THE APPLICATION OF A 3D SCANNER IN THE REPRESENTATION OF BUILDING CONSTRUCTION SITE

Naai-Jung Shih

Professor, Department of Architecture
National Taiwan University of Science and Technology
73, Section 4, Keelung road, Taipei, 106, Taiwan, ROC

Abstract: This study offers a method for creating a representation of an on-going construction site by using a geometric approach. The representation includes the definition of 3D data between the design and construction stages. A method is proposed for using a 3D long-range laser scanner to retrieve information on site occurrences, in order to describe the building construction process based on what really occurs at a site. 3D scans are made in stages or at various time intervals. Retrieved shapes are collected in a discrete manner or in a configuration as a whole. The data collection is conducted wholly or selectively for key referencing based on registration points. Investigated issues involved are target positioning, identification, retrieval, tracking of objects, behavior description, characteristic description, and integration of segmental geometric information. A special procedure is developed to fabricate initialized object parts through a 3D rapid prototyping process to facilitate communication in substantiated form.

Keywords: 3D scanner, construction

Introduction

VR or 3D modeling approaches are used to simulate tasks to facilitate a better visualization of building construction. (Retik et al., 2000; Retik & Shapira, 1999; Vaha et al., 1997). However, making a digital representation of a construction site is a complicated task. Not only are some objects too trivial to be represented, but also the undefined data may come from the construction process itself. Starting from the design stage, 3D computer models are usually used to facilitate an inspection in the design stage only, by showing related component definitions like walls, columns, openings, etc. in a built form. This type of representation may be sufficient to visualize a building in its final stage or be used as the basic definition of process. But an actual construction is much more complicated in terms of objects and associated motions. Not only are the defined activities in the construction schedule more numerous than the original design models can describe, but also the machinery, workers, materials, and all objects presented and not included in the original 3D model are left to be noted only in a text or chart form, based on judgments derived from related experiences.

Construction site monitoring is an on-going process that records and monitors data for immediate and post-construction analysis (Al & Salman, 1985; Atkin, 1986; Bjoerk, 1993). The monitoring of a site and the correspondence of activities defined by a schedule requires object identification and a thorough record of site occurrences. To achieve this goal, the function of 4D monitoring focuses on a pre-construction study for the better management of a site afterward (Haymaker & Fischer, 2001). During construction, object identification and comparison to scheduled activities are essential functions of site monitoring, and are usually conducted by supervisors as human-based tasks. That means site monitoring is an analogical process. Functions that could enable the digital identification of an object and the ability to check whether it is on schedule would be very helpful.

A reversed description method is proposed to improve the disadvantages of 4D technologies by recording site occurrences in geometric form and comparing them with the activities recorded on the schedule. The comparison is made as a reference base for evaluating actual progress. In contrast to 4D technology, which is based on data from the design stage, the application of a 3D scanner retrieves data on a construction site to facilitate an as-built description of models in a precise and reversed verification manner.

Proposes

This study proposes a method for represent an on-going construction site through a geometric approach. The representation includes the definition of 3D data between the design and construction stages. A method is proposed for using a 3D long-range laser scanner to retrieve information on site occurrences, in order to describe the building construction process based on what really occurs at a site. 3D scans are made in stages or at various time intervals. Retrieved shapes are collected in a discrete manner or in a configuration as a whole. The data collection can be conducted wholly or selectively for key referencing based on registration points.

Systems

The system consists of a long-range (50-100 meters) 3D laser scanner Cyrax 2500 (see Fig. 1) that comes with an editing software, Cyclone 3.1. The laser can create a matrix of point clouds up to 999*999 dots in width and height. Scans can be made individually or registered onto a large project by referring to tie-points. Each scan can reach a tolerance of 2mm / 50 meter. The system comes with a notebook computer, which figures 1GHz CPU and 512 MB RAM, to handle the data received on site.

Levels of manipulation

The possibilities for manipulation of scanned geometric data can be classified into three levels:

- Level I – point clouds: Initial data retrieval is collected through 3D scans. Each point is initialized with x-, y-, and z-coordinates only. Points can either be initialized with absolute coordinates or modified to show relative location. At this level of three-dimensional representation, measurements can be made to estimate linear distance between two points or between a point and a plane. Data are in a generic form that opens up a referencing base for following manipulation. It is suggested that at least one copy of raw scan data should be kept unchanged in terms of point coordinates, viewpoint, and the images associated with scan orientations.
- Level II – object initialization: Structural detail, which represents the components and their mutual relationships, is created by fetching or matching points with geometries like mesh or various shapes of primitives. In contrast to one-dimensional representation, volumetric description enables calculations to be made of surface area and of object volume. Relative location between objects becomes more meaningful for the boundary of objects is defined and can be manipulated afterward. In addition, the volumetric data can be exported to domain-specific applications for further visualization or analysis.
- Level III – attribute designation: Initialized geometry objects are mapped with images or textures to illustrate surface attributes. At this level, additional

Figure 1. Cyrax 2500 3D laser scan system, registration points, and site example

visual detail is presented. Models created at previous levels can be used to build up a more visually attractive scene.

Object representation

Why do we need a detailed geometric description of an object at a construction site, especially when the data retrieved can be too fragmental to facilitate further manipulation? The reason is a construction site is a very complicated scene; a detailed description of it can facilitates analysis without the risk of missing any valuable data. The fragmental nature of site information can now be changed by registering the fragments together.

One of the 4D disadvantages actually comes from the effectiveness of digital representation of site occurrences. In general, two types of comparison exist between real objects in physical form and digital form:

- An object's digital representation: This representation comes from scanning or computer modeling of real objects. Computer models for design evaluation are usually created before construction begins. Objects initialized from scanned point clouds represent a physical form in a finished stage. Nevertheless, the intermediate stages between design and construction stages can also be represented through scans of partially completed building parts and components allocated accordingly.
- An object's behavior and schedule: The big picture of a digital construction representation includes construction components, component behavior, and component relationship to the construction schedule. The representation of a construction at a certain stage does not necessary reveal the behavior of its components. This behavior, as described in a previous section of this paper, provides more details than the information collected for a certain task.

Process and Methods

To match objects and their roles specified in construction schedule, there are many sub-tasks have to be conducted. Manipulation geometric and image data are classified into three levels of data manipulation:

- dimension-related geometric characteristics check: The initial level of data manipulation emphasizes a preliminary use of scanned data and dimension-related checks based on geometric characteristics. Usage of scanned data can be shown in analysis, measurement, record, or visualization. Measured data can be used for dimensioning, defining relative location, and recording geometric atributes. For example, a scan records geometric information of a steel joint for further control such as spacing or form works. Steel-bar-related checks that can be derived from the scanned data include spacing, size, numbers, and the relationship with adjacent components. Dimension-related checks are made in terms of standard deviation, which mainly comes from stress-related (pressure, force, fire) deflection or bad construction quality. Geometry-related attributes of the scanned data are categorized based on their usage in one, two, and three dimensions.
- object identification and behavior monitoring: During construction, when objects are scanned and initialized into geometries, there is a need to tell how close the scanned geometries are to their product specification. The identification can be categorized into image-based and geometry-based approaches. Images usually contain more details than geometric representation. While the function of abstraction and segmentation for images or videos is limited, a pre-design study in a visual form must be conducted from a modeling approach, leaving an image approach to be conducted based upon what is already constructed as an as-it-is situation.

Behavior represents the spatial movement of construction components over a period of time. An object's movement is the response of its own or external forces along a time span. The monitoring of behavior notifies us of an object's activities. With the environment scan included, the object's response to its surroundings is also specified from itself as well as construction instruments.

- integration of segmental geometric information: Due to unexpected blockage of other objects, scanworlds have to be integrated to complete an omni geometric representation of an object. Scanned data or image-derived photogrammetric data offer partially complete descriptions. Only when an object's movement or orientation changes so as to lead to more exposure to the receiving devices or applications can additional data be perceived as a complete set. In a chronicle recording, each object may inherit a different level of data segmentation. Integrating the chronicle-based segmentation is a challenging task and is currently made by registration through referencing points.

Exemplification of 3D scans has been made to construction site for dimension-related check of geometric attributes. Related studies are also made to interior design (proofing; as-built scan for renovation documenting) and a long term chronicle documenting of construction in the mean time.

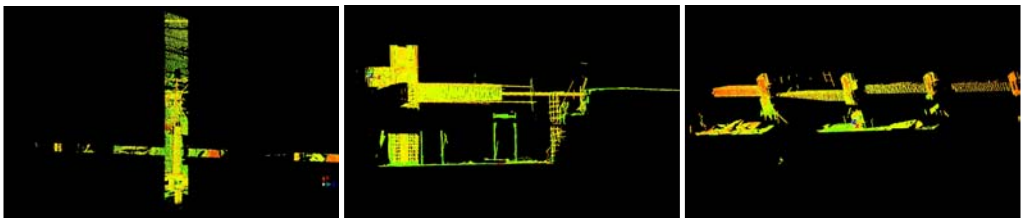

Figure 2. Two referencing sections through whole site

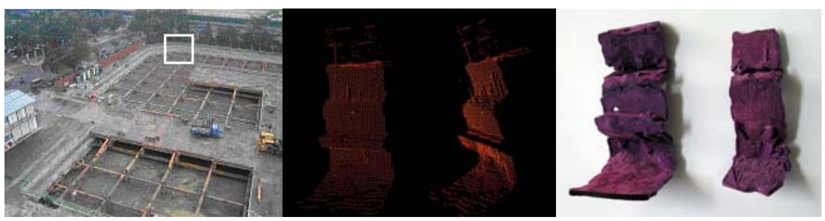

Figure 3. Photo, point cloud, and RP output (from left to right) of retaining wall section

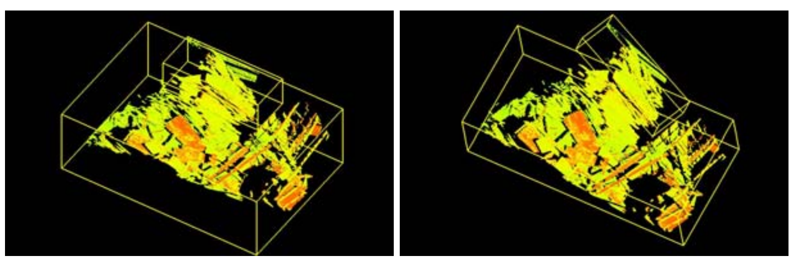

Figure 4. Two segmented clouds are shown in ordinary (left) and minimum volume (right) presentation

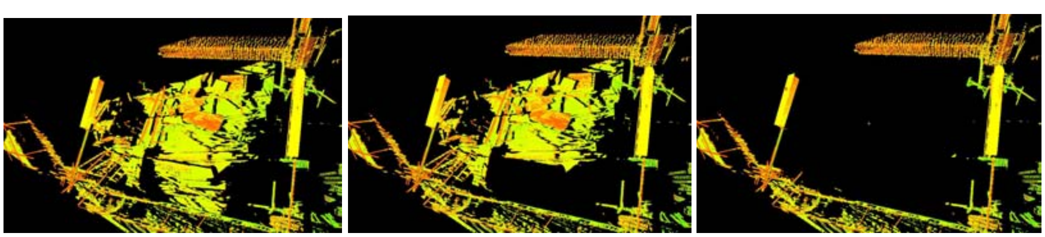

Figure 5. Center parts of the cloud is segmented into two and stored in difference layers

<u>Section referencing through whole site</u>

A 3D scan is suitable for a clear review of a cross-section of a site (see Fig. 2), not just to review an object as a whole from outside. The process does not have to be undertaken in a traditional manner, made by creating models and conducting software cuts. The purposes of the scan are to show:

- structural and compositional relationship: to reveal aggregation and segregation of building parts
- hidden components and spaces: to illustrate what can be left unseen
- part-whole generating process: to create a time-based transformation description of the "how & why" of occurrences

Most important of all, sections are made based on what really occurs at a site. The section is a good manner of spatial representation suitable for construction quality control, such as for levels or clearance between slabs. Additionally, initialized object parts can be fabricated through a 3D rapid prototyping process to facilitate communication with substantiated forms (see Fig. 3).

Boundary and box approximation

The number and complexity of objects at a construction site may be too numerous and detailed to be modeled exactly. But recording the presence of objects is still an important task to be aware of. In order to conduct the following study, a boundary or box approximation is conducted for the following purposes:

- simplified volumetric representation: The boundary representation can be created based on either current orientation or minimum volume illustrated by a rectangular wire frame (see Fig. 4).
- interference analysis: The presence of a boundary enables an interference check between adjacent objects in a user defined manner. For example, a designer or site supervisor can select the segmented clouds of interest to create a group, and then compare the boundary with another group for interference. This method enhances current interference checks provided by similar 3D modeling applications in a systematic review of, for example, a plumbing part and an HVAC part. Not only does the analysis provide dimension-related data, but also a diagrammatic illustration of the field of influence.
- data segmentation: In each scan, all points in a cloud are considered as an entity (see Fig. 5). Although intensity-based segmentation can be conducted, the result subjects to the distribution of points and the density may not provide a segmentation that matches the perception of ordinary experience. Cloud segmentation is usually manually made and interpreted as needed.

Trade-off of 3D scan

- Time-saving operation: The data retrieval is directly made by a scan that takes about 17 minutes for each scanworld. Even with the follow-up object initialization included, the time needed is much less than for conducting computer modeling from scratch.
- Effort-saving operation: The geometric data are retrieved with x-, y-, and z-coordinates. The effort required to process geometric data is much less than for modeling that starts from each component.
- Spatial barrier free: Scans can be conducted from different orientations to retrieve almost all the part of objects, without being presented close to the parts. A scan of a distance also helps to prevent possible dangers in positioning oneself above ground level.
- The trade-offs of the 3D scan approach include:
- Tolerance: Scanned data still bears tolerance in terms of position, distance, or angles per unit length.
- Data amount: When a scan is made of 999x999 points, the registration of several scanworlds can easily accumulate up to millions of points. The object initialization and differentiation of scanned data can still be effort consuming. One way to simplify the task is to select key objects of interest only or to apply box approximation representation.

Conclusion

This study offers a method for representing a site under construction through the data retrieved from a 3D scanner. The data are point clouds that can be stored as records or can be initialized as geometry shapes afterward for the purpose of analysis and visualization. Although trade-offs exist, a site under construction can now be digitized. In contrast to the traditional 4D approach, the digitized data provide a referencing base made after the design stage for forward verification and backward simulation.

REFERENCES

Al, S. and Salman, T.: 1985, *Large-scale construction projects: management, design and execution*, London: Batsford.

Atkin, B.: 1986, Computer supported information interchange for construction projects, p.55-65, *IABSE workshop* Zuerich.

Bjoerk, B.C.: Autumn 1993, A case study of a national building industry strategy for computer integrated construction, *International Journal of Construction Information Technology*.

Haymaker, J. and Fischer, M., “Challenges and Benefits of 4D Modeling on the Walt Disney Concert Hall Project,” CIFE working paper #064, January 18, 2001.

Retik, A., Clark, N., Fryer, R.: 2000, Hasrdiman, R., McGregor, D., Mair, G., Retik, N., and Revie K., *Mobile Hybrid Virtual Reality and Telepresence for Planning and Monitoring of Engineering Projects*, http://www.brunel.ac.uk/depts/mes/Research/Groups/vvr/vrsig97/proceed/018/VRSIG-TX.HTM.

Retik, A. and Shapira, A.: 1999, VR-based planning of construction site activities, 8(6), pp. 671-680, Special issue: *Organisation and management of construction*.

Shih, N.J.; Tsai, Y.L.; Lai, Daniel, and Chang, H.Y., " A Preliminary Application of Panoramic Supervision System in Construction Site," Proceedings of the 2001 Information Visualization, pp. 103-8, July 25-27, 2001, London, England (2001).

Vaha, P., Kansala, K., Heikkila, R. and Kaisto, I.: 1997, Use of 3-D product models in construction process automation, *Automation in construction*, 6(2), pp. 69-76.