A Construction Site in a Scan-based Digital Representation

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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 can be conducted wholly or selectively for key referencing based on registration points. Investigated issues involved are target positioning, identification, retrieval, tracking of objects, behaviour description, characteristic description, and integration of segmental geometric information.

1 INTRODUCTION

VR or 3D modelling has been used to simulate construction tasks as a visualisation aid for research analysis (Retik et al. 2000; Retik and Shapira 1999; Vaha et al. 1997). However, creating 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 unexpectedly. Starting from the design stage, 3D computer models are usually used to facilitate an inspection by showing related component definitions like walls, columns, openings, etc. in a built form. This type of representation may be sufficient to visualise a building in its final stage or be used as the basic definition of process. An actual construction is much more complicated than that in terms of objects and associated motions. Based on judgments derived from related experiences, 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.

Construction site monitoring is an on-going process that records and monitors data
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for immediate and post-construction analysis (Al and 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 and 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 representing 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 long-range 3D 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.

ISSUES TO BE EXPLORED

The application of 4D technology in construction site simulation, for the purposes of process evaluation and communication, has been developed for some time. The combined description of schedule and geometries of a particular scheduled event in a chronicle manner helps to visualise the construction process. This kind of simulation is conducted at the design stage as a prediction of what will take place in the following construction process. In the representation of building parts in computer models, the site occurrences are much more complicated than the computer models. The initiated construction sequence does not necessarily reflect in details what the schedule defines. As a result, problems occur in trying to match architectural components and construction events defined by a schedule. The simulation, which cannot draw a complete picture of a site, may need additional assistance to fulfil an evaluation purpose.
Two issues are raised:

- The development of as-built geometric description: Building renovation or an additional construction needs as-built measurement to prepare correct construction drawings. A building may not be built exactly the same as proposed design specification. Deviation in terms of location or height from the original design surely generates the needs not only for the control of construction precision, but also for a better prediction of the subsequent steps. How to retrieve as-built geometric description is of concern.

- The representation of an on-going construction process: 4D technology involves a geometric approach in relating object configuration to schedule, based on design and predefined computer models of parts. A schedule represents an on-going construction process that should include all the activities associated with the change of detailed object locations along a period. As site activities increase, an object-based modelling not only is insufficient for a detailed description, but also is incapable of providing a reference base for chronicle comparisons of a component’s change by shape and location.

Figure 1 Cyrax 2500 3D Laser Scan System, Registration Points and Point Cloud

Figure 2 A Point-cloud-based Chronicle Record of a Site Excavation

4 SYSTEMS

The system consists of a long-range (50-100 meters) 3D laser scanner Cyrax 2500 (Figure 1) that comes with an editing software, Cyclone 3.1. The laser can create a
matrix of point cloud up to 999*999 dots in width and height. Scans can be made individually or registered onto a large project by referring to registration points (tie-points). Each scan may bear a tolerance of 2mm in a range of 50 meter. The system comes with a notebook computer, which figures 1GHz CPU and 512 MB RAM, to handle the data received on site. Figure 2 shows the concept of a point-cloud-based chronicle record of a site occurrence, which can provide detailed description and referencing between objects.

5 SCAN-RELATED ACTIVITIES

This study starts the site scan in a chronicle manner along with a panoramic recording for the visual referencing of site occurrence. The data retrieved from the initial scan facilitates basic measurement and analysis activities in a visual or numeric manner. The scanned volumetric data also enable a measurement to be made three dimensionally.

5.1 Site Scan

This scan is made every Tuesday. The size of construction site requires two scans to cover about 95% of the area. In addition to the three registration points to combine the two scans, three fixed points are selected for weekly references. Point cloud accumulates as site construction moves forward. A point-cloud-based chronicle record presents the most fundamental and unbiased record possible of site occurrences. It’s similar to taking a 3D picture that includes all the objects of concern for any possible manner of later identification (Figure 1 right). The traditional manner of recording can be replaced by geometry-based and depth-based measurements that are capable of providing dimension-related details.

An object can be scanned from different orientations and locations before being registered as one. The density of dots may vary based on the desired spacing between dots. Multiple scans can simultaneously exist in the same or different sets of scanworlds. A scan that is made along with another scan within the same scanworld at the same orientation may have a higher density than the rest of the area in order to retrieve more details from the part concerned.

5.2 Object Representation and Levels of Manipulation

The 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 initialised with x-, y-, and z-coordinates that are feasible for creating polygonal surface.

- Level II – object initialisation: Structural detail, which represents the components and their mutual relationships, is created by fetching or
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matching points with geometries like mesh or various shapes of primitives. Objects initialised from scanned point clouds represent a physical form in an as-built description.

- Level III – attribute designation: Initialised geometry objects are mapped with images or textures to illustrate surface attributes.

6 DIMENSION-RELATED GEOMETRIC CHARACTERISTICS CHECK

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. Figure 3 shows the distance between a binding steel bar, steel bar spacing, and level heights. The spacing for concrete should be slightly larger with form thickness reduced. Spacing can also be measured as a, b, c, and d.

![Figure 3 Form-column Distance, Steel Bar Spacing, and Level Heights](image)

- One dimension:
  - Length, width, height:
    - Desired dimension: to check whether room length, width, or height meets design specification
    - Sideways displacement: to check whether steel columns, window panels, or building façade is within tolerance level for wind pressure; forms may move sideways while encountering concrete side pressure
    - Air space: to check the gap used for air space or insulation to be installed between retaining wall and exterior wall in a basement; the side stress comes from soil pressure possibly push the retaining wall inward to make the gap narrower near the bottom than at the top level
    - Levelling: to check the amount of surface raise or recess
    - Depth: to measure site excavation
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- Angles:
  - Vertical angles: to check whether component election is perpendicular
  - Slope: to check the slopes for pedestrian walk, vehicles, or drainage pipes
- Linear smoothness:
  - Finish quality: floor pavement, mortar, ceiling tile layout
  - Quality control: surface smoothness for building components like H-steels or any linear object
- Levels:
  - Horizontal level
  - Edges: to check if a pond’s level are built with all edges are located at the same height
  - Deflection: to check whether stressed steel beams are displaced within tolerance level after suffering from fire damage or load (live, dead, or sudden impact)
- Two dimensions: area- or surface-related measurement or attributes check
  - Size or area: to check for void object such as a hole or a solid object
  - Smoothness:
    - Finish quality: to check finishing work on interior surfaces
    - Construction quality: to check forms and concrete masonry works
  - Deformation: to check the deformation of shapes
- Three dimensions: volumetric or configuration-related measurement
  - Size: to check whether the volume meets design requirements
  - Bill of material (BOM): to estimate the volume of land to be excavated

7 METAL-LEVEL DATA MANIPULATION

The advanced level of data manipulation is a meta-level data handling emphasizing object identification, behaviour monitoring, object and schedule match, integration, referencing, and boundary approximation.

7.1 Objects Identification

When objects are scanned and initialised into geometries during construction, there is a need to tell how close the scanned geometries are to their product specification.
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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 modelling approach, leaving an image approach to be conducted based upon what is already constructed as an as-it-is situation.

Identifying anonymous or subtle subjects which are hidden within complicated scenes is made easier for explicit representation of measurements. Those subjects can be important and their identification enables layer’s grouping to facilitate different purposes of object categorization.

7.2 Behaviour Monitoring

Behaviour is represented by the movement of construction components over a period of time. An object’s movement indicates the response of its own or external forces. Now the geometric information of an object and its surrounding environment can be retrieved directly in 3D form. So behaviour simulation or analysis can be conducted based on volumetric data converted from scans.

Figure 4 shows the point cloud of a ground work made by construction machinery. Pre-set scan speed is not fast enough to capture a still figure of a moving object. But in this case, the ground profile is captured because its changing speed was relatively slow compared to the scanning speed of the laser beam. This study manually enabled a batch scan to retrieve data periodically.

7.3 Object and schedule match

3D scan facilitates the comparison between schedule and task-related objects. To match objects and their roles as specified in a construction schedule, there are many sub-tasks that have to be accomplished. The issues involve geometry retrieval, target identification and positioning, object tracing, and behaviour description. Objects have to be identified before being traced. After that, object behaviour is characterized with segmental geometric information. Some of the tasks have already been stated in previous sections of this paper. During the scan made on every Tuesday, we found a one-week delay in excavation once.
7.4 Integration of segmental geometric information

Due to unexpected intrusion 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.

7.5 Section referencing through whole site

A 3D scan is suitable for creating a clear review of a site’s cross-section (Figure 5), not just to review an object as a whole. The process does not have to be undertaken in a traditional manner, made by creating models and conducting software cuts. The purposes of creating sections 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 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, for example, of levels or clearance between slabs. Additionally, initialised object parts can be fabricated through a 3D rapid prototyping process to facilitate communication in physical forms.

Figure 5 Section through Whole Site (top) and a Two-way Cut of Land (bottom)
7.6 Boundary and Box Approximation

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

- Simplified volumetric representation: The boundary representation can be created based on either current orientation or on minimum volume illustrated by a rectangular wire frame (see Figure 6).
- Interference analysis: The presence of a boundary enables an interference check between adjacent objects. 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.
- Data segmentation: In each scan, all points in a cloud are considered as an entity. 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 by layers.

Figure 6 Two Clouds in Ordinary (left) and Minimum (right) Vol. Presentation

8 TRADE-OFFS OF 3D SCANNING

The advantages of applying a 3D scan include:

- Time-saving operation: The data retrieval is directly made by a scan that takes about 17 minutes at a maximum density set up of a scanworld. Even with the follow-up object initialisation included, the time needed is much less than for conducting computer modelling 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 modelling 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 in a distance also helps to prevent possible dangers in
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positioning oneself above ground level.

The trade-offs of a 3D scan include:

- **Tolerance**: Scanned data still bears tolerance in terms of position, distance, or angles per unit length.
- **Data amount**: When a scan is made up to 999x999 points, the registration of several scanworlds can easily accumulate up to millions of points. The object initialisation 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.

9 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 initialised as geometry shapes afterward for the purpose of analysis and visualisation. Although trade-offs exist, a site under construction can now be digitised in an as-built form. In contrast to the traditional 4D approach, the digitised data provide a referencing base made after the design stage for forward verification and backward simulation.

REFERENCES


