Scan to BIM: Factors Affecting Operational and Computational Errors and Productivity Loss

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Abstract

3D laser scanning technology is now widely and increasingly used to create as-built 3D CAD or Building Information Models (BIM) of existing facilities and new construction. Errors occurred during scanning and data processing stages cause a higher registration error, which in return lead to inaccuracies during the modeling stage. The paper introduces 3D laser scanning technology and its applications. It also reviews consecutive steps of creating as-built BIM using 3D laser scanning technology and identifies the sources of error and inefficiencies at each stage. The focus of this study is on the accuracy of scanned point cloud registration as well as time requirements for different processes in currently practiced scanning operations.

KEYWORDS: laser scanning, registration, target, error, building information modeling

INTRODUCTION

3D laser scanning (LADAR: laser detection and ranging, LIDAR: light detection and ranging) is a field data acquisition system, initially developed for surveying and mapping. The technology is now applied in indoor mapping (Tommaso, 2006), reverse engineering, quality control (Chia-Lung Chang, 2005), excavation measurement (Geraldine S. Cheok, 2000), construction assessment (Cheok, 2000), historic preservation (GSA BIM Guide, 2007), and construction metrology (Geraldine S. Cheok W. C., 2001). Use of 3D laser scanning for construction progress measurement (El-Omari & Moselhi, 2008), and development of as-built 3D CAD and Building Information Model (BIM) of existing facilities (Arayici, 2007) are increasingly realized in the Architecture, Engineering, Construction, and Facilities Management (AEC/FM) industry. Using 3D laser scanning as a data acquisition tool to feed into BIM as a central data repository of the project extends the application of BIM to construction and then occupancy stages of project life cycle. Having a real-time as-built BIM technology (i.e. AutoDesk Revit, Graphisoft ArchiCAD, Digital Project) tied to a central database management system (i.e. SQL) that is capable of bi-directional data communication with Computerized Maintenance Management Systems (CMMS) (i.e. Famis, Maximo), can be used to link the acquired data for numerous applications.

Scan-to-BIM process consists of three major steps: scanning, registration, and modeling. There are many inaccuracies and inefficiencies associated with each of the aforementioned processes that lead to inaccurate end product, as-built BIM, and also that increase the cost of Scan-to-BIM operation. This paper identifies sources of errors and time inefficiencies at different stages (scanning, registration, and modeling) and provides recommendations for future research to improve some of the disadvantages of current practices.

SCAN TO BIM

Scanning

The scanning process involves installing the scanner, total station and a set of planar or sphere artifacts, referred to as "targets". Since 3D laser scanners are line-of-sight instruments, multiple scans are needed to cover invisible parts of the scene and targets are used as common points to merge the scans together. The output of the scanning process is a complex set of points, known as "Point Cloud Data" (PCD) containing geo-spatial information of the scanned environment in a Cartesian or Spherical coordinate system with an RGB value indicating the return pulse intensity of the scanner's laser beam. Kiziltas et al (2008) showed that total stations give more single point distance and angular accuracy in the delivered sparse point data versus those of laser scanner's dense point cloud. Hence, a total station could be used as an independent surveying system to capture targets' position as control points and the difference of two recorded ranges represents the budget of uncertainty, which is the determining accuracy factor.

Prior to the scanning, the scan crews need to develop a scan plan that designates the prospective locations of targets, scanner, and total station. They usually start with the first scan station and place the targets, then moving to the next scan station and making sure that the targets are visible to the scanner. This process may require iterations in designating the locations of targets and scanner. At the end, the total station needs to be placed at a location where it can face all the targets. The number and type of targets to be used is dependent on the scan scene geometry as well as the surface materials. For example, installing certain types of targets requires having metal surfaces to hold magnetic mount or edges to hold clips. A combination of a set of fixed and paddle targets are usually used. Paper targets are placed at locations that do not require re-orientation and paddles are placed at turning points and corners. The scan plan usually gets finalized in the field.

Setting up a PCD database, reorienting targets, installing scan equipment, acquiring targets with total station, scanning, processing initial point cloud, finding targets in the point cloud, rescanning targets, and repositioning equipment are the steps that compose the scanning operation (Figure 1). The scan time varies from less than a minute to half an hour depending on the selected resolution and the instrument's speed. While the scan time is constant and constitutes a small portion of duration of the entire operation, target re-orientation may take considerable amount of time in specific situations. Large open areas, indoor industrial settings with multiple levels, atrium spaces, and generally, wherever the scan crew needs to place the targets at difficult to reach or far locations involve such situations. Scan crew needs to spend a significant time to reach the target and re-orient it. They often need to walk long distances, climb up and down stairs or ladders, which may also pose danger in certain situations. A significant amount of time is wasted in these circumstances which increases the scanning operation cost, while it does not contribute to the quality of the end product, whether it is registered point cloud or 3D CAD model or BIM.

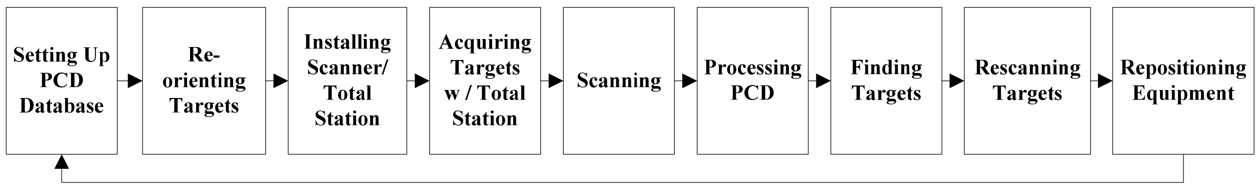

Figure 1: Scanning operation sequence of work

Calibration errors, environmental conditions such as instrument vibration and thermal expansion due to sunshine and wind, surface reflectivity, and dynamic scan scene are some of the sources of error realized during the scanning process (GSA BIM Guide, 2007). Mixed-pixel phenomenon is another problem that causes inaccurate data acquisition. A mixed-pixel forms when the laser beam hits two objects simultaneously so that two ranges are recorded for one point. It usually happens when edges of objects are scanned, objects are thinner than laser beam, or bottom edge of object is resting on the ground (ground interaction) (Hajian, 2009).

Registration

3D laser scanner sets a new coordinate frame for each scan and assigns coordinate values to the scanned points. However, these coordinate frames should be consistent so that multiple collected PCDs could be merged. The process of transforming two or more scans of the same scene from different locations to a single point cloud to have a common reference frame is called "registration".

PCD registration is another source of error in the Scan-to-BIM process. There are two categories of registration methods practiced in the industry: target-free and target-based. Target-free category includes control points and cloud matching methods. The 3D laser scanner is set over a point with known coordinates (a control point) and the operator back sight to another known point to measure the orientation (GSA BIM Guide, 2007). This method is not used frequently in the industry since it requires accurate instrument installation over specific points, which is subject to human error. Moreover, any error made in acquiring the position of a point makes the data collected at that point unusable. Cloud matching methods work based on either feature extraction (C. Dold, 2006), (D. F. Huber, 2003) or maximization of correlation of global characteristics (A. Makadia, 2006). These methods are mostly explored by computer scientists in the field of computer vision. The need for data pre-processing, additional scans that provide large overlap areas and extractable geometric features are the main disadvantages of this category of methods (Franaszek, 2009).

Target based methods use at-least 3 targets (5 is recommended), which are visible and could be captured in both scan shots. Planar targets with high contrast surface, are the most popular targets used in the industry; however, reflective and sphere targets are also used commonly. As depicted in Figure 2, target-based registration starts with selecting the PCD's that share common targets and are to get merged together. The targets that were acquired and labeled at the scanning stage play the role of registration constraints. Hence, they need to be labeled consistently in all PCD's so that the Point Cloud Engine (PCE) can set the constraints correctly. Once the PCD's are selected and the constraints are set, the registration can be executed. The PCE generates an error report for each target used in registration. Any mislabeling will lead to wrong registration and high error report for related targets. Wrong target acquisition at scanning stage can also incur high error. In that case, the faulty target needs to be removed from the constraints list. This is why more than 3 targets are recommended to be installed in the scene. Having faulty targets identified and removed, the operator re-executes registration and follows the next steps accordingly.

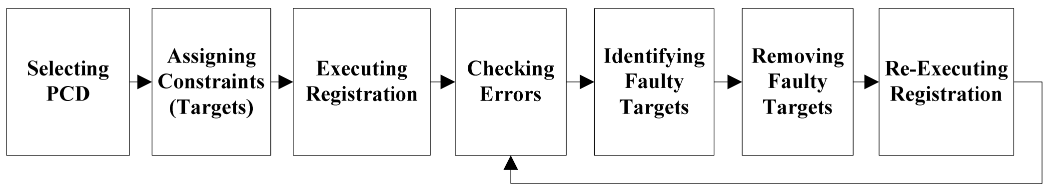

Figure 2: Sequence of work for target-based registration

Targets need to be securely placed at fixed positions since any displacement of targets leads to an inaccurate registration. Manual re-orientation of planar targets to face the new location of the scanner may cause such displacement. The planar targets need to get rotated by the scan crew, while sphere targets are superior to planar ones in this regard since they are viewed the same from any angle. This feature of sphere targets removes the possibility of unintentional target displacement, which makes the target unusable for registration. Planar targets have either a reflective or high contrast surface, which makes it look distinct from other objects in the PCD. PCE utilizes a target acquisition algorithm to detect the exact location of the identified target's center point using its high color contrast or surface reflectivity. Depending on the type of target used, the scan crew needs to set the PCE accordingly, so that it knows how to search for the targets. An error is also associated with the target acquisition algorithm. Non-uniform distribution of targets throughout the work volume is another source of registration error while using the target-based method (GSA BIM Guide, 2007). Placing targets in a line at the same height may result in a rotational degree of freedom around the line. Therefore, targets should be placed at as uniformly scattered as possible in the space with different heights and angles with respect to the scanner to tighten the registration. The best target setting is the one in which targets are scattered in the space at different Cartesian and polar positions with respect to the scanner covering the scene surrounding it.

Modeling

Having point clouds registered, the modelers export them to a CAD environment and fit primitive CAD objects to them using fitting algorithms, followed by some manual adjustments and drafting. Since tracing the points in a 3D space is difficult, the modelers may need to prepare planar sections of the PCD, parallel to plan and elevation planes of the scanned environment. The as-built BIM is then created based on the measurements made off the as-built CAD model. Figure 3 shows the sequence of modeling tasks as described earlier. Depending on the availability of the as-designed CAD documents, modeling process could be different. Modelers first create as-designed BIM and then export it to CAD to overlay it with the scanned PCD. The discrepancies and deviations from the designed plan are then measured in CAD and reflected in the BIM environment.

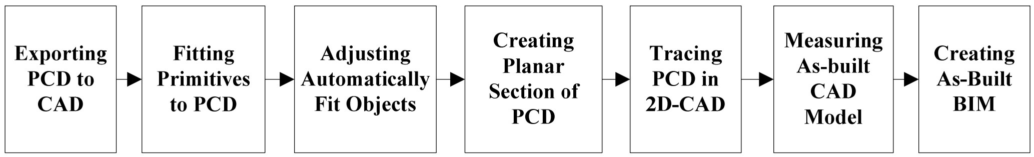

Figure 3: Sequence of work for modeling

The resolution of the PCD and accuracy of the generated as-built model is currently mainly driven by client's requirements. The level of detail needed for each area of interest determines these requirements. For instance, GSA BIM Guide requires minimum resolution of 152 x 152mm with 51mm tolerance for level 1 (lowest level of detail) and resolution of 13x13mm with maximum error of 3mm for level 4 (highest level of detail). This requires modeling every object designated as level 4 that is larger than 13mm and the dimension error value of the modeled object should be kept in the range of 3mm. However, these requirements may change based on the client's specific needs and no standard is set yet.

Since objects are modeled based on the registered point cloud, errors made in the registration process lead to an inaccurate model. The PCE matches some basic primitives to the registered PCD. The errors of range data fitting algorithms affect the accuracy of the created model. Modeler in a CAD environment models objects with complex geometry manually. Therefore, the accuracy of the final product also highly depends on the modeler's skills. The current modeling process is labor intensive and time consuming, as the process is noticeably manual (Arayaci, 2008). Several methods have been developed for automated modeling (Bosche, 2008); however, current methods are not sophisticated enough to cover several objects with various geometric forms.

CONCLUSION AND FUTURE RESEARCH

Although 3D laser scanning is increasingly used to create as-built 3D CAD models or BIMs, there are still some challenges to overcome and gaps to be researched at each stages of the Scan-to-BIM process. The following paragraphs summarize the conclusions and the future research plans of the authors.

Scanning: Scanning is a time consuming operation and any research that leads to introducing more efficient scanning processes would be of high value. Part of the future research will be on improving current processes of scanning in order to save time, which affects the cost directly. Re-orienting, finding and labeling targets constitute a large portion of scanning operation in the current practice. While the scanner views sphere targets as long as there are no obstructions between the target and the scanner, paddle targets need to be rotated manually to face the scanner. As mentioned before, finding and labeling targets are also manual processes, which make them subject to human error and they are time consuming. Automating these processes can reduce the scanning time considerably.

Registration: The effect of using different types of targets on registration errors were reviewed qualitatively, while it should be studied quantitatively as well. Experiments with mixed paper, planar paddle (tilt & turn), and sphere targets will be conducted to quantify the results gained by using these three most-commonly-used target types. Automatic target acquisition and labeling will set the stage to start research on automating the registration process. A dynamic registration that can be executed as the PCD's are generated and the targets are labeled, removes the need for manual registration.

Modeling: Creating as-built BIM from PCD involves an intensive manual process, which is subject to human error, thus raising the budget of uncertainty. It also incurs high cost since it takes a considerable amount of time. Currently, commercially available BIM tools are not able to import point clouds and the modeler needs to model in CAD first just to take measurements for modeling in BIM. Eliminating the intermediate CAD modeling step and direct modeling in BIM environment would save a lot of time and energy. However, automatic as-built creation from PCD would definitely be the ideal solution, which requires minimum manual modeling. The past research efforts on automatic CAD object creation from range data should get directed toward BIM environment. Future research will focus on automated Scan-to-BIM process.

Standards: No standard guideline is established to determine the resolution needed to meet the required level of detail for different environments and objects to be modeled. As mentioned in the previous sections, the current practice in the industry in this regard is driven by the client's requirements. A universal set of standards need to be developed to define the level of detail and required resolution for laser scanning operation. This is another crucial area that the future research should focus.

The end product of the current Scan-to-BIM process lacks semantic data. By using advanced 3D laser scanners, the created model is accurate geometrically but not semantically. For instance, since the modelers are not usually part of the scan crew and even if they were, no semantic data is collected from the scan scene automatically. Common practice is taking field notes that are later on passed to the modelers for reference. Hence, a generic type is selected for the modeled objects in the BIM environment and usually no technical information about the modeled equipment is assigned. Therefore, the as-built BIM delivered is usually not semantically rich and another step of adding semantic information needs to follow for semantically rich as built BIMs. As the owners are increasingly considering the use of BIM during operations and maintenance, capturing of the necessary information during scanning is of crucial importance. To achieve this goal, first the information, that are of interest of the facilities management teams, should be identified as part of a framework to manage building's semantic information. This future framework will include a workflow for semantic information collection and link to the as-built BIM created from PCD.

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