Computers & Geosciences 89 (2016) 12–20

Contents lists available at ScienceDirect

Computers & Geosciences

journal homepage: www.elsevier.com/locate/cageo

Research paper

An approach to 3D model fusion in GIS systems and its application in a future ECDIS

Tao Liu*, Depeng Zhao, Mingyang Pan

Navigation College, Dalian Maritime University, Dalian, 116026, China

ARTICLE INFO

Article history:
Received 13 October 2014
Received in revised form
24 September 2015
Accepted 15 January 2016
Available online 16 January 2016

Keywords:
3D model
Map
Chart
Fusion
GIS
ECDIS

ABSTRACT

Three-dimensional (3D) computer graphics technology is widely used in various areas and causes profound changes. As an information carrier, 3D models are becoming increasingly important. The use of 3D models greatly helps to improve the cartographic expression and design. 3D models are more visually efficient, quicker and easier to understand and they can express more detailed geographical information. However, it is hard to efficiently and precisely fuse 3D models in local systems.

The purpose of this study is to propose an automatic and precise approach to fuse 3D models in geographic information systems (GIS). It is the basic premise for subsequent uses of 3D models in local systems, such as attribute searching, spatial analysis, and so on. The basic steps of our research are: (1) pose adjustment by principal component analysis (PCA); (2) silhouette extraction by simple mesh silhouette extraction and silhouette merger; (3) size adjustment; (4) position matching. Finally, we implement the above methods in our system Automotive Intelligent Chart (AIC) 3D Electronic Chart Display and Information Systems (ECDIS). The fusion approach we propose is a common method and each calculation step is carefully designed. This approach solves the problem of cross-platform model fusion. 3D models can be from any source. They may be stored in the local cache or retrieved from Internet, or may be manually created by different tools or automatically generated by different programs. The system can be any kind of 3D GIS system.

1. Introduction

3D models are widely used in GIS, medical field, mechanical field, movie, game, and so on. They have become the fourth data type of multimedia after sound, image, and video (Cui and Shi, 2004). As an information carrier, 3D models are more visually efficient, quicker and easier to understand and can express more detailed information than traditional two-dimensional (2D) graphics. They can dramatically improve users' awareness of the environment and cognition of the objects they describe. GIS researchers start to use 3D models to describe spatial objects such as buildings, terrains, and so on. This significantly improves the cartographic expression and design and greatly promotes the development of GIS applications.

With the development of 3D information systems such as digital earth, digital city, and so on, there is an increasing demand for 3D models. Development and maturation of 3D modeling tools make the modeling process easier and easier. Tools such as 3DS Max, SketchUp, Building Information Modeling (BIM) tools, and so on, help users conveniently create 3D models. Increasingly advanced Internet technology provides the conditions necessary for people to conveniently share and search 3D models. This promotes the development of 3D models. All these have led to an explosion in the number of available 3D models on the Internet and in domain-specific databases. And these have resulted in the rise of a 3D model retrieval platform for public usages (Funkhouser et al., 2003; Chen et al., 2003; Zhang, 2005; Tangelder and Veltkamp, 2008). A number of 3D model data-sharing databases and data centers have been established, such as 3D Warehouse, 3D Source, and so on. Moving Picture Experts Group (MPEG) researched multimedia content description interface standard (MPEG-7) to provide the standardization of content-based description and retrieval specifications of 3D models (Sikora, 2001). And MPEG-7 made the web as searchable for multimedia content as it is searchable for text. This further promotes the application of 3D models.

Many researchers in the GIS area have studied the application of 3D models to provide 3D systems, aimed to reduce the cognitive load and provide more rich and intuitive spatial analyses. Coors (2003) presented a data model for the search of 3D models and studied the visualization of 3D models in 3D GIS. Wu (2004) presented a universal 3D model, generalized tri-prism for 3D geoscience modeling system and real-3D GIS. Yu et al. (2004) introduced a novel approach to the mesh editing of 3D models with

* Corresponding author.
E-mail address: dlmult@hotmail.com (T. Liu).

http://dx.doi.org/10.1016/j.cageo.2016.01.008

the Poisson equation as the theoretical foundation. Apel (2006) proposed an integrated data model for geological observation data and geomodels and presented an approach for querying observation data and 3D geomodels based on their 3D spatial and geological properties. Gruen (2008) presented the urgent need for the generation, administration, analysis, representation and manipulation of 3D models in digital earth. Isoda et al. (2009) explored an approach for creating large-scale urban 3D models using GIS data. Thompson et al. (2011) analyzed the emerging issues for the creation of an information rich and geometrically accurate 3D model for two adjacent cities with the conclusion that 3D models could offer much greater accuracy and efficiency for the planning process. Xu and Coors (2012) combined system dynamics model, GIS and 3D visualization to assess the urban residential development. Mali et al. (2012) used 3D city models to give the precise information support to management policies and future planning of urban resources. Jakubiec and Reinhart (2013) used detailed geometric urban massing models and Daysim-based hourly irradiation simulations to predict city-wide electricity gains from photovoltaic panels.

In the aspect of ECDIS, since Ford (2002) first introduced 3D navigational charts, many researchers have studied 3D charts to provide chart display systems, aimed to reduce the amount of marine accidents caused by fatigue, mental overload and limited awareness of the navigational situation. Gold et al. (2005) presented a prototype of an interactive 3D "pilot-book" with 3D model (map) derived from Electronic Navigational Chart (ENC). Porathe (2006) proved that compared with traditional 2D charts, 3D charts were more efficient and could dramatically reduce the number of human errors. Ternes et al. (2008) proposed a type of 3D visualization system that worked with manually prepared 3D models, for the support of navigation during hydrographic surveys. Ray et al. (2011) introduced a 3D chart to facilitate the understanding of maritime behaviors and patterns at sea. Liu et al. (2014) proposed a type of future ECDIS, where 3D models in this system are fused with 2D charts to describe entities in the navigation environment such as buoys, buildings, wharves, bridges, etc.

There is a huge potential of applications in reach, if we can take advantage of the 3D model in overwater and overland GIS applications. It should be noted that, in all applications, we need to solve a problem first: fuse the 3D model into our own system or software. Since systems vary widely and there are so many available 3D models on the Internet and in databases, this problem will be more complicated. However, most of the researches listed above only focused on the construction and visualization of 3D models. Few researchers studied how to automatically, precisely and efficiently fuse 3D models in GIS systems, especially in ECDIS.

In this paper, we propose an automatic and precise approach to fuse 3D models in GIS systems based on 2D vectors. 2D vectors can be extracted either from maps and charts or from remote sensing images. 3D models from different sources may be in any pose, size, and position. First, we give some basic concepts and describe our system AIC 3D ECDIS. Then we introduce the fusion approach. The approach is mainly divided into four parts: pose adjustment, silhouette extraction, size adjustment and position matching. At last, we implement our method in our system AIC 3D ECDIS to provide a more precise and efficient 3D depiction for a future ECDIS. Also the application shows the effectiveness of our approach. The automatic and precise fusion of 3D models in GIS systems is studied.

2. Basic concepts and AIC 3D ECDIS

In order to give a detailed introduction to our fusion approach, this section first introduces some basic concepts. Section 2.1 gives the concept of model representation; Section 2.2 gives the definition of simple mesh, which is an important concept in our fusion approach; Section 2.3 introduces our system AIC 3D ECDIS; Section 2.4 describes exiting problems in the 3D model fusion.

2.1. Model representation

Representation methods of 3D models are usually divided into two classes: boundary representation and space-partitioning representation, although not all the methods completely belong to one of them. Boundary representation methods use a group of curved surfaces to describe 3D models. Space-partitioning representation methods are used to describe the internal properties of 3D models. They divide up the space the model occupies into regular or cubic voxels.

The most commonly used way of boundary representation is to use a set of surface polygons (usually triangles) to surround the object. Many graphics systems use a set of surface polygons to store the description of the object. Because the description of each surface is a linear equation, it is helpful to simplify and accelerate the rendering of the object. For this reason, the polygon description is usually referred to as "standard graphics object". In some cases, polygon description is the only way of boundary representation. But many graphics packages also allow users to use other methods to describe an object, such as spline surface. Then these packages convert the description to polygon description and send the results to rendering pipeline. Our research is based on standard graphics object. Each model is given as triangle meshes.

2.2. Simple mesh

In geometry, a simple polygon is defined as a flat shape consisting of straight, non-intersecting line segments or "sides" that are joined pair-wise to form a closed path.

In this paper, we define a simple mesh as a graphics object consisting of continuous, non-intersecting triangles that are joined together to form an entity whose projection is a simple polygon in the specified direction. The "specified direction" in the definition is determined by the specific application.

2.3. AIC 3D ECDIS

AIC 3D ECDIS is a future ECDIS (Liu et al., 2014). This system provides a 3D description for the future ECDIS based on digital earth. The data of this system are mainly divided into six categories: 2D vector ENC data, sounding data, terrain data, tide data, 3D model data, remote sensing image data, which are based on the entity modeling method and digital earth theory. All these data are fused together to provide a more visually efficient ENC system. This system can support global spatial data and 3D visualization, which merges the artificial ENC water surface object with the 3D navigation environment in a unified framework and interface. It fuses multiscale charts into 3D scene based on underwater topography and remote sensing image (Liu et al., 2015). In order to meet operation requirements of the chart work and practices of navigators, Mercator transformation is constructed to transform the fusion data between spherical coordinates and Mercator projection scene coordinates in the system. And this system can be published on the web to provide application and data service through the network.

The main difference between our system and other GIS systems is that our system can support the fusion and global visualization of multiscale vector ENC data, underwater topography, 3D model data, remote sensing image data and other spatial data. This system can provide more spatial calculations and analyses compared with traditional ECDIS, especially in such cases as when the ship enters and leaves port, or when the ship crosses under the bridge.