Earthquake Disaster Scene Simulation System for Buildings Based on 3DGIS Technology

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SUMMARY:
According to the features and demands of earthquake rescue on-site, automatic modelling and scene generation methods based on fundamental geographic data were investigated, and an earthquake scene model was proposed considering both effect of local site conditions on ground motion and vulnerability of different buildings. Based on ArcGIS Engine, the system in which the scene of pre-earthquake and post-earthquake can be created automatically and demonstrated intuitively was built with auxiliary functions such as analysis on global seismic damage, prediction of major search and rescue areas and query for key objects. Using fundamental geographic data of earthquake area and basic parameters of earthquake as input data, the developed system can estimate and analyze the seismic damage of buildings and its spatial distribution in earthquake region rapidly as soon as getting basic earthquake parameters, and forecast major search and rescue areas subsequently. The proposed system is suitable to use in earthquake search and rescue, which provides efficient support for earthquake emergency commanding.

Keywords: Scene simulation; Earthquake; 3DGIS

1. INTRODUCTION

After destructive earthquake occurred, it is the most urgent and important work to rescue the trapped people in damage areas. Obtaining their information (location, distribution, survival status, etc.) is the foundation of rescue work. However, it is very difficult to get all accurate information about these people throughout the disaster area in a short time. Some valuable information can be collected by several ways such as report of people from disaster area, the monitoring system setting in earthquake zone, etc. But this information is generally scattered and messy, which can not be used before collating and synthesizing. Moreover, more overall information about earthquake damage and casualties is essential for emergency management and formulation of the rescue plan. The information includes the destruction of buildings throughout the earthquake zone and the damage of roads, bridges and other infrastructures. The information also includes spatial distribution of trapped people, especially their concentration areas. Based on this information, more scientific rescue plan can be made and more specific relief operations can be performed effectively.

Therefore, a supportive analysis and decision-making tool, which can estimate damage extent of structures and spatial distribution of trapped people rapidly, is required to provide efficient support for rescue work and emergency commanding. In this Paper, A simulation system of disaster scene for buildings in earthquake was designed and developed based on 3DGIS technology.

2. REQUIREMENT ANALYSIS

Earthquake rescue work has high mobility and demands good timeliness, which makes some special requirements on functionality and deployment of earthquake scene simulation system. Firstly, it is the most major functional requirement to rapidly estimate the extent of the damage of structures and its spatial distribution in earthquake zone. In such demand, using different colors to represent different levels of damage is more intuitive and practical where the real three-dimensional geometry modeling function is not necessary. Secondly, the establishment of the scene should not rely on too complex parameters. It is appropriate to utilize public fundamental data which is easy to get and free to use. Thirdly, the speed of scene generation and display must be fast. The time of scene generation and refresh should be controlled in minutes and seconds respectively. Finally, the system is mainly used in portable computers, so hardware requirements can not be too high. System deployment and usage mode must be as simple as possible, so that users without training can use it smoothly.

According to these requirements, it is appropriate to use 3DGIS technology to build simulation system of earthquake disaster scene. Large-scale three-dimensional scene can be built automatically based on fundamental geographic data. The scene has high generation and rendering speed in which the attributes of objects are described in different colors. Such a system can run smoothly on portable computers.

3. SCENE MODEL DESIGN

After Strong earthquake occurred, energy produced by fault rupture spreads in form of seismic wave, which will be local enlarged and cause strong ground motion when it comes to the surface. Under the action of the ground motion, buildings, bridges, roads and other structures will be subject to different degrees of damage, and then form the earthquake disaster field which is called disaster scene in the visual. Unlike urban planning and virtual touring, earthquake scene simulation focuses on the performance of the failure modes of various objects, especially the destruction forms of buildings. Therefore, the earthquake scene design not only discusses how to present damage form of single object, but also lets the layout of the scene be consistent with the spatial distribution of seismic damage.

There are three ways to establish three-dimensional scene: manual, automatic and semi-automatic. In manual method, geometric solid model of each element in scene will be created using three-dimensional modeling software. The advantage of this method is that produced scenes are very realistic, and the disadvantage is the heavy workload and it also needs to collect detailed information of each scene element. Automatic mode creates three-dimensional geometric models through program which utilizes basic geometric data of scene element, such as building floor plans and building height. In this way large-scale three-dimensional scenes can be built automatically and quickly without some details, such as texture and mapping. Semi-automatic mode sets up three-dimensional geometric models of some typical scene elements and constitutes a geometric model library. The most matching geometric model will be automatically searched according to basic geometric data of the scene element, which will be added to the scene after orientation and geometry transformation. Semi-automatic mode has the advantage of manual mode and automatic mode. High-quality scenes can be established automatically, and the generation and rending of scenes can be very fast. However, semi-automatic method needs the support of scene drive module and impeccable geometry model library, which can only run smoothly on high-performance computers. Based on the practical requirements of rescue work, this paper sets up pre-disaster and post-disaster scenes using automatic method. Damage state of buildings is characterized with different colors.

The establishment of pre-disaster scene is based on the support of GIS development components and fundamental geographic data. According to geometry parameters contained in building layer, solid models of buildings will be created quickly and automatically with 2.5D modeling function. Based on the digital elevation data in the study area, three-dimensional terrain can be also generated automatically.

The establishment of post-disaster scene can not perform without the support of attenuation law of ground motion and seismic damage prediction methods. According to the basic parameters of the earthquake (epicenter location, focal depth, magnitude), earthquake influence field will be got through the law of propagation and attenuation of ground motion, and then damage grade of each specific building in disaster area can be determined by damage prediction method for buildings(Fig. 3.1).

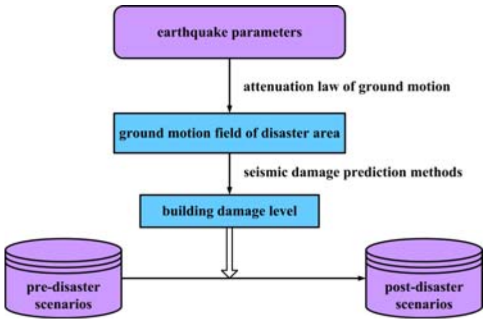

Figure 3.1. Establishment processes of post-disaster scenarios

This article is not devoted to the research on attenuation of ground motion and seismic damage prediction method. Seismic damage prediction method uses (Dezhang SUN, 2008), and attenuation model of the seismic intensity uses (Suyun WANG, Yanxiang YU, Ajia GAO, et al, 2000).

4. SYSTEM IMPLEMENTATION

In this paper, Visual C# 2005 (Jesse Liberty, 2007) was utilized to develop the simulation system, in which ArcGIS Engine (ESRI, 2004; Renyi LIU, Nan LIU, 2006) was taken as underlying driver. The major advantage of ArcGIS Engine is that it can be independently used outside the large framework of ArcGIS Desktop. So it can combine with many mainstream programming languages and the developed applications can run independently.

The system comprises master control module, ArcEngine-support module, ground motion filed & seismic damage calculation module, scene-generation module, and interaction interface module. The master control module is in charge of integral control. The scene generation module establishes and shows the scene before and after disaster on the support of ArcEngine. The ground motion filed & seismic damage calculation module is responsible for estimating the influence of seismic intensity and the damage degree of buildings, which provides the basis for the generation of seismic disaster scene. The interaction interface module takes charge of communication with user.

4.1. Procedure Framework Establishment

ArcObjects is a set of components based on Component Object Model (COM) technology, which provides almost all of the underlying functionality of the GIS. Each major GIS module is divided into several components and each one of them performs specific functions. So GIS components and non-GIS components can be easily integrated through visual development tools and forms various applications to meet different specific situations. ArcEngine is essentially a subset of ArcObjects, which encapsulates its major functions. Because .NET platform can not directly access unmanaged COM components, its interoperations with COM components must be achieved by COM Interop technology. ArcEngine provides a set of Interop Assembly (PIAs), which makes COM components can be used in .NET environment. PIAs take all classes, interfaces, and constants of the COM components as .NET managed classes.

Based on the above basis, building a custom GIS application in Visual C# 2005 environment only needs a few simple steps: 1) Creating forms. Forms provide containers for GIS controls and other visual interface elements. 2) Adding necessary GIS controls, then setting display and interaction area for them. 3) Adopting ESRI object library and making these controls functions apply in project. 4)

Adding necessary "Using" statement in code of form classes, which makes the required interfaces, classes, methods and properties be used. In this paper, GlobeControl is used to display three-dimensional scene; TocControl is used to control layer positioning and display; ToolbarControl contains some built-in buttons related to data load and control of the scene display. Component library referenced includes System, SystemUI, Geodatabase, Geometry, DataSourceFile, DataSourceRaster, Display, Carto, Output, Controls, 3DAnalyst and GlobeCore.

4.2. Pre-disaster Scenarios Establishment

Fundamental geographic data of a specific area serves as data source to establish the scenarios before earthquake. Building layer comprises plane geometric data of buildings and fields describing building height (some files provide the number of building layers from which building height could be calculated out according to structure type). Based on these two kinds of data, geometric solid models of buildings can be set up by the underlying support of ArcEngine. It transforms the original plane polygon point-set into spatial polygon point-set firstly and then the polygon is stretched to the solid model. Fig.4.1 is part of building layer in Heihe city, Heilongjiang Province, China. Fig.4.2 is the stretched three-dimensional scene. The establishing time of scene before earthquake is related to the number of buildings. For instance, it takes about 20 minutes to stretch about 13,000 buildings in Heihe city. For same region, the pre-earthquake scene built every time is always same. So the pre-earthquake scene just needs to be created once. The stretched Shape file can be saved and reused in the follow-up analysis.

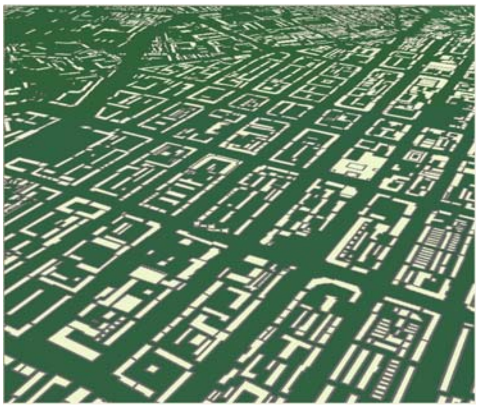

Figure 4.1. The building layer before stretch

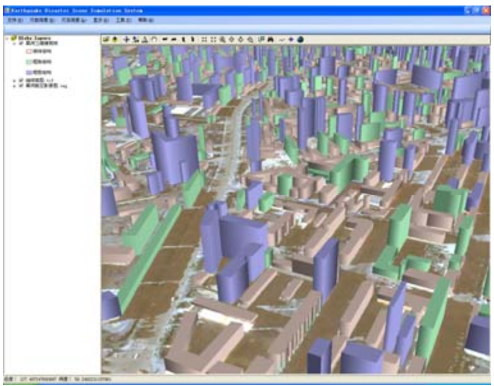

Figure 4.2. The pre-disaster scenario with aerial image

Loading stretched scene, double-click the corresponding layer in TocControl, and the study area will be navigated. By TocControl and toolbar buttons, functions such as scenes view, zoom and layer switching can be achieved. The initial building scene is monochrome rendering, and you can click "color characterization" option to represent different structure types in different colors. If there is aviation map of the study region, it can be added to the scenario to improve the fidelity of the scene. Fig 4.2 is pre-disaster scenarios of Heihe City where the aerial image map was added.

4.3. Post-disaster Scenario Establishment

The establishment process of post-disaster is shown in Fig 3.1, and it is mainly achieved in ground motion filed & seismic damage calculation module. Firstly, basic parameters of earthquake are received by FormEarthquake class, and influence intensity of each building is calculated according to seismic intensity attenuation model. Secondly, using the influence intensity as input, the damage level of each building is estimated considering structure type, construction standard, building age, building height (layers), site type and other factors, and then it will be deposited into DamageLv field of scene file. Finally, each building model with different damage level is rendered in turn using specified colors and the disaster scene formed is displayed in GlobeControl (shown in Fig 4.3).

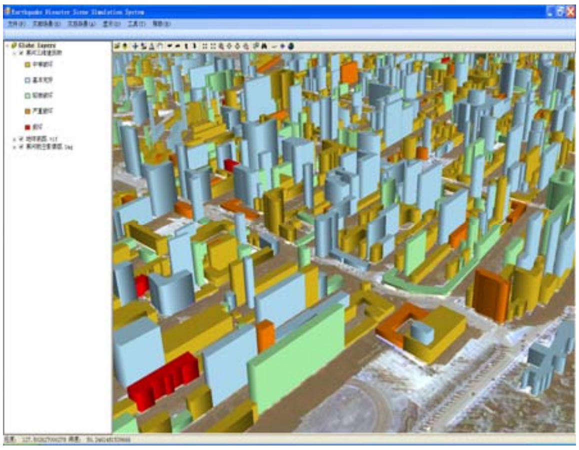

Figure 1.3. The post-disaster scenario

The establishment of post-disaster scene is separated from rendering processes. It has two advantages: 1) calculation of influence intensity and seismic damage grade of buildings is quite time-consuming, and for the same seismic parameters, the calculation process actually needs only once. Separating calculation from rendering process can significantly improve the performance of programs; 2) separating calculation from rendering, post-disaster scenario data can be stored with the pre-disaster scenarios data in same file, so it is easy to switch between pre-disaster scenario and post-disaster scenario.

4.4. Analysis of Post-disaster Scenario

According to the needs of on-site search and rescue work, the following analysis functions are achieved in post-disaster scenario:
1) Analysis of the overall damage. In the aerial mode, overview of seismic disaster can be browsed intuitively and serious areas can be determined directly. By zooming and moving the scene, the destruction level of every building (moving the mouse to the corresponding geometric model, its latitude and longitude coordinates will be automatically displayed in the status bar) can be clearly observed. The number of each type of structures at different damage grade and its proportion will be checked in pie chart by clicking “Statistics” menu. The results of overall analysis can be used as the initial basis for rescue command decision-making and rescue plan programming.

2) Attributes query. Click “Properties Query” menu and click the building which needs to be queried, and then the building will be highlighted. At the same time a dialog box will pop up, which shows the building’s name, address, type of structure, building area, height and other attribute information. Verifying the earthquake damage of key objects and directing specific search and rescue operations need to use these basic data.

3) Group query. Through group query, the information of buildings meeting certain conditions can be extracted, displayed and output in batch. For example, if you click “ruinous buildings” menu, then all buildings at the damage grade of “ruin” will be highlighted in the scene, and a form will be created to display basic properties of them. Another example, setting query condition to “masonry structure && medium damage”, related data of masonry structures at damage level of “moderate damage” can be obtained (shown in Fig 4.4).

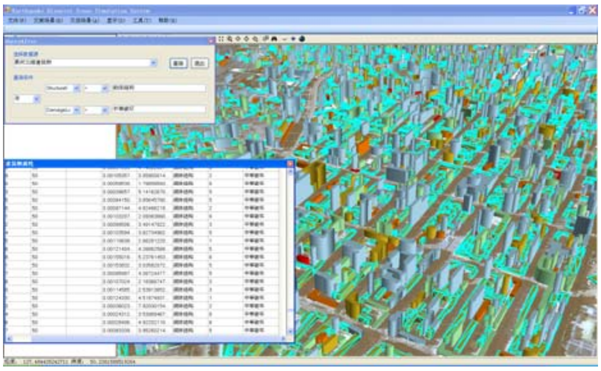

Figure 4.4. Group query

4) Major search and rescue areas analysis. Usually, the place where the building damage is more serious is also the more concentrated area of trapped people, so major search and rescue areas can be inferred from the damage level of the buildings. In this paper, different damage levels are assigned different weights (weight is 0 when the damage grade is intact or minor). For each building at damage grade of ruin or severe damage, all buildings around within a certain distance are retrieved to calculate their sum weight. If the sum weight of an area is greater than a threshold weight, the area will be selected as a major search and rescue area. If there are intersecting areas, they will be merged together. As shown in Fig 4.5, each red area is a major search and rescue area. The digit marked on the figure represents overall damage weight of each region, which can be used as the basic priority of search and rescue.

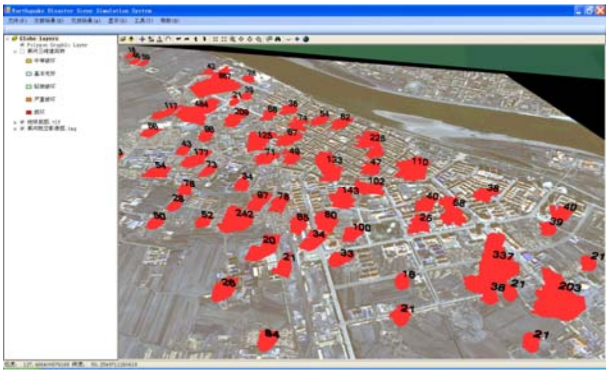

Figure 4.5. Major search and rescue areas analysis

5. CONCLUSION

In this paper, a simulation system of earthquake disaster scene for buildings was designed and implemented based on 3DGIS technology to meet practical needs of earthquake rescue work on-site. Using fundamental geographic data of earthquake area and basic seismic parameters as input data, the developed system can estimate and analyze the seismic damage of buildings and its spatial distribution in earthquake region rapidly, and forecast major search and rescue areas subsequently. The proposed system is suitable to use in earthquake search and rescue, which provides efficient support for earthquake emergency commanding.

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