Research and Development of 3D Modeling

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Summary

3D modeling is a key technique to much research and applications. In different fields of research and applications, 3D modeling methods of model-data acquisition and modeling have their own specialties. The paper systemically introduces equipments of 3D data acquisition and modeling methods, discusses the characters and developments of laser scanning system and Image-Based Modeling and Rendering (IBMR) in recent years. The paper also introduces applications of 3D modeling including tissue engineering and heritage protection. Finally, several main problems and a few deficiencies are pointed out and further challenges foreseen from three aspects: modeling retrieval, digitizing method, and dynamic modeling.

Key words:

3D modeling; IBMR; Data Acquisition; Rendering

1. Introduction

Building exact models to simulate and present principles of things' behaving, is a general and important method for modern science. In applications and science area, there is also a growing interest and trend in modeling the world in digital three dimensions. To model and simulate the real world, it is a process of digitizing objects' shape, motion, texture and other properties according to the emphasis.

Much work has been done and has received remarkable achievement on digital equipments and software. Computer-aided 3D modeling tools, including laser scanning system and Image-Based Modeling and Rendering (IBMR), are getting more and more powerful. Modeling objects evolve from objects with simple structure to complicated human face, limb, hair, and even fluid.

In the past, the main applications of 3D modeling were visual inspection and robot guidance. Nowadays, the emphasis is shifting. 3D modeling has been widely used in areas including computer graphics, virtual reality and communication, and there is more and more demand for 3D content for tissue engineering and heritage protection. In different fields of research and applications, 3D modeling methods of model-data acquisition and modeling have their own specialties.

In this paper, the process of 3D modeling including 3D data acquisition, modeling and rendering is introduced systemically. The paper also discusses the characters and developments of laser scanning system and IBMR in recent years, introduces applications of 3D modeling including tissue engineering and heritage protection. Finally, several main problems and a few deficiencies are pointed out and further challenges foreseen from three aspects: modeling retrieval, digitizing method, and dynamic modeling.

2. 3D data acquisition

To model an object, it is necessary to get data about object's size and depth at first. In different fields of research and applications, there are different demands accordingly. Equipments and modeling methods adopted in the modeling process are also different. For example, to reconstruct 3D underwater environment, people have to make use of sonar and ocean satellite to get the underwater terrain data. To improve the understanding of a human operator driving an underwater Remotely Operated Vehicle, U.Castellani reconstructs 3D underwater environment by acoustic camera system in real time, and the resolution is about 5cm at the frequency of the acoustic signal 500kHz[1].

In general, measurement systems comprise of contact and non-contact methods [5]. The contact methods vary from simple measurement using tape to the sophisticated Coordinate Measuring Machine (CMM). These two methods are commonly used in mechanical engineering. Measurement using tape is conventional and subject to errors. Its efficiency is slow. Though CMM is totally automated and its measurement accuracy is 0.02mm, CMM requires a stable platform and the object's size is limited.

Technology of non-contact measurement is a result of the development of computer graphic and vision, acoustics, optics and related equipments. Non-contact methods include laser scanning system (e.g. VIVID910 laser scanner), geodetic total station system (e.g. AXYZ system, the accuracy is about 0.05mm), close range photogrammetric system (e.g. V-STARS system, its accuracy is better than 0.05mm), and structured light system (e.g. Eyetronics' ShapeCam[2], whose accuracy is up to 0.5mm based on how tight user focuses his grid),etc [5].

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2.1 Laser Scanning System

Laser scanning systems, for example VIVID910, have remarkable advantages: high speed (scanning time varies from 0.3 sec (fast mode) to 2.5 sec (fine mode)), enormous data (up to 77,000 or 300,000 points for fast and fine modes respectively), high accuracy (0.22mm, 0.16mm and 0.10mm in x, y and z respectively), and simplicity. According to object sizes and measurement distances, users also can select and use one of 3 types of exchangeable mounted lens.

To model outdoors environments efficiently and accurately, Toshihiro and Masayuki [3] get range and color data by integrating an omnidirectional laser rangefinder and an omnidirectional multi-camera system. To register multiple range data of wide area stably and simultaneously by the improved ICP algorithm, planar surfaces such as walls and roads are extracted and used in the registration process. The generated surface model is then texture-mapped by omnidirectional images selected in consideration of resolution and occlusion. The omnidirectional laser rangefinder LMS-Z360's measurable range varies 1m to 200m, and its measurement accuracy is ±12mm.

To acquire 3D information of buildings in an accurate and fast way, Yusuf Arayici adopted 3D laser scanner technology for CAD modeling [4]. In this EU funded INTELCITIES project, the CAD modeling is integrated with various systems such as 3D printing and VR projection systems for storing data of existing buildings, e-Planning and e-Inclusion, e-Regeneration, Virtual Urban Planning, etc (www.intelcitiesproject.com).

Tough this type system can get 3D data of objects' surface as point clouds in an accurate, fast and automatic way, the related equipments are expensive and restricted to the condition; some systems do not work well in sun or rain. Though the acquisition phase can profit of automatic procedures, the 3D point clouds needs post-processing for a useable output. To represent an architectural object analytically, it especially requires many manual actions.

2.2 Close Range Photogrammetric System

Close range photogrammetric systems, such as V-STARS system, are relatively cheap. Research results of [5] indicate its practicality in terms of speed, reliability, flexibility and accuracy. In medical area, 3D data of organs and tissue usually come from computed tomography (CT), magnetic resonance imaging (MRI), optical microscopy, micro CT, etc. Each has its own advantages and limitations. The latest development of micro-CT technology has been successfully used to model lung tissue at 10-50 micron resolution [6]. Dhenain et al. scann mouse embryos by micro-MRI, and the resolution achieved is 20-80 micron voxels.

It is easier for IBMR to map a suitable texture on model's surface. But effect of this method mainly depends on the algorithmic design of modeling. These algorithms, such as modeling based on shadow or silhouettes, are mostly complex and need more computing resource. In addition, this type of algorithm can hardly model accurately an object with a concave part of surface. It is a common issue for perspective-based algorithms.

In recent years, to acquire 3D information in laboratory, some researchers adopt common equipments including a turntable and a digital camera [8, 9, 10]. The components are not complex and easy to find, install, and use. In these systems, the cameras are all fixed. By turning the turntable, obtain the real object's multiview range images. To register and merge range images into a common coordinate system automatically, Soon-Yong Park et al. introduce and calibrate a turntable coordinate system with respect to the camera coordinate system [8]. Ulaş Yılmaz et al. propose a vision based camera calibration algorithm and use this algorithm in the extraction of the rotations axis [9]. Miguel Sainz et al. [10] and [8] add artificial fiducial patterns to the scene to help detect features and calibrate the stereo camera. The hardware configuration is simple and inexpensive. The complexity of the methods is also decreased. But the design of these systems limits their application, especially for wide area environment and objects that can't be moved.

Before constructing models, calibrating camera to get camera's internal and external parameter is important and necessary. For systems that use fixed cameras, calibrating is easier, but some parts of object with key geometry characters may not be sampled and acquired. The model reconstructed will have inevitable deficiency of structure and texture. Compared with fixed-camera system, systems that use hand-held cameras can get object's 3D data of all sides, but it brings difficulties of camera calibration and image matching.

To get hand-held camera's parameter, Liu Gang [11] accordingly selected some characteristic points of range images by human-computer interaction. This type of system also can input some patterns in the scene or the background to help calibration, while the object to be modeled might occlude partially the pattern. Anselmo Antunes Montenegro et al. [12] adopt a calibration method based on model recognition, which is an adaptive space-carving algorithm that uses photometric and segmentation information.

3. 3D modeling and Rendering

Graphics-based modeling and rendering (GBMR) is a traditional method. 3D modeling software, such as AutoCAD and Maya, can help modeling by interaction. But it is time-consuming and demands many skills for users, especially to model scenes with complicated and irregular structures.

3.1 Image-Based Modeling and Rendering

While traditionally computer graphics focuses on transforming 3D data into 2D image projections, images play a more central role in IBMR. This field is comparatively young; its configuration is simple and mostly uses common equipments; it can model objects with different sizes; it also can get the information of depth and texture at the same time. IBMR is still a focus in 3D modeling field.

Carlos Hernández Esteban [13] classifies methods of IBMR according to the information they use. The first class is methods of shaping from silhouette. These methods obtain an initial estimation of 3D model known as visual hull. They are robust and fast, but because of the type of information these methods use, they are limited to simple-shaped objects. The second class includes methods of shaping from shading. These methods are based on the diffusing properties of Lambertian surfaces, and very dependent on the light condition. The third class is the methods that use the color information of the scene. There exists different ways of using the color depending on the type of the scene to be reconstructed. One way is to carve a voxel volume by color consistency, while the result is a model composed of a set of voxels, which is difficult to represent a 3D mesh model. Another way is to guide a deformable model by the color consistency, which is sensitive to light condition for these methods' comparing absolute color values. The other way is to compare local variations of the texture, such as cross-correlation methods described in [14]. Some methods of using color information use some other type of information at the same time, such as texture and silhouette integrated in [13]. Though these methods can achieve a better model, the quality is still limited for the way of merging different data.

3.2 Researches and Development of IBMR

After getting range images, the first step is calibrating the camera by feature extraction and matching. Normally, in this step, select and match at least 7 pairs of corresponding points between two images, calculate the fundamental matrix by polar geometry constrain, and get projection matrix at last.

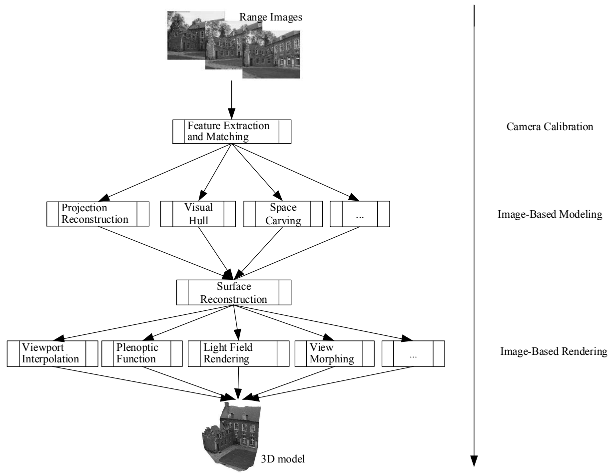

Fig. 1 Image-Based Modeling and Rendering (IBMR)

Next step of modeling includes different methods (Fig. 1), such as projection reconstruction, visual hull, space carving. [15] proposes an algebraic dual-space method that requires no correspondences. The method estimates depth information on contours from curvature information and creates a visual hull of the object. The method also requires that surfaces should be sampled more densely where curvature changes rapidly.

In traditional, model's surface is constructed by polygon mesh. While in many 3D information acquisition systems, the 3D data got is point data or point clouds. As point clouds do not possess topological connectivity explicitly, they are proven to be more convenient to simplify latter processing and presenting. They are more suitable in applications that do not require continuous surface or perform view-dependent multi-resolution re-sampling.

IBMR can map texture on object's surface easily to synthesize a realistic model [10, 11, 16]. During the process of image-based rendering (IBR), operations need not much computing resource; the rendering time is independent of the complexity of the scene, and the method can synthesize realistic scenes and animation in real time. Most methods of IBMR are independent of scale, so it can obtain a 3D model of the whole site or object. IBR mainly include methods of viewport interpolation, plenoptic function, view morphing, light field rendering, concentric mosaics.

When modeling outdoor environment and buildings, [3] and [17] integrate laser scanning and IBMR these two different types of method, which can not only get point clouds in an automatic, fast and accurate way, but also present models in detail, which is the advantage of IBMR in texture mapping. So, these two methods are complementary in a certain sense.

4. Applications of 3D modeling

Nowadays, 3D Models are used in a large range of exciting applications areas: Animation, Archaeology, Architecture, Dentistry, Education, Fashion and Textiles, Foot Wear, Forensics, Games, Industrial Design, Manufacturing, Medical, Movies, Multimedia, Museums, As-built Plants Rapid Prototyping, Reverse Engineering, Sculpture, Toys, Mold Making, and Web Design. 3D modeling has become a key technology in many applications.

Research on 3D modeling promotes the development of heritage protection. There exist some projects of heritage protection that use laser scanning, such as Digital Michelangelo Project [18, 19], Stanford Digital Formae Urbis Romae Project [20]. [21] uses ShapeCam, a structured light system, to build a detailed 3D model of the Antonineny mphaeum at the ancient city of Sagalassos (SW-Turkey). Pagpagiannakis et al. built Turkey Istanbul's internal and external models of SS. Sergius and Bachhus Church by 3D Studio Max.

Computer-Aided Tissue Engineering (CATE) is a new field of biomedicine. In this field, 3D modeling is widely used to help modeling tissue and organs, guide the design of artificial organs and tissue, such as bones and vessel, and perform tissue engineering [22, 23, 24].

5.Conclusion and discussion

More and more fields now need and adopt technologies of 3D modeling. There are a number of directions in which we need to continue. Foremost among these is 3D model retrieval. To measure similarity of models, characters of 3D models, such as shape, topological construction and texture, are used. These characters are difficult to describe for users and complicated to calculate, while an effective retrieval function is necessary for an integrated 3D modeling system.

Nowadays, the visual quality becomes one of the main points of attention. There is more and more demand for 3D content with higher accuracy. Information of scene and object could not be collected absolutely during the 3D data acquisition, and some data is inevitably lost, we could not recover the real word from videos or images by the current design. So, it is worthy for us to explore new methods to digitize the real world.

Dynamic model is our new direction for the future work. Dynamic models can simulate reciprocal actions of objects, which is also very helpful in exploring the discipline of thing's evolvement.

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