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REAL-TIME 3D MODELING FOR ACCELERATED AND SAFER CONSTRUCTION USING EMERGING TECHNOLOGY

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ABSTRACT: The research presented in this paper enables real-time 3D modeling to help make construction processes ultimately faster, more predictable and safer. Initial research efforts used an emerging sensor technology and proved its usefulness in the acquisition of range information for the detection and efficient representation of static and moving objects. Based on the time-of-flight principle, the sensor acquires range and intensity information of each image pixel within the entire sensor's field-of-view in real-time with frequencies of up to 30 Hz. However, real-time working range data processing algorithms need to be developed to rapidly process range information into meaningful 3D computer models. This research ultimately focuses on the application of safer heavy equipment operation. The paper compares (a) a previous research effort in convex hull modeling using sparse range point clouds from a single laser beam range finder, to (b) high-frame rate update Flash LADAR (Laser Detection and Ranging) scanning for complete scene modeling. The presented research will demonstrate if the FlashLADAR technology can play an important role in real-time modeling of infrastructure assets in the near future.

Key words : convex hull, Flash LADAR, high frame rate range sensing, obstacle avoidance, real-time 3D modeling, safety.

1. INTRODUCTION

Contrary to other industries, construction is well known for its long implementation cycles of new technologies. Frequently stated reasons such as high purchase cost and a too complex integration within existing construction processes characterize some of the construction industry's main impediments to invest in new technologies faster.

In this paper, the needs for technology in construction are identified as physical devices or methods which can provide accurate and fast data acquisition from entire construction sites, allow real-time data processing and provide rapid feedback, are low in cost to buy and maintain, and are small in size, easy and safe to install and use [1]. One of these emerging technology devices is a prototype 3D range sensor, called Flash LADAR. It enables to capture three-dimensional range information of entire scenes in real-time.

2. BACKGROUND AND LITERATURE REVIEW

This paragraph focuses on the background of the construction environment and introduces the literature to the existing Sparse Point Cloud and Flash LADAR approaches, and points at safety and navigation as application examples.

2.1 Construction Environment

A previous research effort at The University of Texas at Austin involved three-dimensional laser scanning and was based on single laser beam scanning of sparse point clouds of static objects [2, 3, and 4]. Since construction sites are characterized by complex processes of static and moving objects, single laser beam technologies have the limitation in handling such multi-object-task situations. In particular, with this method complete scenes consisting of moving workers or equipment can not be covered at a high frame rate.

To cover multi-dimensional scenes, such as the dynamic construction environment, a rapid modeling technique at speeds of sub seconds is needed.

Furthermore, to comply with the research goal of creating a safer construction environment, an automated system could ultimately use the output of sensed and analyzed scenes to navigate machines automatically or at least assist the machine operator with a warning signal if a restricted or endangered area is entered.

2.2 Laser Range Scanning

Laser range scanners have been widely used to obtain 3D range data for construction site scenes. Unlike traditional survey instruments, laser range scanners require no target reflectors, but they can provide a large amount of precise, dense data. With significant cost and time benefits, one true value of range sensors lies in their ability to rapidly build virtual representations to facilitate construction tasks [5], where timely on-site decisions require rapid recognition and accurate measurement of objects in the workspace [6].

Existing range scanning techniques for 3D modeling have focused on issues such as capturing 3D as-built conditions [7]. They can be categorized into *sparse point cloud* and *dense point cloud* approaches. A sparse point cloud approach traditionally enables magnitudes more rapid modeling than dense point cloud approaches. However, recent research interests focused on a *Flash LADAR approach* that can address static and moving environments in real-time.

2.2.1 Sparse Point Cloud Approach

The sparse point cloud approach focuses on selected points to avoid high computational costs of dense range point cloud information and therefore requires only a few minutes to model a scene. The sparse point cloud approach is based upon three basic transformations: (1) Fitting sets of range points to primitive forms, (2) creating bounding objects, and (3) merging and compliance checking. Human intervention is needed in all three steps to select meaningful points from a cluttered scene. Figure 1 and 2 demonstrate a typical construction environment and its model. Bounding algorithms allow for grouping all range points into bounded objects such as convex hulls [7]. This process abstracts or simplifies objects into three-dimensional forms. The minimized computational burden allows it to be used for real-time applications.

The major limitation (and power) of the sparse point cloud approach is the requirement for human judgment and the focus on static environments. Judgment is used in the process of acquiring distinct (single) range point clouds. This enables rapid modeling of the static elements of work spaces within minutes. However, moving objects can not be captured without distracting the operator.

Results of the Sparse Point Cloud approach are not presented in this paper, but are discussed in [1, 2, 3, and 8].

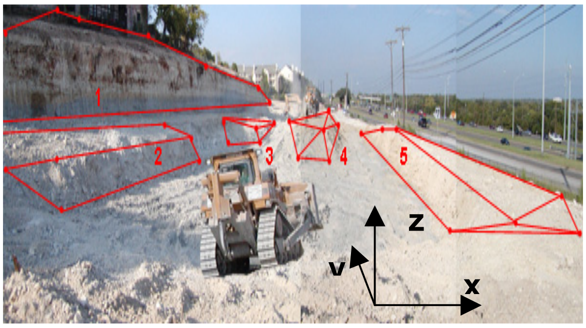

Figure 1. Outdoor Construction Environment Scene with Selected Points to Characterize Target Objects, e.g. here: Embankments for Earth Moving

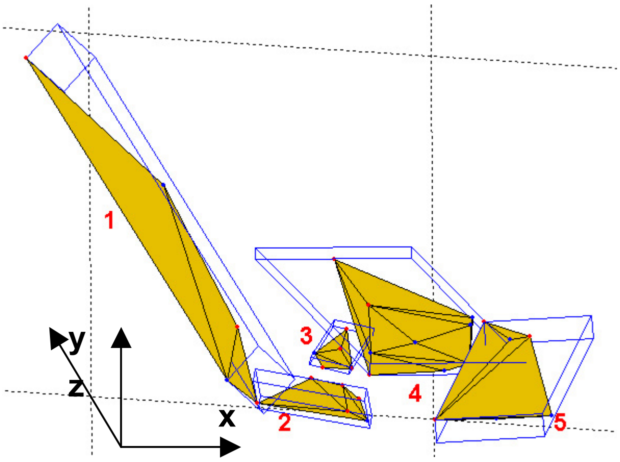

Figure 2. Three-Dimensional Model of Convex Hulls of Outdoor Scene based on Sparse Point Cloud approach

2.2.2 Dense point cloud approaches using LADAR

LADAR is used commercially primarily to accurately model as-built conditions based on its acquisition of very dense precise range point clouds. Taking millions of points can requires anywhere from 20 seconds up to several hours. In addition, the reliance upon analyzing dense point cloud data requires computationally intensive processing. Despite the cost of between $25,000 to up to $1,000,000, the slow speed in extracting objects from dense point clouds is a limitation of current modeling systems based on LADAR,. Thus LADAR cannot be applied to real-world automated, semi-automated, or robotic equipment, since the geometric information of target objects must be obtained rapidly [9].

2.2.3 Flash LADAR approach

Using sparse point clouds acquired with a single axis laser range finder can satisfy most of the requirements for local area 3D modeling. However, it cannot adequately handle actions of vehicles, workers, or equipment which are moving from one location to another. Therefore the capability of Flash LADAR in the detection and efficient representation of static and moving objects (including people) can be employed to complement the 3D graphical-modeling. Still some of the disadvantages of the Flash LADAR, as common in all optical range scanning devices are the need for line-of-sight and influence of weather conditions on the quality of the scanned image. Weingarten et al. [10] and Teizer et al. [11] demonstrated some promising preliminary results in using the Flash LADAR approach.

The range information acquisition process using a Flash LADAR is faster, safer, and less expansive than using a LADAR as it low in purchase cost and does not require surveying or inspection personnel to set-up and operate instruments in dangerous zones.

2.3 Application Examples: Safety and Navigation

Safety plays an important role in many different areas of daily life. Operation of heavy equipment in hazardous work environments like road construction or night operations is one of the primary issues of construction related to the transportation industry. According to OSHA (Occupational Safety and Health Administration), the construction industry continues to report the largest number of fatal work injuries of any industry. A significant number of equipment-human or equipment-objects accidents resulted from missing safety features installed on currently operated heavy equipment [12].

In 2002, the Bureau of Labor Statistics publicized a statistic that the category "contact with objects or equipment" accounts for 18% of 1,125 fatal injuries in U.S. construction. But the portion of injuries actually involving construction vehicles and equipment is probably greater. Falls were responsible for 33% of fatalities in the construction industry, 24% in transportation incidents, exposure to harmful substances or environments killed 18% workers (of which 74% were related to contact to electrical current and overhead power lines), 18% had contact with objects and equipment (about half each were "struck by" or "caught in"), fires accidents and assaults each were attributable to about 3%. Three categories combined ("struck-by", "caught-in", electronic shock incidents) accounted for over 58% of total fatalities and were largely due to accidents stemming from false operations of heavy equipment [13].

Real-time, 3D modeling of workspace will help the construction and transportation industries avoid accidents, fatalities, and thus longer shut-downs. It may lead to faster equipment navigation and can reduce scheduling times.

3. MODELING PROCESS

The ultimate objective of the research is to model static and moving objects within a specified space. In Figure 3 the modeling process of a Sparse Point Cloud approach is compared to a Flash LADAR approach. Both approaches are conducted at the Field Systems and Construction Automation Laboratory (FSCAL) at The University of Texas at Austin.

Previous research efforts had used a single laser beam range finder to collect sparse range points. In a defined workspace including only static objects, human surveyors make a decision which target objects need to be modeled. To those objects, a few single range points (approx. 10-15) are measured with a single beam laser range finder. Then, an algorithm creates a convex hull. After the modeling of one object, the modeling process can be repeated for other objects on demand. Once the range data acquisition is complete, a three-dimensional local area model (model of the field of view) is created and uploaded in a world model (consisting of all local area models).

Current research efforts focus on the emerging technology of Flash LADARs. A Flash LADAR acquires distance points of full range images at a high frequency. Subsequently, range points of the entire object within the image are collected. Human input to select points is not required. An algorithm processes the model into an occupancy grid. The grid is segmented into clusters of objects. Convex hulls bound the objects. The cluster features allow the determination of center of gravity and volume to each objects and give a chance to track and plan its path. The Flash LADAR approach developed at FSCAL is able to handle static and moving objects while the sensor is in a static or moving position.

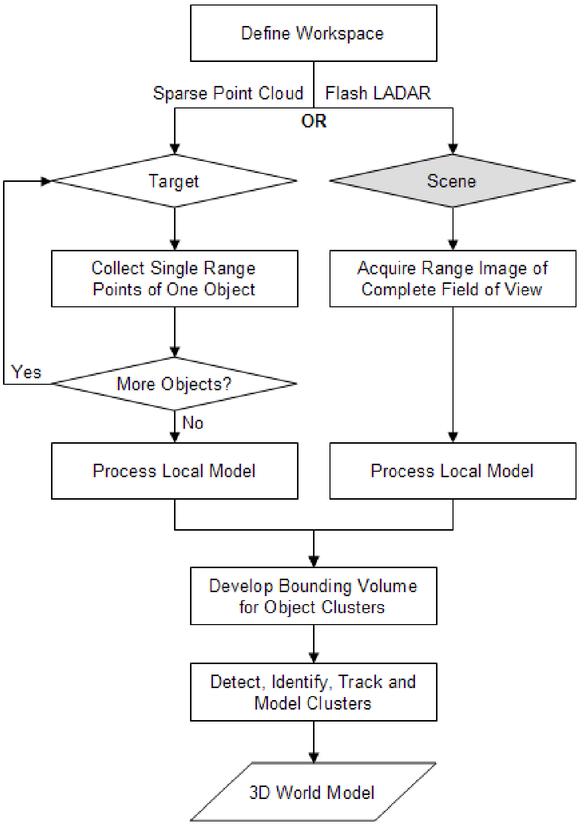

Figure 3. Modeling Process

4. EXPERIMENT AND RESULT

This paragraph compares initial research results of the Flash LADAR approach with existing results of the Sparse Point Cloud approach. A discussion of the results follows. An experiment was conducted which had two objectives:

1) Demonstrate the feasibility of the Flash LADAR approach for future real-time 3D modeling.
2) Understand the conditions and useful application areas for Sparse Point Cloud modeling and the Flash LADAR modeling in the future.

The approach of Sparse Point Cloud laser range scanning and processing is moderately fast. A model of a single object can be done in a matter of some few minutes. For example, a skilled and trained surveyor can shoot range and model a scene consisting of five objects into a three-dimensional model within about ten minutes. The resulting modeling output, convex hulls of individual objects, have an accuracy in centimeter range or even higher. However, only single points in a static scene are collected since a single beam needs to be manually pointed to the next relevant point characterizing the shape of an object. Once points are collected and a convex hull encompasses all points belonging to one object, the processing of all points is in the magnitude of seconds. Overall, the strength of the

Sparse Point Cloud approach is in the accuracy of measurements of static objects. Even thin objects like electric wires or cables can be modeled precisely.

Compared to the Sparse Point cloud approach, the Flash LADAR approach is based on dense point clouds. It delivers higher details of entire scenes including static and moving objects. The Flash LADAR approach is faster in range data acquisition and processing, but is still influenced by noisy range outputs originating from the prototype status of the sensing equipment. New and advanced Flash LADARs will eliminate this problem.

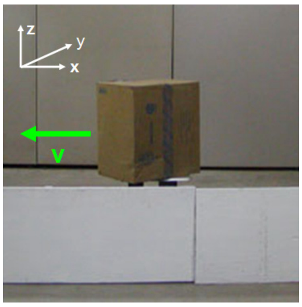

Figure 4. Objects: Fascia Wall, Box, Background Wall

In Figure 4, three objects are within the field of view of the Flash LADAR sensor. After the acquisition and processing, convex hulls were generated (see Figure 5 to 8 in the Appendix). Including the processing steps, the generation of convex hulls takes less than two seconds. The results of this experiment demonstrate that, with a Flash LADAR, it is possible to create convex hulls of static and moving objects. Furthermore, real-time 3D modeling of objects becomes feasible with existing prototype technologies.

To determine the full 3D view of the object, in both approaches the sensor's standpoint or the orientation of the object needs to change to a different location, so more information from other object's sides can be measured.

Concluding the current research results, the advantage of a Sparse Point Cloud Approach using single beam laser range finder lies in creating the boundaries of a workspace or of any object which is static and bigger than the Flash LADAR sensor's field of view. Sparse points can be used to build the world model (boundaries), while the Flash LADAR's field of view creates local models to be integrated in the world model in real-time.

4. CONCLUSION

This paper has demonstrated that real-time laser range scanning is feasible. The Sparse Point Cloud approach and the Flash LADAR approach are two approaches supporting this idea. Both have benefits and limitations in usage and a combination can satisfy most of the requirements for real-time 3D modeling.

Flash LADAR improves existing approaches of three-dimensional modeling in reducing significantly the processing time and increasing the scene detail, but still generates noisy range images. Flash LADAR allows the detection of static and moving objects for safer construction operation and may accelerate the navigation of heavy equipment.

ACKNOWLEDGMENT

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APPENDIX

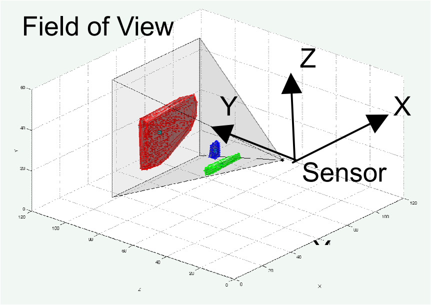

Figure 5. Convex Hulls of Flash LADAR: Isometric View

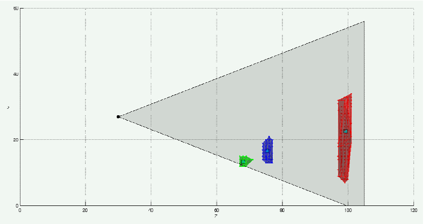

Figure 6. Convex Hulls: Elevation View (Z-Y)

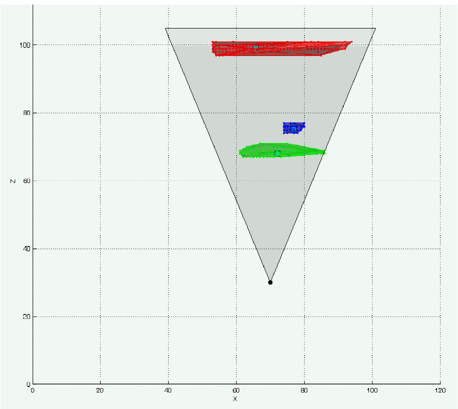

Figure 7. Convex Hulls: Plan View (X-Z)

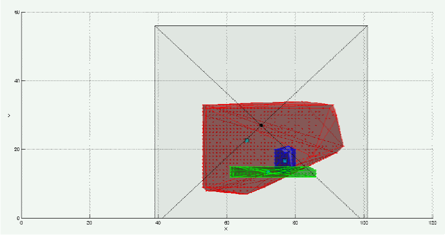

Figure 8. Convex Hulls: Front View (X-Y)

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