The application of Web GIS in emergency flood control system

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Abstract Web GIS integrates Web and GIS (geographic information system) together in order to take advantage of their special characteristics. The development of Web GIS, has played an important role in information query and emergency service flood control decision support systems. According to the characteristics of flood control and Web GIS, this paper describes the requirement analysis of emergency services, and presents the key techniques in the process of applying Web GIS to emergency flood control. The key techniques mainly include site location, earth-rock volume calculation, emergency material operation and 3-D-scene visualization in the process of levee emergency repair. Through a case study in Heilongjiang Province, it was shown that it is feasible and necessary to design a Web GIS-based emergency flood control system (EFCS), and the technique of Web GIS cannot only improve the efficiency of emergency flood control, but it can also guarantee the decision's reliability.

Key words 3-D-scene visualization; decision support system; emergency flood control; Web GIS

INTRODUCTION

Flood disasters happen frequently and widely in China. About 50% of the population and 70% of property are in the flood risk area. The annual economic losses due to floods are very large, and are rising. Compared with other countries, China faces more difficulties in flood control. Emergency flood control work has life-and-death results, not only with the sustainable development of the society and economics, but also with the safety of property and people's lives.

Because of the national power and financial situation, the design standard of flood control projects is not high enough. It has been proved in the practice of flood control that it is impossible to control great floods by depending only on unmixed structural measures. The best way to control floods is to adopt the strategy of combining structural measures with non-structural measures. The flood control decision support system (FCDSS) is a very important part of non-structural measures (Hu Siyi *et al.*, 1996). Based on the design thinking of FCDSS, this paper emphasizes the application of Web GIS (World Wide Web and geographic information system) and its decision support ability to emergency flood control. The paper describes the requirement analysis of the emergency services and presents the key techniques in the process of applying Web GIS to emergency flood control. A case study in Heilongjiang Province is given.

REQUIREMENTS ANALYSIS

Web GIS integrates Web and GIS together in order to take advantages of their special characteristics, such as easy usability, abundant geographical information, powerful spatial analysis, and so on. Since the development of Web GIS, it has played an important role in information query and emergency service in FCDSS (Zhou *et al.*, 2003).

There are numerous factors to be considered in the pre-research and practicability analysis of emergency work, including the terrain, social economy, volume of earth-rock, emergency materials, vehicles, manpower, and so on. Analysing the requirements in the process of emergency flood control, the function and framework of EFCS based on Web GIS, are illustrated in Fig. 1. EFCS consists of six function modules: emergency information query, site location, earth-rock calculation, emergency material operation, three-dimensional- (3-D)-scene visualization and database management, which are the important parts of the system. There are several types of data to support decision making on emergency flood control, such as spatial data, material warehouse data, transportation data, construction standard data, and data of the final decision plan. All these data are stored in a network database.

KEY TECHNIQUES

Levee emergency repair plays a more important role in EFCS. In the flood season, according to the flood emergency situation, levee may need to be heightened, and damaged levees must be repaired, and even more importantly temporary levees must be built up rapidly to control unusual floods. These emergency measures are very important to emergency flood control. In this case, not only should "hard" techniques be enhanced, but also some "soft" measures should be developed, which include an emergency levee flood control system. Addressing the topic of emergency repair of subsidiary levees, this paper studies four main techniques, such as site location, earth-rock volume calculation, emergency material operation, and 3-D-scene visualization, which will give strong support to decision making for emergency flood control work.

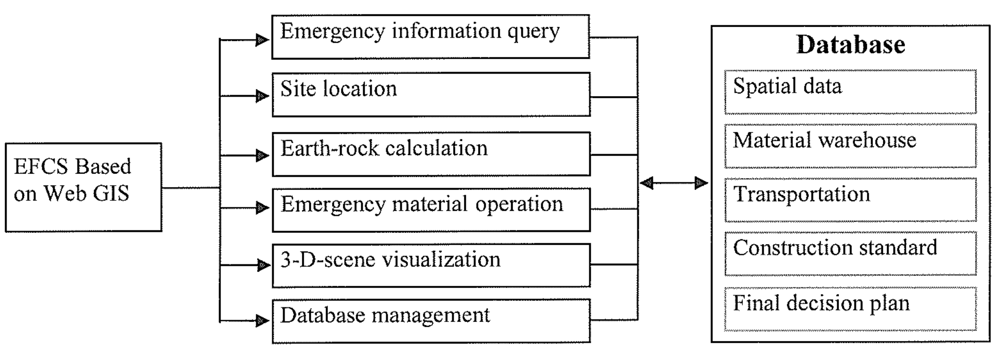

Fig. 1 System framework of emergency flood control.

Site location

Site location is the first step in emergency flood control work. Using traditional measures, a lot of fieldwork is needed in the process of the site location, and a large amount of manpower, material resources and time are used. Through Web GIS, the abundant information about emergency flood control, such as flood emergency, terrain, social economy, materials warehouse, road network, vehicle etc., can be queried quickly. Browsing and analysing the integrative information in the emergency area, the decision-maker and technician can locate the emergency site and find the material storage places quickly and conveniently.

Earth-rock volume calculation

Method of earth-rock calculation The methods of earth-rock calculation can be sorted into three types, i.e. section method, grid method, irregular triangle method. For the variety of terrain, the scale size of the map, the precision demand of the algorithm and the computing speed, the different methods for the actual conditions are used to process earth-rock calculation (Xu *et al.*, 2002). This paper chooses the vertical section method to calculate the volume of earth-rock, which is one of the section methods and has the characteristics of high calculation precision, easy-to-make computer programming and realization facilitation.

Procedure of earth-rock calculation Elevation data of the ground surface where the levee is repaired are automatically retrieved from the system by means of DEM (digital elevation model). Then according to the difference between the ground elevations and design altitude of the levee, the earth-rock volume can be computed by the vertical section method. The procedure of earth-rock calculation is illustrated in Fig. 2.

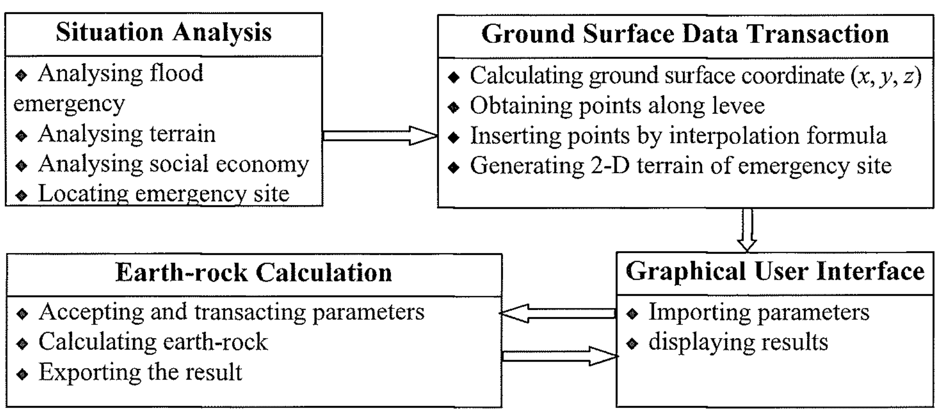

Fig. 2 Procedure chart of earth-rock calculation.

The main steps of earth-rock calculation are as follows:

(a) Situation analysis. In the process of emergency flood control, the decision-maker will firstly analyse information about flood emergency, terrain, social economy, etc. The emergency site is then located correctly after a lot of work has been done by means of Web GIS, such as querying, finding, measuring, buffer analysing, etc.
(b) Ground surface data transaction. Once the levee site is located from the first step, the levee line intersects with a set of contour lines. The program automatically obtains the 3-D coordinate values of these intersection points in terms of DEM. These points form a polygonal intersection line between the levee to be repaired and the ground surface. Because this polygonal line is not smooth enough to calculate earth-rock volume accurately, an interpolation formula is introduced to insert some other suitable points along the line. Then the program will generate 2-D terrain, a vertical section plane of the levee, with respect to the intersection line.
(c) Earth-rock volume calculation. The program accepts the parameters from Graphical User Interface (GUI), and automatically transacts them. Then the earth-rock volume is worked out. At last, the results computed from above steps are sent to GUI and visually displayed to decision makers.

Emergency material operation

Shortest path analysis Considering the special situation in the process of emergency flood control, the time of the emergency material operation is a key factor, which affects whether the emergency work will be finished successfully. Therefore the main objective function for optimizing the material operation decision model is to minimize the operation time. If the time of loading and unloading with materials is constant, the operation time can be minimized and simplified to minimize the transportation time, and be further simplified to minimize the path distance. As for other conditions, e.g. road and weather conditions, technologists can classify them into different grades and give them corresponding coefficients in the material operation. For example, if a road is broken by floods, the coefficient is $+\infty$.

This paper chooses the Dijkstra algorithm (Dijkstra, 1959; Wang *et al.*, 1994; Wu *et al.*, 2001) to solve the shortest path problem, i.e. to find the shortest paths from a given source to a goal point.

Data flow design of emergency material operation The data flow of emergency material operation is illustrated in Fig. 3. The main steps are as follows.

(a) The program will pre-analyse the volume of local earth-rock, and the plan of using local materials will be put in practice. If it does not meet the demands of the emergency work, the information of the material warehouses will be searched out from the database, and the appropriate material warehouse will be selected with regard to the material demand.
(b) According to the information of the selected material warehouses and the geography information of the emergency site, buffer analysis will be processed through Web GIS, and the information of road network among the buffer region, such as distance, path, road condition etc., is extracted.

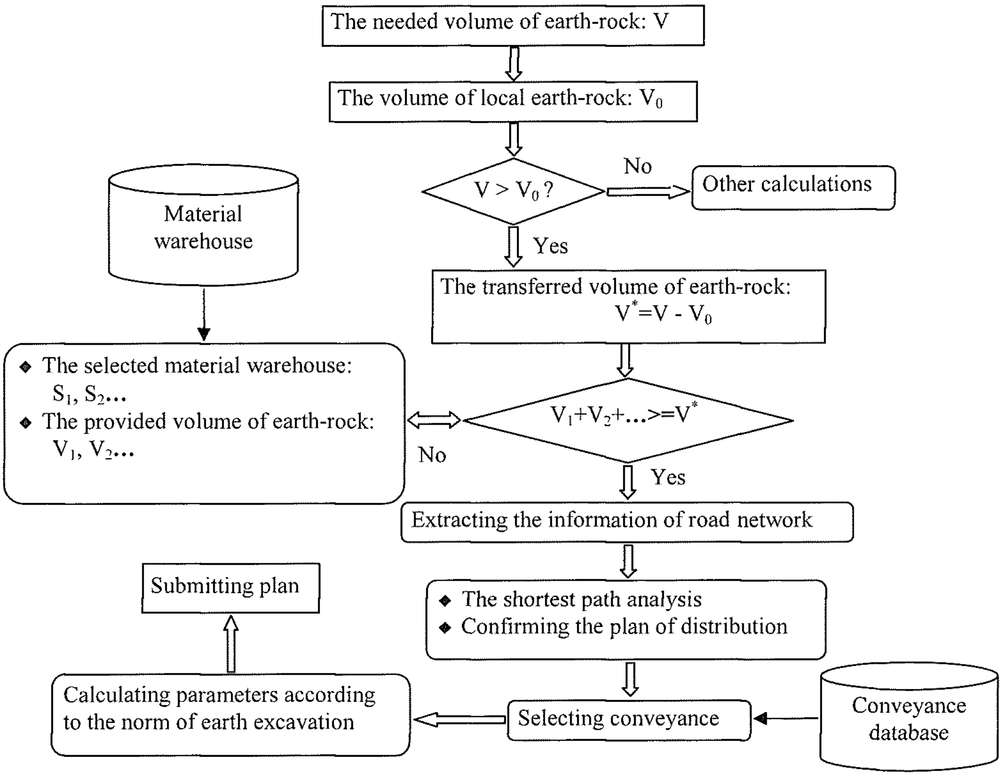

Fig. 3 Flow chart of emergency material operation.

(c) Integrating the information of road network, emergency materials and vehicles, Dijkstra algorithm is introduced to analyse and calculate the relative shortest path between material warehouses and emergency site. The shortest route will be visually displayed on a GIS map. According to the operation principle of handy transportation, the program automatically dispatches the demanded materials from the material warehouses to the emergency site.
(d) With regard to the amount of the dispatched materials from each warehouse and the weather situation, decision-makers analyse the information of operation, and put forward a feasible plan in which vehicles and equipment will be distributed to the transportation routes.
(e) According to the norm of earth excavation, the parameters of the final plan will be confirmed, which are the volume of mass transport, the detailed transportation route, the type and the number of vehicles, the amount of construction equipment and the labour force.
(f) The information of the final plan is submitted to the server and stored in the database. If the plan does not meet the demand, it can be called back from the database and be modified.

3-D-scene visualization

3-D-scence visualization is very useful to help analysts and decision makers form a visual vision to the real situation and make correct decisions. In this paper a method is introduced to realize 3-D-scene visualization, and its detailed steps are as follows: (a) through the client's browser, the terrain vector data are downloaded from the spatial database by the spatial server; (b) the downloaded data are transferred into DEM data by interpolation methods; (c) DEM data need to be processed further, and the geographic coordinate system (GCS) and the projected coordinate system (PCS) are created; (d) if the basic data meet the precision demand of application, the 3-D model of repaired levee is built. If the remote sensing (RS) data of the researched area can be obtained, it can be processed in the same way, and (e) based on the DEM data, levee's 3-D model data and RS data, 3-D-scene visualization is simulated by 3-D-viewing program (Xiao *et al.*, 2001; Liu & Liu, 2002).

APPLICATION CASE

Heilongjiang Province is one of the biggest inland provinces in China. There are 1918 rivers with catchment areas of more than 50 km^2. But there are few large control reservoirs to prevent great floods in Heilongjiang Province. In the Songhuajiang River and Nenjiang River catchments, the present measure of flood control mainly depends on embankments. So it faces more difficulties and increased loads in emergency flood control.

The above study is applied to Heilongjiang Province Flood Control Decision Support System, which not only improves the efficiency of emergency flood control,

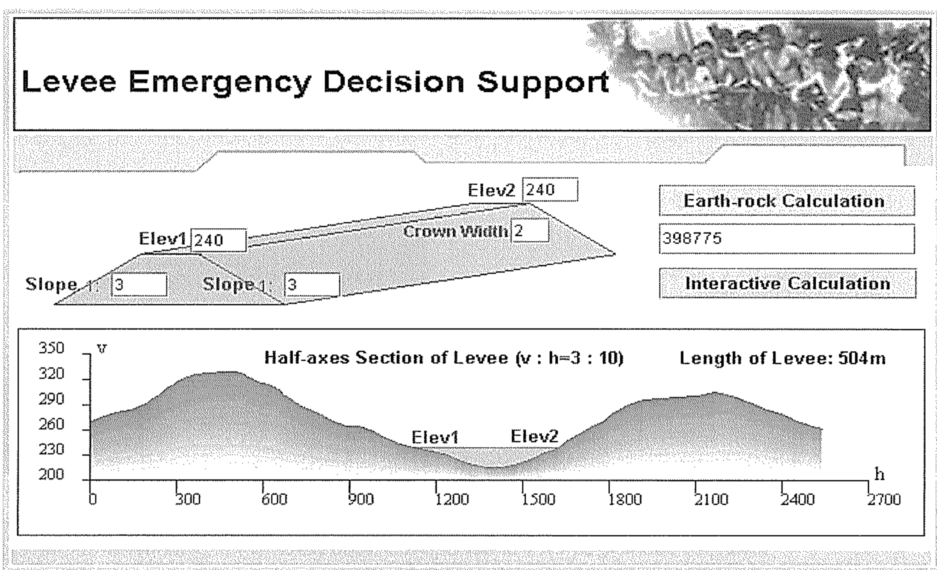

Fig. 4 GUI of earth-rock calculation.

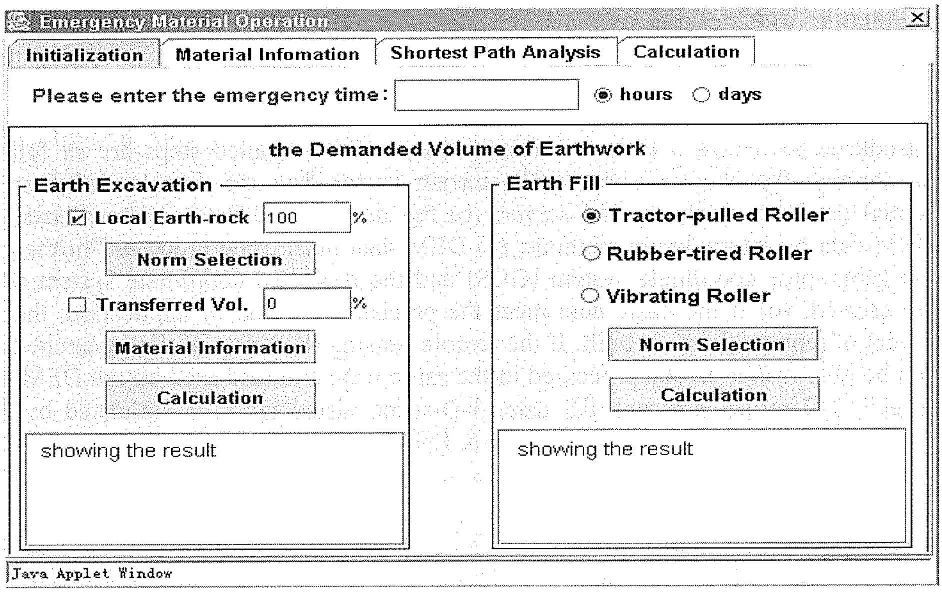

Fig. 5 GUI of emergency material operation.

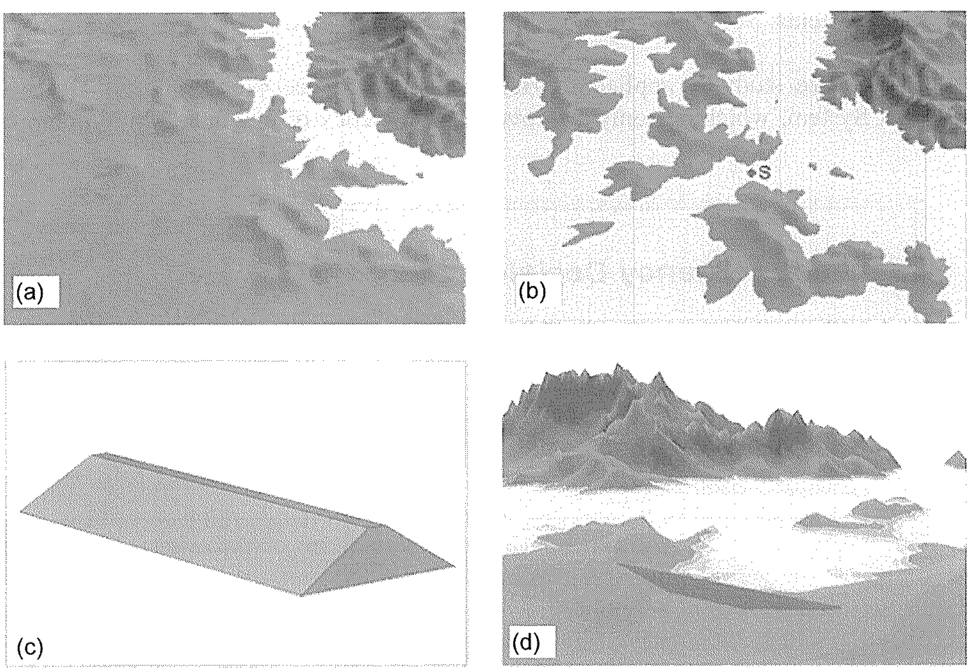

Fig. 6 Effect of 3-D-scene visualization. (a) Flood travelling state under normal water level; (b) submerged area under a given flood level; (c) 3-D model of the levee; and (d) 3-D-scene visualization of repaired levee.

but also guarantees the decision's reliability. The graphical user interfaces are as follows:

(a) GUI of earth-rock calculation is shown in Fig. 4. It is convenient for decision makers to input the parameters for earth-rock calculation, such as starting-point elevation, end-point elevation, top width, upstream slope and downstream slope of the levee to be repaired or built.

(b) GUI of emergency material operation is shown in Fig. 5. In this GUI analysts can do system initialization, query material information, analyse the shortest path for material transportation, and make a detailed plan of emergency material operation for decision makers.

(c) The effect of 3-D-scene visualization about the terrain, flood area and levee, is shown in Fig. 6. Figure 6(a) shows the flood travelling state under normal water level. Figure 6(b) shows the submerged area under a given flood level, and the emergency site is located at the flood entrance *S*, where the levee must be built up to control the flood. Figure 6(c) shows the 3-D model of the levee. Figure 6(d) shows 3-D-scence of the emergency site, where the temporary levee has been built up.

CONCLUSIONS

In the course of the rapid development of Web GIS, it has been applied to flood control decision support systems successfully, and has been playing an important role in information and emergency services. This paper studies how to integrate Web GIS with the analysis and calculations of emergency flood control, effectively. These Web GIS-based techniques of emergency flood control, such as site location, earth-rock calculation, material operation and 3-D visualization, are researched in detail. The result of this paper shows that it is feasible and necessary to design a Web GIS-based EFCS, and it can improve the efficiency of emergency flood control and guarantee the decision's reliability.

REFERENCES

Dijkstra, E.W. (1959) A note on two problems in connection with graphs. *Numerical Math.* **1**, 269–271.

Hu Siyi, Song Dedun & Wu Yongxiang (1996) Framework and design of the Yangtze River flood control decision support system. *Adv. Water Sci.* 7(4), 283–294.

Liu Renyi & Liu Nan (2002) Study of GIS-based calculation of flood area and visualization of virtual reality. *J. Zhejiang University (science edition)* **29**(5), 573–578.

Luo Xinlei (1999) Some problems in emergency and flood control. *Adv. Sci. and Technol. Water Resour.* **19**(4), 10–12.

Wang Sunan, Song Wei & Jiang Wensheng (1994) Comparison of the shortest path algorithms. *Systems Engng Electronics* **5**, 43–49.

Wu Lun, Liu Yu & Zhang Jing (2001) *Geographical Information System——Theory, Technique and Application*. Science Press, Beijing, China.

Xiao Lebin, Zhong Ershun, Liu Jiyuan & Song Guan-fu (2001) A Discussion on basic problems of 3D GIS. *J. Image and Graphics* **6**(9), 843–848.

Xu Jinghai, Li Mingfeng & Liu Weiqing (2002) A method for calculating cubic meter of earth volume based on DEM. *J. Nanjing Architectural and Civil Engineering Institute* **1**, 26~31.

Zhou Huicheng, He Bin, Liang Guohua, Xiao Jianmin & Yin Junxian (2003), Application of the Web GIS to the provincial flood and command information service subsystem. *Adv. Water Sci.* **14**(1), 104–108.