LADAR Sensing Applications for Construction

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1. Need/Potential

Surveying has been the traditional method used to map terrain as well as to control and monitor the status of construction jobs. This is a manual, time-intensive task that requires a two-person crew at minimum. There are numerous situations where traditional surveying simply cannot be used effectively -- e.g. in hazardous environments; for situations requiring the simultaneous monitoring of moving construction components; and for the monitoring of "amorphous" construction objects -- such as the instantaneous volume and surface contour of a concrete pour. One of the chief sources of lost time in earthmoving operations is the scheduling of "stake-out" crews to lay out excavation profiles. Often during summer months, operations may sit idle waiting for a crew mark the next set of cut and fills. The inability to monitor the details during construction frequently leads to "re-work" -- a process of tearing down and rebuilding to meet the engineering intent. These errors could have been prevented if a means existed to obtain instantaneous geometry of the construction site, including the position and orientation of all erected components. This latter issue, and the closely related practice of returning to a site after completion of construction to document what was actually built (as opposed to the design intent) account for some 5% of the labor cost of a typical commercial construction job. When one considers that 13% of the U.S. GDP is construction based, the "need to know" what is happening on a construction site takes on a more compelling financial meaning.

One potential breakthrough technology that stands to revolutionize construction surveying and status monitoring is known as laser range imaging. The device used to obtain the field data is known as a LADAR (Laser Distance and Ranging). With LADAR it is possible to rapidly capture true 3D data for an entire construction scene. Essentially, the LADAR acquires hundreds of thousands to millions of survey "shots" that cover a field of view from the viewpoint of the sensor location. It is possible to do this rapidly because, unlike traditional survey, no target reflectors are required -- range is determined based on either time-of-flight or the phase shift of the signal reflected from the natural objects in the scene. The resulting flood of raw data form a "cloud" of three dimensional points. In the land surveying and stake-out business, such point clouds could be considered as instantaneous "stake-outs" with a degree of precision and speed that lends itself both to web-based volume take out determination and billing and, even more powerfully, enables the automation of the machines that move the dirt. In the case of constructed facilities such data could be further processed to create accurate 3D surface models from which the positions and orientations of individual parts could be deduced automatically to high accuracy through object recognition -- thus producing automatic "as-built" models of the facility. In short, LADARs will likely pave the way for improved survey accuracy and speed; will make possible automated construction status assessment; and will enable the first instances of truly automated construction processes.

2. Background

LADARs have been used for industrial applications since the late 1970s. The principal factor limiting their use, then and now, is the cost of the instrument. Substantial LADAR development work has been undertaken by the DoD for applications involving battlefield assessment and for autonomous vehicle navigation. Real-time applications based on LADAR sensor data have recently become possible owing to advances both in imaging sensor acquisition rate and computer processing speed. Since the early to mid-1990s, the use of LADARs to generate range images has been growing rapidly in the area of aerial survey (topographic mapping and bathymetry) due to the speed of acquisition and the inherent compatibility of the resulting data with GIS-based asset management systems. Generation of 3D as-built models of constructed facilities has also been an area that has grown in interest during the last few years. These 3D models are used for documentation when building plans are not available; for reverse engineering; for retrofit purposes; and for maintenance planning and inventory assessment. In contrast, the use of LADAR to improve and to automate construction work processes has mainly been in the research arena.

3. State of the Art

The use of LADARs for construction management and automation is still in its infancy. This is largely because of the general conservatism of the construction industry and the lack of conclusive financial data that would unambiguously demonstrate return on investment (ROI) for general LADAR use. The reasons for this are discussed in section 5 below. In general, LADARs can be categorized based on their working range:

Application	Construction As-builts/ Manufacturing (Object Modeling Sensors)	Construction / Large Scale Manufacturing (Terrestrial Sensors)	Topography (Remote Sensors)
Range	≤ 20 m	100 m to 300 m	> 600 m
Accuracy	mm or better	2 cm to 5 cm	5 cm to 30 cm
Costs	$200 k to $400 k	$100 k to $250 k	> ≈$1M

LADARs that fall within the middle category in the table are those that will likely see use in the construction industry in the near future on a regular basis. Due to the high cost of acquisition most commercial construction LADAR work today is performed by service bureaus closely allied to or that are subsidiaries of instrument developers. In one case study, a savings of 75 % in survey cost and post-processing time were achieved by using a LADAR to survey a foundation site for a dam. In another project, cost savings of approximately $10 M were realized in the retrofit of a power plant -- derived from reductions in modeling time (50 %) and in the reduction in change orders during construction.

There are a number of related fields that will ultimately bear on the routine use of LADAR at construction sites. These include: continually improving GPS sensor accuracy and update rates -- essential for positioning and referencing the LADAR unit both in static and vehicular-mounted systems; MEMS technology to increase speed, but most importantly to reduce size and costs of LADAR units; laser technology to increase speed and accuracy (reduced beam divergence); novel signal detectors to increase range and accuracy (reduce noise); computer technology to decrease post-processing time; and wireless communications for ease of field data transfer.

4. Centers of Activity

The National Institute of Standards and Technology currently has a substantial program in construction LADAR technologies with specific focus areas in traceable calibration and performance measurements for LADAR sensors; the development of web-based management systems based on LADAR (and other site) sensor data; and fundamental research in collaboration with industry to develop the Next Generation LADAR (NGL) for general automated construction. Carnegie Mellon University (CMU) has used LADARs to enable autonomous operation of construction machinery. Work at the University of Tennessee has centered on development of procedures for the characterization of certain LADAR systems. The U.S. Army Corp of Engineers Topographic Engineering Center as well as NOAA have been using airborne LADAR for mapping vast tracts of lands and coastal regions/flood plains. There are a number of DoD sponsored organizations currently involved in the development of LADAR technology including MIT's Lincoln Lab, Sandia, the Army Research Lab, Raytheon, the Rockwell Science Center, and Lockheed Martin.

Manufacturers of LADAR sensors for possible use in the construction industry include 3rdTech, CSEM, Cyra, Mensi, MetricVision, Optech, Riegl, SICK, Dimensional Photonics and Z&F. Some software with the capability to post-process LADAR data include: Esri ArcInfo, Cyclone, Erdas, Polyworks, Spectra Precision TerraModel and PayDirt. There are also numerous startup companies, e.g. Reality Capture Technologies, that are providing as-built services based on LADAR technology.

5. Gaps

There are a number of presently unresolved issues that will severely limit the emergence of LADAR technology at construction job sites. These include, in order of importance:

- Lack of Traceability: There are presently no standards against which to compare LADAR systems. Contractors and business owners need the assurance that the work they pay for is what was done. Artifact-traceable standards are needed for instrument calibration, scene registration, and object recognition. Confidence limits have to be established for derived quantities, position, and pose determination.

- High Cost: While pricing and availability of existing sensors may be acceptable for military missions and the development of national performance metrics, they are beyond the resources of most contractors. Thus, the development of a low cost, high-resolution system is paramount. A cost reduction of 100 to 1 is likely needed to achieve ubiquitous use.

- Large Size: Presently available LADAR systems with accuracy sufficient for construction control are too large for ubiquitous use, eye safety issues not withstanding. Many automation experts believe that coffee-cup sized LADAR units, mounted on construction assembly systems, will be crucial to automating construction as well as to achieving automated tracking of construction materials. A size reduction of 10 to 1 is needed to achieve this objective.

- Robust Post-processing Software: Although substantial efforts are underway at several LADAR-based startups, algorithms that can automatically process LADAR data are still in the nascent research stage. Application specific programs to automatically calculate billable quantities and to automatically generate as-built CAD data sets for constructed infrastructure remain the holy grail in this field.

The first of these issues is currently being addressed by efforts at NIST to develop a national artifact standard LADAR test course and to develop web-accessible metrics for LADAR performance. Given the small size of most companies working on LADAR development, and the high risk of attempting radical new technology integration, it appears certain that the only means by which the second and third issues will be resolved will be via a concerted government/industry consortium. If the first three issues can be resolved, the private sector and academia are well positioned to provide the fourth.