MERGING POINT CLOUDS FROM HETEROGENEOUS 3D SCANNERS FOR FAST UPDATE OF AN EARTHWORK SITE MODEL

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Abstract

In earthwork sites, its terrain shapes are changing continuously as the work proceeds. If someone wants to grab three-dimensional geometry data of such sites, currently available technologies such as 3D laser scanners are unable to collect reasonably precise data in pseudo-real time (i.e., 1-10 scans per second). To tackle the problem, the authors took ‘dual scanners’ approach, where low-speed (yet highly-precise) laser scanners are used for initial scan of the work site, then augment the initial data using the 3D geometry data collected from excavator-mounted stereovision. For this approach, the authors used ICP (Iterative Closest-Point)-based algorithms for merging the stereovision data with the laser scan data, where similarities of both data are limited due to changed site shape.

KEYWORDS: Laser Scanner, Stereo Vision, Shape Registration, Intelligent Excavator, Earthwork

INTRODUCTION

Background and Purpose of Study

More than a couple of decades, linking construction with IT industry has been considered important for better productivity and quality assurance. Modelling existing structure is one of the core technologies for that purpose. The technology is also an essential element for automating the construction works because virtually all of robotic equipments should rely on three-dimensional information of their work space. The technology of obtaining 3-D information of the object and topography is continuously being developed and revised; nonetheless, quicker and more accurate technology should be developed.

The purpose of this study is to propose a near-real time update algorithm of a three-dimensional model of earthwork site, by merging existing site model (which we call a 'world model') with 'patches' of small models acquired from equip-mounted stereovision cameras in real-time (which we call 'local models').

Research Scope and Methodology

Our scope of this study is to develop a merging two 3-D point clouds that are acquired from different sources- one from a wide-range laser scanner, and the other from a stereovision camera. The detailed study methods are as follows.

1) Analysis of the latest technology and related researches for surveying up-to-date trend in acquisition of 3-D information

2) Review ICP algorithm (and its derivatives) for seeking improvement of the algorithm

3) Development of a merging process based on ICP

4) Preparing test data sets as real world data is not available

5) Application of the derived algorithm against the test data: the 'original' ICP algorithm is used for comparison with our algorithm, with analysis of the results from both algorithms.

LITERATURE REVIEWS

Acquisition of 3D models of real-world objects

Recent researches of 3D shape acquisition and modelling can be classified into 1) finding efficient methods of shape acquisition 2) recognition of the acquired shape data through features in the data, and 3) proposing a novel site-management method utilizing the acquired 3D models.

For efficient acquisition of 3D shape models, Moon et al (2009) proposed a method for matching the 3D point clouds of a work site with a panoramic image of the corresponding site. Elberink et al. (2009) showed graph-based matching for the sensor-acquired 3D models. Kim (2008) took an object-oriented approach for faster acquisition of the work environment model using geometric primitives.

For recognition of the shape, the need for matching shape data with corresponding CAD model is claimed in Bosche (2009); Shipu et al (2009) used outlines extracted out of the shape data for matching; Kwon et al. showed extraction of geometry primitives such as cylinders.

For application of the 3D shape acquisition and recognition technologies, Gordon et al. (2003) called for an 'early-warning' system for construction errors using the 3D shape acquisition technology; Han et al. (2008) later showed a method of extracting reinforcing bars from the scan data for inspecting them against its CAD data.

Although the research area is under active development, but the most studies shown above use single device or technology to obtain 3D information such as laser scanner or stereo vision. Although laser range-finder based systems offer very accurate outputs, most of currently available devices do not offer fast scan time enough for managing earthwork sites, which should provide at least one ‘frame’ per minute; For wide-range 3D scanners, they typically take at least dozens of minutes to perform a single scan of a moderate-sized work site. To make things worse, to minimize the ‘shadows’ (the area laser beam cannot reach due to beam-obstructing objects, causing ‘missing parts’ in the scan data), the scan should take place several times, multiplying the scan time by factor of 3 to 6, for instance.

To counter the scanning time issue for conventional laser scanners, we used multi-sensor approach – complementing it with very fast, yet less accurate point clouds taken from a stereo vision camera (See [2] for further details of this approach). Since point clouds produced from the stereovision can capture only narrow region within the camera’s field-of-view, we mounted it to the excavator so any changes to the earthwork site made by the excavator can be captured by the camera.

Now we can capture the shape changes of the earth work site; provided with the initial shape of the entire site (which would have previously been captured by the laser scanner prior to the earthwork), we can update the site model (i.e. world model) with the patches captured by the excavator-mounted stereovisions. By replacing a small patch of the world model with the ‘newly updated’ data fed from a stereovision will do the job; the problem is to find the ‘right’ place of the patch acquired from the camera, which only approximate information of its location.

Methods for merging two 3D point clouds

For merging point clouds of a physical object scanned from multiple points to avoid shadows, the iterative closest point algorithm (Besl 1992) and its derivatives are widely used. The algorithm (and its derivatives also) basically assumes that a point in one point cloud would match the closest point in the other cloud; mean value of the point distances are used as an ‘error’ function- by calculating a transform matrix that minimize the function, both point clouds can get closer, and could make them close enough by applying the calculation iteratively (hence the name comes).

The Algorithm has been used mostly for registering scan data of a same object such as a machine part, a building facade, etc. For merging terrain data, ICP is considered less suited due to its shape irregularity and fewer shape gradient than desired for the algorithm (for instance, merging two scan data of a flat-shaped site is extremely difficult because it would match to a local minima, rather than the correct registration point.

For our system, the ICP algorithm also has an issue to be addressed: the local model contains an updated shape, which significantly differs to the corresponding world model that has older shape data. To enable merging these data, we made two assumptions:

First, the local data are provided with approximate coordinate information (with errors less than few meters, which was done in [2] by utilizing on-board GPS and an orientation sensor). With the approximate information, the registration result which converges to a local minima can be rejected.

Second, for calculation of closest distances, we only choose points within a certain error ranges (i.e. distances between two closest points). The approach is based on the method used in Zhang (1992), yet we trim out more points as the calculation is iterated to cancel out the effects caused by the updated points; by contrast, the conventional ICP uses more points for matching as iteration increases because two point clouds should be virtually identical.

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Acquisition of the earthwork site shape

The research consortium in which authors participated are currently developing an intelligent excavation system, which relies on 3D shape information of the work site. To acquire the precise shape model of the work site in shorter time, a vehicle-mounted laser scanner is used. As the excavator operates, its windshield-mounted stereovision camera captures the work progress and converts it into 3D point shapes, with approximate coordinate information captured with onboard GPS and orientation sensors (see [2] for details).   You et al. (2009) describes further detail of the hardware and tools helping correct registration of the entire site model (i.e. world model).

Figure 1 : Two sensor types used in the intelligent excavator system. Left: a vehicle-mounted laser scanner for scanning workspace model. Right: an excavator-mounted stereovision camera for capturing work progress

Preparation of test data

Since our intelligent excavator system was being under development, we prepared a set of artificial data that resemble the earthwork shapes. A set of text files containing three dimensional coordinate of the point clouds were created. To represent time-lapse representation of the work progress, three similar, yet not-identical data sets were created. The data set named 'Test Map1' represented an initial condition, followed by 'Test Map 2' and 'Test Map 3'. They were produced with Microsoft Excel. All of these three maps contain 1581 points each, positioned in same locations except for their depth.

Test with existing ICP implementation

We first used publicly-available ICP implementation written in MATLAB (Bergstrom 2006). The algorithm uses singular value decomposition for calculating least squares of the closest distances. It also generates meshes from the point cloud using Delaunay triangulation for generating surface vectors for a precise result. The Figure 1 shows the test results of the MATLAB implementation. Because the output from the operation is a transform matrix (for rotation) and a translation vector, in the real world situation the world model data will be 'replaced' with the local data of correct location, rather than merged.

The result showed that merging Test Map1 with Test Map2 resulted in 'correct' result, enough for used in real-world situations; on the other hand, merging Test Map2 with Test map3 introduced more errors, tilting Test Map3 slightly.

For typical PCs having an Intel Core 2 duo-class processor running on Windows XP, It took 2-3 minutes for completing the calculation.

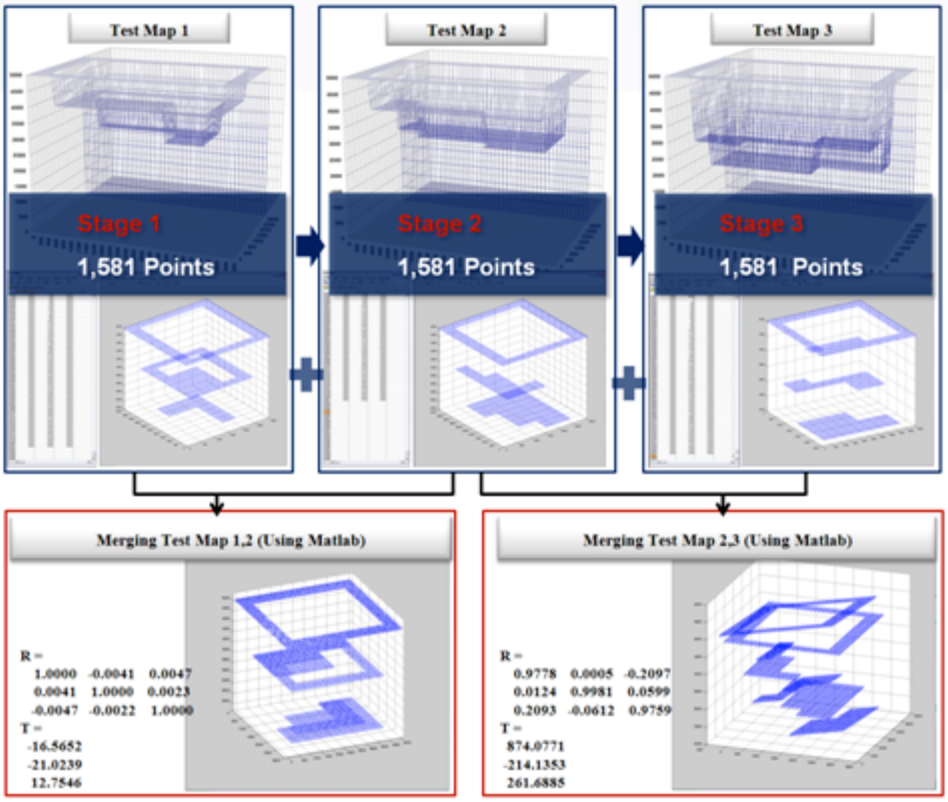

Figure 2 : Three test maps and merging results using Matlab implementation (Bergstrom 2006)

Test Map 1, 2, and 3 don't have realistic shapes for simplicity of testing and comparison of the results. For more realistic shapes found in real-world earthwork sites, we created artificial shapes that have more natural looks using fractal algorithms.

Implementing ICP-based merging algorithm and test

Bergstrom's Matlab implementation showed two shortcomings: first, it didn't merge Test Map2 with Test Map3 correctly; second, for small size of our test set, it took too long time to be used in our projected use case, which demands at most 1 minute for refreshing the work space model. For those reasons, we developed our own ICP implementation addressing the issues.

Our implementation is based on the algorithm presented in Zhang (1992). The algorithm uses statistical analysis for determining 'right' points to be merged, which corresponds to our need that point clouds from updated areas need to be stemmed out from calculation. Also, the algorithm provides merging shape data without surface normals, relieving the need for calculating meshes of the cloud (with expense of reduced accuracy). For calculation of transformation from the error function (mean distance between closest points identified), Zhang's algorithm uses dual-quaternion method, which was introduced in Walker et al. (1991).

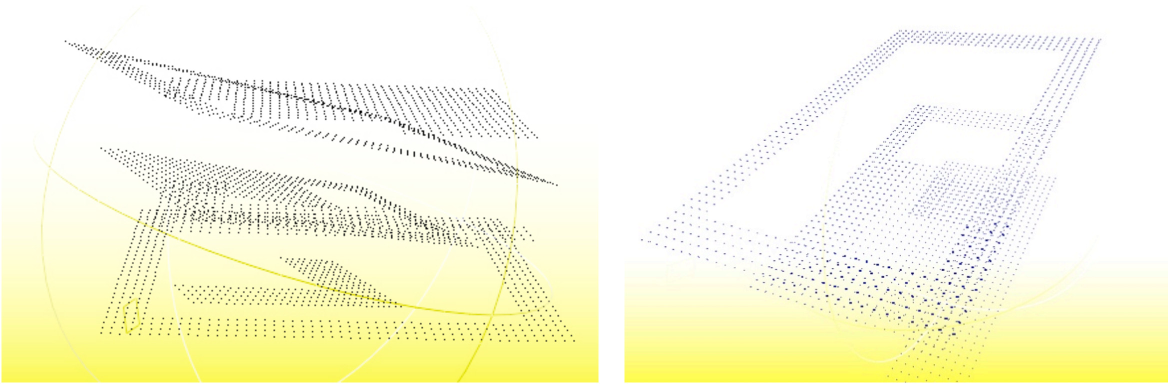

Figure 3 : merging test sets without surface normals (left) and with tem (right)

Our implementation is written in C/C++, and compiled with Microsoft Visual Studio 2008. For visualization of the result, Meshlab software (Cignoni et al. 2008) was used. Figure 3 shows results from merging Test Map1 and 2, where the local model was tilted to 45 degrees against the center of the reference model. Since we used point clouds only (i.e. surfaces and their normals were not calculated for faster calculation), we modified the algorithm to include the normals, which caused more reasonable result, shown in Figure 3. Both calculations took less than a second using same system used for running the Matlab implementation.

For more realistic shapes generated with a fractal algorithm, our algorithm fared well. The right-side picture in Figure 4 shows the result of ten iterations using our implementation, which took very little time (ran instantly with the same PC we used), with reasonable accuracy even without the surface normals; on the other hand, the same data was merged in Matlab in 5-10 seconds, still slower but significantly faster than the cases using our 'planar' test maps.

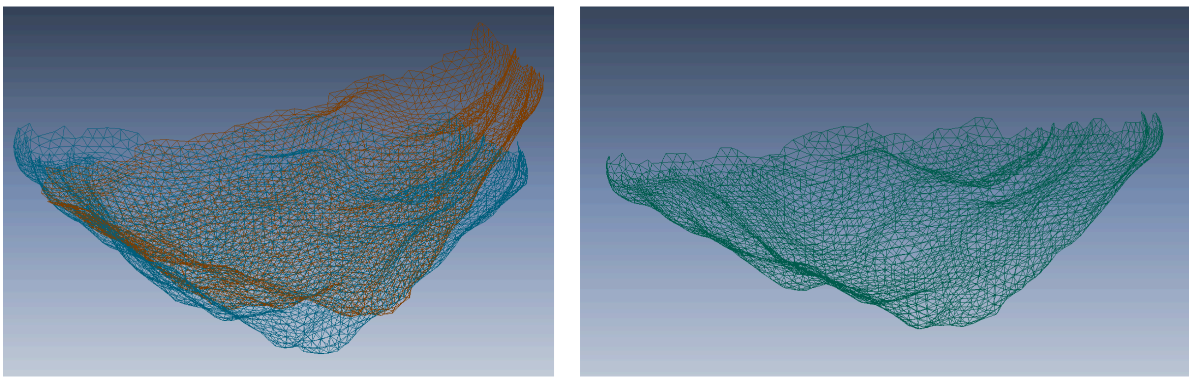

Figure 4 : Running our merging program against our synthetic shapes: left, before merging; right, after merging

DISCUSSION

Compared to the original algorithm by Zhang (1992), our implementation, at its first version, resulted in very similar outcome even with tweaks we made, showing problems in synthetic data sets having planar shapes. Although the real-world shapes are less likely to have such shapes, our algorithms need to be revised to handle the conditions because later stages of the earthwork may have such shapes; on the other hand, the shape-normal based approach yielded better result in that specific condition, however, which made little difference in our fractal data set despites increased processing time.

For smaller number of points (~2000 pts), our implementation took very short time- less than a fraction of a second, allowing pseudo-realtime update of the earthwork site model. Given that our assumed tolerance of shape error is ± 5 centimeters, an square-shaped area as large as 4 meter-by-4 meter can be covered in a single patch (unit of merging operation) with this number of points.

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