The Use of Boston Dynamics SPOT in Support of LiDAR Scanning on Active Construction Sites

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Abstract –

With the recent commercial availability of autonomous mobility platforms, construction researchers have focused their attention to the application of advanced robotic tools on jobsites. One such mobility platform is Boston Dynamic's robot, "SPOT." The software development kit (SDK) enabled, quadruped robot has the infrastructure to attach interchangeable payloads including LiDAR (Light Detection And Ranging) scanners. Researchers have conducted a pilot study comparatively analyzing terrestrial LiDAR scans from a human-based tripod scan system and the scans executed by SPOT in both manual and autonomous modes. The research looked at three metrics – quality of scans, productivity savings, and robot accuracy. The result shows that although scan quality is slightly diminished due to the height and shape of the robot, the productivity gains from an autonomous robot could offset the scan quality with additional scans. In addition, in small sample testing, the robot was accurate in returning to a pre-defined location in autonomous mode. Due to the page limit, this paper only presents the results and findings of quality of scans of this this research study.

Keywords –

Autonomous Robots; Construction Robotics; Construction Site Monitoring; Data Capture; LiDAR Scanning

1 Introduction

Light Detection and Ranging, or more commonly known as "LiDAR", is an important data capture instrument on construction projects. This technology is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) from the scanning device to an object. These light pulses generate precise, three-dimensional information about the shape of the items within range of the scanner and its surface characteristics [1]. The resultant data collected by the scanner is rendered by specialized software creating a 3-dimenional "point cloud." Such point clouds created from terrestrial LiDAR have an accuracy measured in millimeters and is a reliable mechanism for existing condition assessment and as-built documentation.

Historically, terrestrial LiDAR scanning (TLS) in the construction industry relies on a human setting the scanner on a tripod in predetermined locations in order to capture a comprehensive view of the space requiring the scan (Figure 1). This process works, but does require human intervention and depending on the number of scans for coverage of a designated area, can take a significant amount of time.

Figure 1: Example terrestrial LiDAR scanning (TLS) approach using a tripod.

With the recent availability of autonomous mobility platforms, researchers have focused their attention to the application of advanced robots on construction sites. One such mobility platform is Boston Dynamic's SPOT. Described by Boston Dynamics [1] as, "an agile mobile robot that navigates terrain with unprecedented mobility, allowing [users] to automate routine inspection tasks and data capture safely, accurately, and frequently." SPOT is a SDK (software development kit) enabled, quadruped robot, allowing for the attachment and integration of payloads. One such payload is the FARO S-350-series Laser Scanner (Figure 2). By mounting scanners like the FARO S-350 onto an autonomous mobility platform, interfacing the payload to SPOT, and executing "actions" through the integrated autonomous mode, the possibility exists for scans to be executed without the need for human intervention.

Figure 2: Boston Dynamic's SPOT with FARO S-350 payload.

Based on hours of testing, under ideal conditions, executing actions with SPOT while in autonomous mode is a fairly reliable process; however, executing autonomous actions, on an active construction site, with industry standard hardware has yet to be evaluated. To date, the published literature on SPOT has been mostly conjecture. This is likely due to the relatively recent availability of SPOT for purchase and the high cost. The goal of this research is to conduct a pilot study comparatively analyzing human-controlled terrestrial LiDAR scans from a tripod and the scans executed by SPOT. This research is significant because there is currently no published experimental research evaluating application of the Boston Dynamics SPOT on an active construction site. For this research, the quality between the tripod based scan and robot based scan are being evaluated. The research question being evaluated:

- Is there a quality difference between the point clouds produced by the tripod-based scan and the SPOT-based scan?

2 Literature Review

Semi and fully autonomous robotics have made a significant emergence within the industry in the last decade. Current market robots are designed to execute a wide arrange of construction activities in both the administrative and skilled labor spaces.

The use of LiDAR scanning is a growing trend in the built environment. Research has investigated its application in civil construction [2-6] and building construction [6-8], and has shown that it can provide an efficient alternative to traditional surveying options [6-8]. It has been recognized to be suitable in multiple applications such as project progress monitoring, developing as-built documentation, quality control, historical documentation, and existing conditions analysis [6, 8–12]. Since the commercial availability of LiDAR scanners in the early 2000s, implementation has focused mainly on terrestrial laser scanning (TLS) [2, 3, 13]. TLS involves manual setup, deployment, and relocation of a tripod-mounted scanner by an individual to capture the necessary project elements. Although more efficient than alternative methods, the approach requires considerable time investment and has been identified to have project accessibility limitations [14]. Photogrammetry has been an alternative approach to laser scanning for similar project applications – especially when deployed with a UAV [15]. It has advantages over TLS in terms of portability and price; but it also presents a number of limitations in terms of accuracy, data completeness, scaling, robustness to various material textures, etc.

Mobile applications of laser scanning (MLS) have been developed as a means to resolve the limitations of TLS. Gargoum and Karsten [16] investigated using LiDAR scanners mounted to vehicles for scanning large sections of highways for site distancing analyses. LiDAR-mounted unmanned aerial vehicles (UAVs), have shown beneficial for exterior scanning work – especially in hard-to-access areas such as conducting inspections on bridges or exterior building walls [12, 17-19]. However, most of the research using LiDAR-mounted UAVs has focused on industries other than building construction due to identified limitations for interior building applications because of communication issues with the related global positioning systems on which they often operate [17, 20-22].

Alternative strategies are currently being evaluated to address these issues. Xin et al [23] investigated the use of LiDAR as a navigation system for deploying UAVs in indoor applications where GPS typically falls short. Unmanned Ground Vehicles (UGVs) have been explored as one solution to the limitations associated with UAVs for interior implementation on construction projects (Xin, et al., 2020). The UGV solution has presented challenges related to automation though, especially when ground obstacles are presented. Lee, Park, and Jang [24] utilized a combined drone and wheeled robot mounted with a VR camera and LiDAR to test monitoring capabilities of interior construction progress. Asadi et al. [25] noted numerous studies that combined UGVs and UAVs, but none provided an autonomous solution. They used this previous research as the justification for their investigation of an autonomous combined UAV/UGV approach.

All the previous studies required the use of a UAV and UGV to complete the navigation and monitoring process. One potential solution to this limitation is Boston Dynamic's SPOT; a SDK enabled, quadruped robot, allowing for the attachment and integration of payloads such as LiDAR scanners and cameras [26]. It appears the current research is very limited on a singular autonomous solution like SPOT for construction monitoring [27]. This study is significant as it provides a first look into the application of an autonomous quadruped robot on an active construction site.

3 Methodology

This research project used an experimental setup in order to achieve the goals.

3.1 Experiment Location

The experiment took place on the first floor of a multi-level active construction site with workers present. An active site was preferred in order to identify any limitations to the robot in autonomous mode. At the time of the experiment, the structural elements for the first floor were complete and much of the in-wall and overhead work was taking place. There were numerous stored materials laying around the floor space and no drywall had yet to be installed. This phase of the project is ideal for the "productivity" and "accuracy" portion of the research as the lack of visual markers for the robot to situate itself within the space and the amount of possible route obstructions could put the robots AI (Artificial Intelligence) to the test during autonomous walks.

3.2 Experiment Setup

This research compared the quality and productivity differences between a tripod and SPOT mounted TLS. In addition, the research looked at how accurate SPOT, when placed in autonomous mode, was at positioning itself in relation to the benchmark set in manual mode. In order to quantify these differences, the researchers divided the data collection into the three constituent parts (scan quality, productivity, and accuracy). All experiments used 4 scan locations on the first floor of the active construction site. Figure 3 presents the 4 scan locations as well as the distance between them. In order to get to Location 4 from Location 3, both the human and robot needed to work around some stored materials obstructing the path.

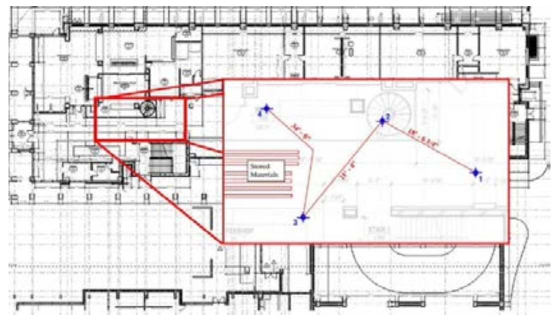


Figure 3: Four scan locations on project floor plan w/ distances between markers.

3.3 Scan Quality

At the 4 predetermined locations, a scan was taken from a FARO S-350 scanner mounted on a tripod (set up by a human) and then again with the same FARO S-350 scanner mounted on SPOT. Each scan used the identical scanning profile as described in Table 1. The series of scans were in immediate succession to avoid possible disruptions that could affect the result, such as difference of sunlight. As an active construction site, the expectation that people would be passing through the scans was assumed. No effort was made to prevent this. Any scan taken during working hours would encounter this issue. The quality analysis in this research was based on the coverage and clarity of the resultant point clouds, not on the specific items that the scan captured. The only variable for this portion of the research was the platform in which the FARO scanner was mounted. The resultant point clouds were processed and registered in FARO SCENE and then exported to Autodesk Recap Pro for evaluation. The quality analysis used two metrics for evaluation, a visual assessment by each researcher and the registration report.

Table 1. Details of Scanning Profile

Setting	Value
Scan Resolution	1/5
Scan Quality	4 x
Scan Duration	> 7:09 minutes
Scan Size	8192 x 3413
Photo Capture	On
HDR Photo	Off
MPts	28.0
Point Distances	0.276 in / 30 ft
Unambiguity Interval	2014.354 ft

3.4 Hardware Setup

The tripod based scanner used a standard hardware setup, with the height of the scanner lens at 5'-5 3/8" from the concrete floor. This elevation was for comfort of the user and was the standard protocol used in TLS.

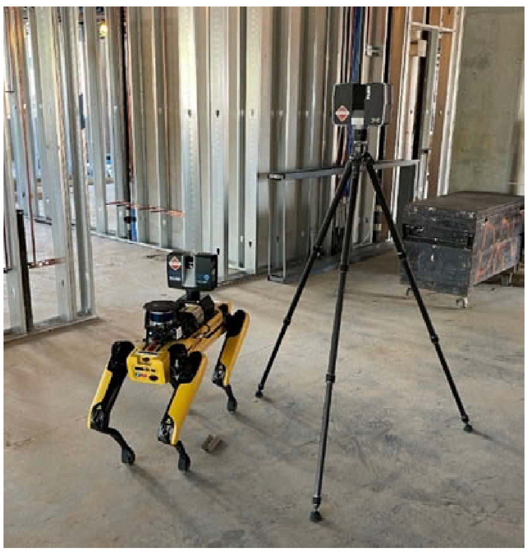


Figure 4: Hardware setup of tripod based scanner and robot based scanner.

The SPOT based scanner has the scanner lens at 2'-7 1/2". This height was a function of the stand height of the robot and the custom mount used to attach the FARO scanner to the robot. Other hardware - A Velodyne LiDAR scanner and SPOTCore processor - on the robot was used to improve the autonomous vision of the robot during Autowalks. This setup improved the vision of the robot from 2 meters, from the onboard cameras, to 100 meters [28]. A week before the experiment, the research team ran checks on the robot in order to verify proper functionality. This included a load cell check, camera check, and camera recalibration. At the time of the experiment, the robot had no internal errors. Figure 4 presents the hardware setup of the tripod-based scanner and the robot-based scanner.

4 Results and Analysis

Scans were taken at four different pre-determined locations as identified on the building floorplan in the Methodology section. However, during execution of the experiment there was a number of materials, tools, and miscellaneous artifacts located in the work area. All items were left in place as a means to capture the full effects of replicating the scans on an active construction site. Some of these items presented specific obstacles that SPOT would have to maneuver around in order to access the scan locations.

The scan quality was evaluated on two metrics, visual comparative analysis and registry report data developed through the registration in FARO SCENCE. The visual comparison yielded mostly inconsequential differences with two visual issues. Firstly, due to the shape of SPOT, in comparison to a tripod-based scan, the rear shadow was substantially larger as shown in Figure 5. When the scanner rotated to the back side of SPOT and pulsed at an angle slightly below 0 degrees, the scan was interrupted by the internal LiDAR scanner that SPOT was using for extended vision. Another issue noticed by the researchers, arguably more substantial, was that the height of the FARO scanner on SPOT (measured as 2'-7 ½) was almost three feet lower than that of the scanner mounted on the tripod (measured as 5'-5 3/8"), which affected the effective coverage of the captured point clouds. As shown in Figure 6, the top surfaces of the jobsite storage boxes and other items behind those boxes in the background were captured by the scan on the tripod setup but not by the scan on SPOT.

The second quality metric was the registration report comparison developed by FARO SCENE software while the point cloud was being processed and registered. The results of point cloud registration reports, as shown in Figure 7, revealed that although the robot-based scans had a mean point error that was more than double that of the tripod-based scans, both sets of scans were showing a Mean Point Error under 1.6 millimeters. Two possible causes of the larger Mean Point Error of the SPOT-based scan are 1) the slightly instability of the mount setup on the robot compared to the very steady tripod setup, and 2) fewer points were captured close to the scanner due to the shadow under the robot which could have been used to improve scan registration. The researchers also expected that the error of the scan registration would be fairly minimal due to the following factors:

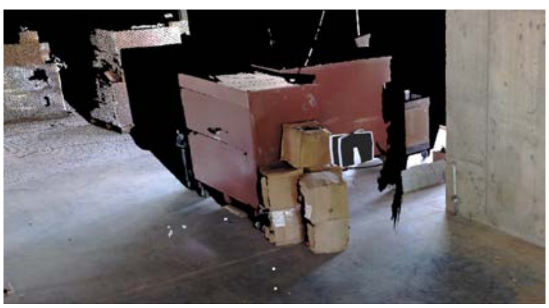
- A very small amount of scans were captured for each round of the field testing
- The scan stations were set up relatively close with the longest distance between any two scans being less than 38 feet
- There were plenty of unique rough and hard surfaces in the testing area captured by the scanner

which were ideal for scan registration

(a) Scan captured on a tripod

(b) Scan captured on SPOT

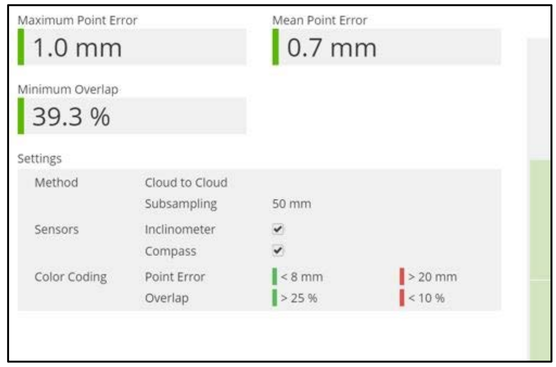
Figure 5: Comparison of shadow cast on tripod-based scan vs. SPOT-based scan.



(a) Scan captured on a tripod

(b) Scan captured on SPOT

Figure 6: Comparison of capture limitations on tripod-based scan vs. SPOT-based scan.



(a) Tripod Based Scans

(b) Robot Based Scans

Figure 7: Registration report comparison.

With other metrics such as overlap, maximum point error, and acceptable color matrix results, the two sets of scans were yielding results that were, quality-wise, indistinguishable.

5 Conclusions and Discussion

The goal of this research was to conduct a pilot study comparatively analyzing terrestrial LiDAR scans (TSL) from a human-based tripod setup and the scans executed using the Boston Dynamics SPOT. Analysis was conducted on the metrics of quality, productivity, and accuracy. However, one the conclusion and discussion regarding the quality of the scan data captured from the study are included in this paper.

5.1 Scan Quality

The scans taken with SPOT identified some challenges with quality of capture related to vantage point and shadow cast. This was due to the physical shape of SPOT, autonomous payloads, and reduced height of the scanner when mounted on SPOT's back. Ideally, LiDAR scans for as-built of the interior of a construction project are captured by scanners elevated to five feet or higher using a tripod. At such height, the scanners are able to capture the surfaces of common features in the buildings, such as desktops, countertops, lavatories, etc. However, when mounted on SPOT, the highest surfaces that the scanner can capture are roughly 2'-8", resulting in null data for elevated finishes. Certainly there are mechanical ways to elevate the scanner on SPOT, such an altered mount, however this will create additional issues that could be far worse than the initial problem. First, mechanically raising the scanner will significantly alter the balance the SPOT system and make it more vulnerable to fall. Second, the programming of the SPOT control system needs to be altered to change its sense of clearance. A potential solution to this could be a reticulating mount, but this product currently does not exist and would need to be manufactured specifically for this application.

The other issue of capturing LiDAR scans on SPOT identified through this research is the relatively large shadow in the point clouds that was caused by the rear payloads and shape of the robot. This issue resulted in a less amount of effective points captured by each robot based scan. Mitigation of this issue can be done in two ways. First, removal of the internal LiDAR scanner (rear payload) from the robot would yield a slightly smaller shadow; however, this may actually be counter-productive to the overall effectiveness and productivity gains acquired from the robot. Removing the rear payloads will likely improve the coverage of the point cloud behind the robot but, as the internal LiDAR gives SPOT additional vision, removal of this system may require additional fiducials, resulting in more human intervention. Perhaps the more effective mechanism for improving the scan coverage in regards to the rear shadow, is to decrease the spacing between scan stations to compensate the shadow areas, resulting in additional scans. Additional scans would obviously effect cycle time, but ultimately, an accurate point cloud is the superseding goal.

5.2 Summary

This study focused on providing an introductory look into employing the Boston Dynamics SPOT autonomous robot on an active construction site to analyze practical uses for terrestrial LiDAR scanning. Recognizing the current literature on this new robot is extremely limited, this research is significant in providing a first look at quality, productivity, and accuracy on an active construction site. It also serves as a proof of concept for a methodology to conduct future research. The results of the study suggest some possible usages for SPOT to be implemented on active construction sites. However, future research needs to be conducted to collect more repetitive and larger samples for analysis quality, productivity, and accuracy. Some specific areas need to focus on how obstacles affect these metrics, consistency and reliability of accuracy, and human intervention required to implement the robot on to achieve consistent and accurate results. Other research should look at options to improve the flexibility of payloads that can be used. Specific to LiDAR scanners, mounting options need to be researched to get the vantage point of the scan higher and to provide a more stable platform for the LiDAR scanner. Future research may want to look at using SPOT for surveying, but that would require greater accuracy and in its current form, does not appear possible without additional programming and/or human intervention. Other robotics companies are focusing their efforts on layout, possibly making SPOT an inappropriate tool for the application.

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