Desktop and Web) are in the external device (tablet, PC, smartphone, etc.). With this architecture, all the characteristics of the DBMS and the spatial database are exploited, and the speed for updating the database modification and query is improved, thanks to a totally dedicated machine.

The deployment diagram of Fig. 1 shows how and where the architecture proposed is to be deployed, reporting the relationships between the hardware and software components used for the implementation of the developed GIS application.

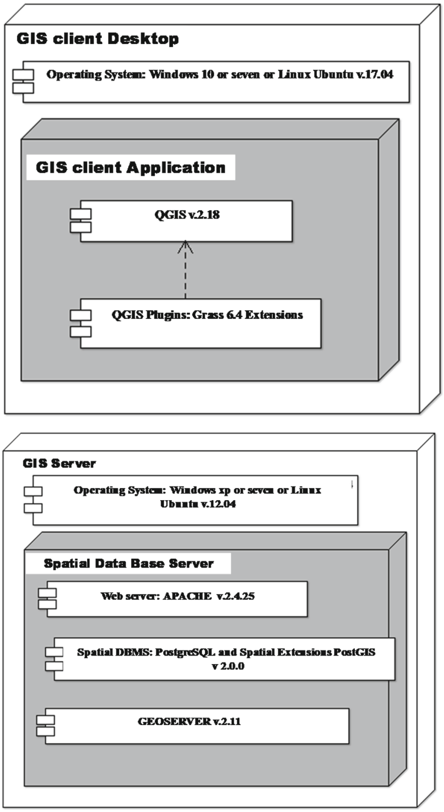

Fig. 1. UML deployment diagram of the GIS application

3 The Spatial Database

The spatial database has been developed using a relational data structure in an open-source external RDBMS. The use of this data structure allows managing different types of geometric information, spatial relationships, topological relations, directional relations, and proximity relations within the GIS application developed.

The design of the data structure to be implemented within the RDBMS has followed three main phases:

1. identification of hospitals and road infrastructures belonging to the area under study;
2. the relationships between the entities previously identified;
3. the conceptual design of the data structure using the entity relationship diagram;
4. the physical implementation of the spatial database within in the spatial RDBMS.

The structure of spatial relational database is characterized by three entities: nodes, arches, hospitals.

The arc-node relation represents the road graph allowing to reach hospitals. The Arc entity is characterized by the attributes Arc_ID and Name, which are respectively the primary key and an attribute. With respect to the architecture arc-node of the road graphs, the entity Arc is the entity related to Node.

The Nodes entity is characterized by the attributes Nodes_ID, Node_type and cost as respectively the primary key and simple attributes. In particular, the node type attribute contains the access or street_node value if it belongs to the road graph or access node to a hospital.

The hospitals entity is characterized by the attributes Hospital_ID, Name and Beds. This entity includes a trigger function that assigns a high cost to the access node corresponding to the hospital that has run out of beds. In this way the access node is discarded by the path search algorithm, providing the user with another destination with available beds.

Figure 2 shows the E-R diagram relating to the entities described above.

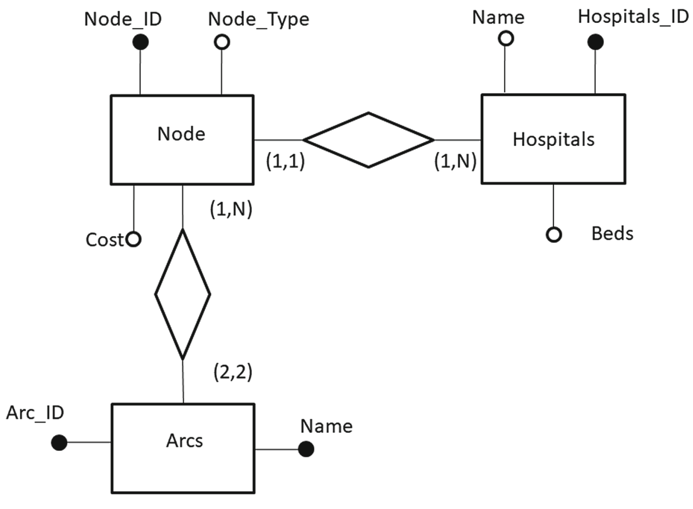

Fig. 2. E-R diagram

4 Test Case: The City of Catania

The developed GIS application was tested on the metropolitan area of Catania (Sicily, Italy), where six main public hospitals are located.

As raster cartographic support, we chose a geo-referenced orthophoto in EPSG 6708, managed in the GIS environment as a WMS service using the web link to "Sistema Informativo Territoriale Regionale - Regione Siciliana" (Fig. 3).

Using this cartographic basis, the arcs and nodes were digitized as vector thematisms with linear and puncture geometry, respectively. These two themes make up the roadgraph shown in Fig. 4.

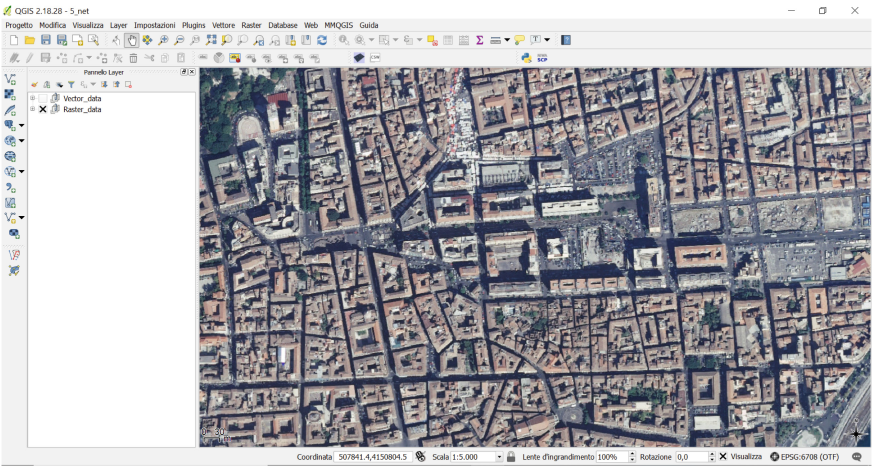

Fig. 3. Raster cartographic support

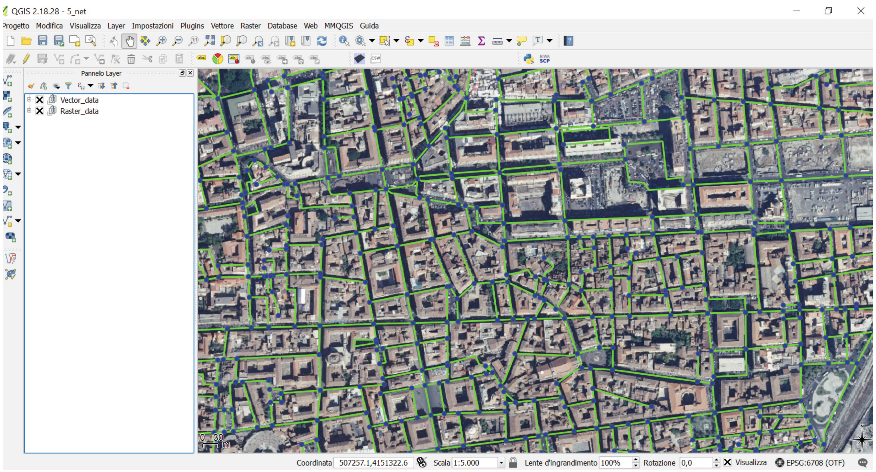

Fig. 4. Road graph of the city

The node thematisms contain both the nodes belonging to the road graph and the access nodes to the hospitals and includes the starting and ending points for the optimal path search algorithm. Therefore, a graphic style was chosen to differentiate the two types of nodes (Fig. 5).

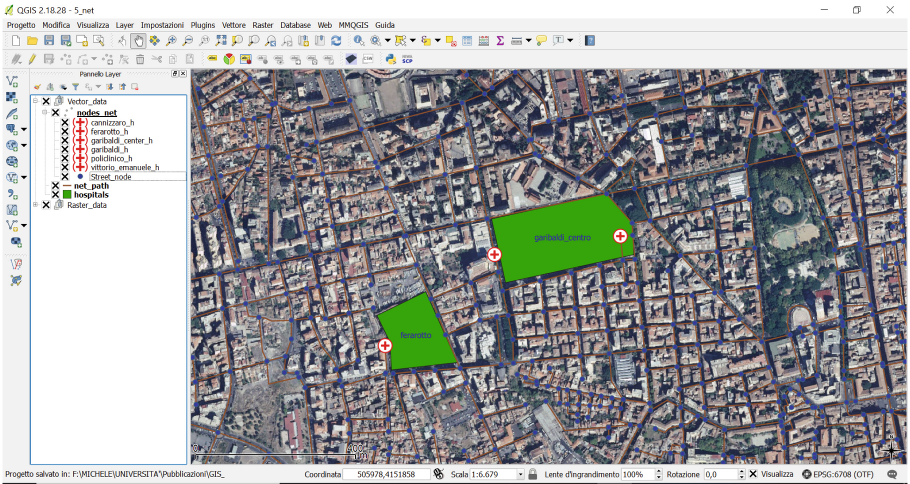

Fig. 5. Access nodes to hospitals

Finally, all the hospitals in the metropolitan city of Catania with COVID-19 beds have been digitized.

The application automatically selects all the access nodes to the hospitals with the lower cost (i.e. with more beds available) and subsequently the shortest path is calculated between the starting point and the node selected at the lowest cost. In case of same costs, the closest point to the starting node is chosen (Fig. 6).

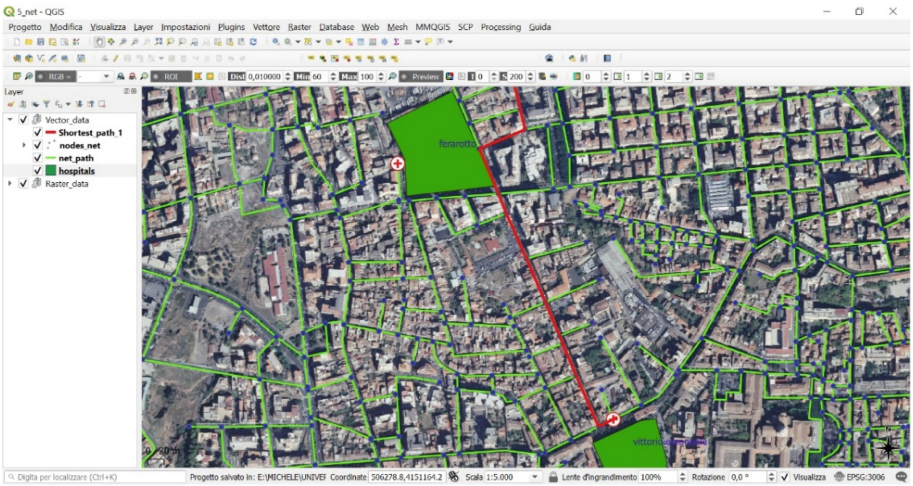

Fig. 6. Best path calculated from a starting point and the nearest hospital with available COVID beds

5 Conclusions

In this work, we present a GIS application that is able to provide a valid tool for the fight against the COVID-19 pandemic.

The methodology we have proposed exploits a spatial database with relational support to the GIS platform to determine the optimal path between a starting point and a suitable hospital to host a COVID-19 patient. The path is optimized because all hospitals with exhausted beds are excluded. This result reduces the travel times of the COVID-19 patient by reducing the exposure times of the medical staff and the arrival times in the hospital.

The big advantage of the developed application is the zero cost, the speed calculation of the shortest path and the expandability of the platform on the web for accessing the application to multiple users at the same time.

The limit of the application is the direct access to the computer system of the hospitals, which should update the database with the actual number of beds available in real time. Thus, our approach can be implemented in governance procedures if the regional health companies can provide the information relating to the beds available through dedicated web portals.

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