Automation in Construction 20 (2011) 263–269

Contents lists available at ScienceDirect

Automation in Construction

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

Generating virtual environments of real world facilities: Discussing four different approaches

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ARTICLE INFO

Article history:
Accepted 24 August 2010
Available online 22 December 2010

Keywords:
Virtual environment
Virtual reconstruction
Visualization
Serious gaming

ABSTRACT

There is an increasing need to generate detailed real-time virtual environments that closely mimic real world facilities. Approaches for the generation of virtual environments can be manual, automatic, or hybrid. Manual approaches are time consuming, inaccurate, and coarse whereas automatically generated data sets are less than optimal for practical use within real-time virtual environments because of the huge unstructured amount of data. Therefore, common approaches are most likely to have a balance between human and computer effort. Based on different projects, we discuss possible distributions of manual and automatic methods for the generation of 3D virtual environments. We present different facets of the pipeline from initial data gathering up to the final deliverable. The approaches employed in these projects vary from fully hand made up to semi-automatic reconstruction of the environments. The paper concludes with recommendations regarding the reconstruction methods.

1. Introduction

There is an increase in use of 3D virtual environments in architecture, engineering, and construction (AEC) industries. Applications like virtual training environments, virtual prototyping of designs, and joint virtual development of information systems require a valid representation of the real environment. Often, the real environments are industrial facilities such as oil rigs, container terminals, or manufacturing plants.

There is no single reason why 3D virtual environments are increasingly popular, but drivers stem from multiple backgrounds. Advantages of 3D virtual environments are found in improving communication [1], increasing insight [17,23], supporting collaboration [4], and supporting decision-making [13]. The divergence in applications requires different levels of fidelities of the 3D virtual environment. This can be illustrated by the different levels of fidelity required in the design process of a manufacturing plant. Designing the plant is mostly done in a 3D environment with high precision. The design drawings are complex, show different layers (e.g. mechanical, electrical, and plumbing), and therefore become hard to understand. On the contrary, for the presentation of the final result to stakeholders, a 3D visualization with a reduced level of complexity is preferred. The 3D visualization can be used as a platform for shared understanding to be used by every stakeholder involved in the design process. The different types of visualizations, both in 2D and 3D, achieve different types of fidelity for each specific goal.

1.1. Realism in 3D virtual environments

According to Webster's dictionary, “fidelity” means the accuracy in details. Fidelity is the general term for the way in which a model is a valid representation of a reference system; 3D modelers tend to use the term “realism,” as their reference system is the real world, i.e. the real industrial facility. Ferwerda [8] distinguishes three varieties of realism in computer graphics: physical realism, photorealism, and functional realism. For each type of realism, there is a criterion which needs to be met in order to achieve that type of realism.

Physical realism is achieved when computer graphics provide the same visual stimulation as reality. This type of realism means that “the image has to be an accurate point-by-point representation of the spectral irradiance values at a particular viewpoint in the scene.” It requires an accurate description of the scene, simulation of the spectral and intensive properties of light energy, and reproduction of those energies by the display device. Technically this type of realism is the hardest one to achieve. Although this aspect is often ignored for models that have to be visually appealing, it might become essential in 3D virtual environments for future uses. In this paper, physical realism is ignored.

Photorealism in a virtual scene provides the same visual response as the real scene. It aims at displaying an image indistinguishable from a photograph of the real scene. Although achieving photorealism has primarily been a task for off-line rendering algorithms (such as

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doi:10.1016/j.autcon.2010.08.004

algorithms for global illumination), modern interactive 3D visualization software libraries tend to surpass the vague threshold towards photorealism.

Functional realism is about providing the same visual information as found in reality. The main concern of this type of realism is about transferring information about the real objects such as their shapes, sizes, motions, and materials. As this type of realism aims at providing the necessary information to perform visual tasks, functional realism can be found in photo-realistic images as well as in simplistic sketches. Measuring whether functional realism is achieved is therefore a challenging task as it requires an interpretation from human observers. The functional realism aimed for in this paper is what engineers would call 'accuracy.'

Although the three types of realism are compared against "reality" and "real environments," a realistic 3D environment is not necessarily one-to-one mapping of an environment found in the real world. A highly populated city could be displayed photo-realistically although the buildings and layout have been procedurally generated (e.g. reference [21]). In virtual environments for AEC, the common practice is to model existing facilities or facilities under design or construction. When under design or construction, a valid reconstruction of the future facility is required before it can be displayed. Several methods and techniques are available to perform these reconstructions. The key aspect in which they differ is the level of automation. Some methods require a completely manual reconstruction. Other methods however facilitate that data can be gathered automatically thus leaving everything up to algorithms which can be run on computers.

1.2. Human and computer effort in the reconstruction of virtual environments

Building a 3D virtual environment based on real world data is a tedious task. In reference [14], we discussed which technologies can be used and which skills are needed. The question remains to what extent automation is feasible and appropriate in building virtual environments of real world facilities. This question has come forward in multiple studies resulting in different approaches. These approaches are mainly situated in one of the following four groups: geometry based, image based, point cloud based and hybrid approaches [3,5,12,19,24].

In the gaming and animation industry, manual 3D modeling is the dominant approach. This approach, known as geometry based approach, is one of the most labor intensive ones. It therefore scales badly to large or detailed environments in which each new object has to be modeled separately. Some level of automation is possible in this approach, mainly making variations on objects and environments. The skills of the designer are essential for the quality of the result.

Image based modeling approaches aim at retrieving 3D models from a single or multiple 2D images of a physical object [6,10,16]. The typical workflow starts with the retrieval of (calibrated) pictures. Then geometry is extracted from these pictures. Once the geometry has been extracted, textures based on the initial pictures are applied. This approach has shown promising results but is still under research (some recent advances are described in references [2,9,18]).

The point cloud based approach uses capturing devices capable of recording 3D points in real environments. Capturing devices are known as active sensors (in contrast to passive sensors, e.g. camera, used in image based modeling) and laser scanners are a well-known example. Active sensors are split in two categories: ground laser scanners and airborne light detection and ranging (LiDAR) sensors [11,20]. Due to the advanced equipment and setup, this approach is relatively expensive and difficult to use. The results that can be achieved are highly detailed 3D models (e.g. reference [7]).

Hybrid approaches use a combination of the aforementioned approaches to surpass some of the disadvantages found in using a single approach. In most cases, these disadvantages are costs and capabilities of a particular approach.

Although image based and point cloud based approaches are near fully automated, they still require a lot of human effort. In image based approaches, taking images need to adhere to specific requirements, and postproduction is a necessity. Point cloud based approaches provide huge data sets which cannot be used directly in current virtual environments. The level of automation is case-specific and approaches are tailored towards requirements coming forward from that case. Besides the visual appearance, semantics have to be added to provide additional information: currently intelligent segmentation of the data is an active research topic [15].

2. Reconstruction of virtual environments in practice

2.1. Introduction

We present four projects wherein a real world facility has been modeled as a 3D virtual environment. The mix of manual and automated approaches varies between all four projects: we start with a project where no automatic generation took place and end with one that was almost generated automatically. For each project, we start with a general introduction and the requirements set in terms of what type and level of reality we aimed for. We continue by discussing the trade-offs we had to make in terms of effort, automation, and use of existing data. Finally, we discuss the choices made, present how the implementation took place, and what the challenges were.

2.2. Training environment for supervisors

The conventional way of training supervisors for the petrochemical industry combines hands-on training in training facilities and the use of videos, slides, and questionnaires. Experiential learning is assumed to improve the knowledge retention over conventional learning methods. A pilot project has been conducted at a large oil company to explore the benefits of 3D virtual training/serious gaming for training supervisors in the petrochemical industry. The objective is not to replace current training solutions but to position serious gaming as an additional teaching method. To do so, we developed an immersive 3D serious game that was based on an actual training location.

2.2.1. Requirements

The 3D environment is based on an existing location in use for real life training. Therefore, a key requirement of the virtual counterpart was achieving a high degree of photorealism with the existing location. Artificial defects were going to be integrated and had to behave correctly.

The following requirements were proposed for the 3D environment:

1. The 3D environment has to look photo-realistic; spatial correctness is less important than visual appearance.
2. Details that are of importance to the training scenario have to be homogeneous to the rest of the environment, so they will not be easily recognizable.
3. When possible, use the photographic information gathered during acquisition for the texturing process.
4. Weather conditions should be changeable.

2.2.2. Trade-offs

We chose a site with a compact size because of the high amount of details needed to be generated. The site was manually modeled based on photographs without rectifications or orientations. Therefore, the models were approximations of the actual objects with regards to dimensions. Nevertheless, they appeared photo-realistic because of the textures that were based on actual photographs.