Project Title

Image-Based 3D Reconstruction of Utah Roadway Assets

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Research Needs

Infrastructure systems are considered as the fundamental foundation of societal and economic functions such as transportation, communication, energy distribution, wastewater collection, and water supply. Most of the infrastructure systems are both geographically extensive and have a long service life. It is expensive to provide and manage any physical infrastructure over spatially extensive areas and for longtime spans. These characteristics of the infrastructure systems complicate the planning for future infrastructure maintenance, repair, and reconstruction of the existing facilities [1].

Asset management is the essential step toward better handling the existing infrastructure. It suggests principles and techniques to apply in policy-making, planning, project selection, program tradeoffs, program delivery data gathering, and management system application. As it could be observed in figure 1, asset maintenance and monitoring are inevitable chains in a healthy asset lifecycle. Therefore, transportation asset management is a strategic approach to managing the existing transportation infrastructure. It promotes more effective resource allocation and utilization, based upon quality information, to address facility preservation, operation, and improvement [2].

Figure 1. Asset lifecycle delivery

In the highway's context - where the asset is the highway itself - the aim is to provide a structured approach to roads maintenance to enable highway authorities to operate, maintain and restore their 'highway assets' to meet key performance requirements. Looking after the highways network is a national priority given its fundamental role in the economy. To fulfil this potential, it needs to be adequately maintained [3].

The National Highway System (NHS) is a major network of roadways and bridges within the overall system. UDOT (Utah Department of Transportation) collects condition data on 100% of the NHS in Utah which consists of: 2,830 centerline miles of roadway, 15, 584 lane miles of roadway, 1,353 state-owned bridges, and 6 locally owned bridges. Figure 2 demonstrates a sample of highway in Utah including various corresponding assets [4].

High quantity and relatively low-cost roadway assets – such as traffic signs, traffic lights, pavement markings, and guardrails – are critical elements in the operation of transportation infrastructure systems. These assets require preventive, restorative, or replacement work activities to preserve their functionality in an accepted level of service. Nevertheless, in recent decades, the significant expansion in size and complexity of infrastructure networks have posed several new problems on how these assets can be monitored and maintained in a timely fashion. The fast pace of deterioration and the limited funding available have motivated the Departments of Transportation (DOTs) to consider prioritizing roadway assets based on their existing conditions [5].

Addressing these challenging conditions requires comprehensive, accurate, and frequently updated inventories on the condition of all assets. The key elements toward the development of an asset management program that is capable of producing such inventories are being inexpensive and continuous data collection and methods that can further analyze the collected data for condition assessment purposes. The DOT practitioners can then leverage these assessments for maintenance and replacement planning purposes and ultimately improve the condition of the overall transportation systems [5].

Despite the significance, there is a lack of reliable, up-to-date and inexpensive databases that can integrate geospatial, economic, and maintenance asset data. The significant size of the data that

needs to be collected also impacts the quality of the data collection. In addition, the subjectivity and experience of the raters have an undoubted influence on the final assessments. The substantial expansion in size and complexity of highway networks, in addition to the difficulties in data collection has made the National Academy of Engineering (NAE 2010) to identify the process of efficiently creating records of the locations and up-to-date status of the civil infrastructure as one of the Grand Engineering Challenges of the 21st century. There is a need for a credible and well-managed asset data collection and analysis that can provide useable asset inventories to DOTs for further condition assessments. This method needs to enable inexpensive and continuous data collection for high-quantity assets and provide detailed data on their conditions [6].

Figure 2. A view of Utah roadway's assets (signs, ramps, and traffic lights) [7]

Despite its importance, the current practices of highway asset data collection are still manual and time consuming or expensive for those which are not being performed manually (using LiDAR).

Time-of-flight-based laser scanners (are LiDAR) are nowadays utilized to sense as-built spatial data of infrastructure. They operate by emitting a pulse of laser light to a target and calculating the distance to the target by timing the round-trip time of the pulse of light. High-definition (dense) and accurate point clouds can be achieved, and very little training is required for the surveyors. However, this technology suffers from high equipment cost, as well as difficulties in terms of project settings and logistics.

UDOT currently utilizes LiDAR technology as the main device for assets management data collection purposes. The agency has a contract with a company called "Mandli" to gather, identify, and process a wide variety of roadway assets along its entire 6,000+ center lane miles of State Routes and Interstates. The winning bidder (Mandli) proposed to use mobile LiDAR as its primary technology on the project (along with an array of other sensors). Sensors on the UDOT Mandli flagship vehicle (shown in figure 3) include a Velodyne LiDAR sensor, a laser road imaging system, a laser rut measurement system, a laser crack measurement system, a road surface profiler, a position orientation system, and more. [9, 12].

Figure 3. Sensors on the UDOT Mandli vehicle [12]

Over the past few years, cheap and high-resolution video cameras and extensive data storage capacities have enabled researchers and practitioners to capture high quality videos and images in a very undemanding fashion. In addition, several new computer vision-based algorithms and inexpensive software packages are developed that we can use for automatically 3D reconstruction and recognition of assets in roadways by those captured videos and images [6]. Figure 4 illustrates a sample of generated point clouds for a highway using the LiDAR technology [12].
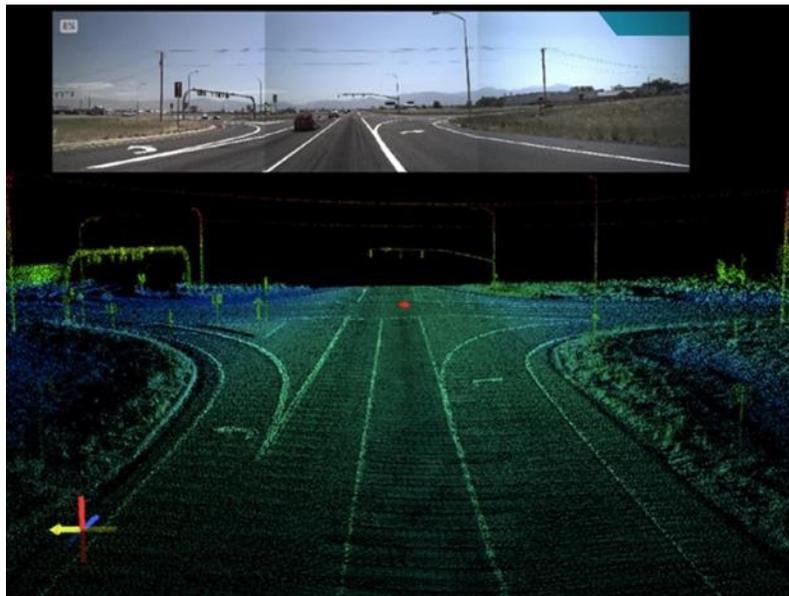

Figure 4. 3D point cloud of signalized intersections created by LiDAR technology

As indicated earlier, the highway asset management and data collection processes using LiDAR provides very promising results, however the highly expensive operations motivate transportation agencies (including UDOT) to consider other more cost-effective solutions.

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Research Objectives

The objective of this research project is twofold:

1) Feasibility study of using photogrammetry as an alternative for LiDAR for roadway asset management purposes.

2) Developing and evaluating necessary hardware settings for generating point clouds of highway assets using photogrammetric techniques.

Research Methods

The project consists of the following components:

1) Evaluating the performance of existing photogrammetric software packages in terms of generating high quality point clouds of highway assets. Under this step, a number of popular photogrammetric software packages listed in table 1 will be considered and implemented for generating point clouds of a number of highway assets as case studies. The results will be compared with the corresponding point clouds generated by LiDAR technology. The comparison will take place considering a number of factors including accuracy, density, and quality of the generated point clouds as well as processing time, ease of use, and the associated costs.

Table 1. List of the software packages with the ability of image-based 3D reconstruction

Software Package	Interface	Aerial Images	Processing videos	Quality of the generated Point Cloud	Cost (perpetual license)
Reality Capture	Quite User-friendly	Acceptable	Capable	Very Good	15000 Euro
Agisoft	User-friendly	Acceptable	Not Capable	Good	3499$ professional edition
Autodesk Recap pro photo	User-friendly	Acceptable	Capable	Good	310$ per year
Photo Modeler Premium	Almost User-friendly	Acceptable	Not Capable	Medium	2995$
3DF Zephyr	User-friendly	Acceptable	Capable	Good	2400 Euro

2) Developing necessary hardware and software requirements for data collection and processing using the photogrammetry: Other than implementing necessary photogrammetric algorithms, an important step toward image-based asset management of roadways is to developing necessary hardware settings and data collection procedures. To

achieve this goal, a number of different scenarios (e.g., evaluating different types and resolutions of cameras, data collection procedures using mobile vehicles, using existing visual data repositories such as google street, etc.) will be considered (figure 5).
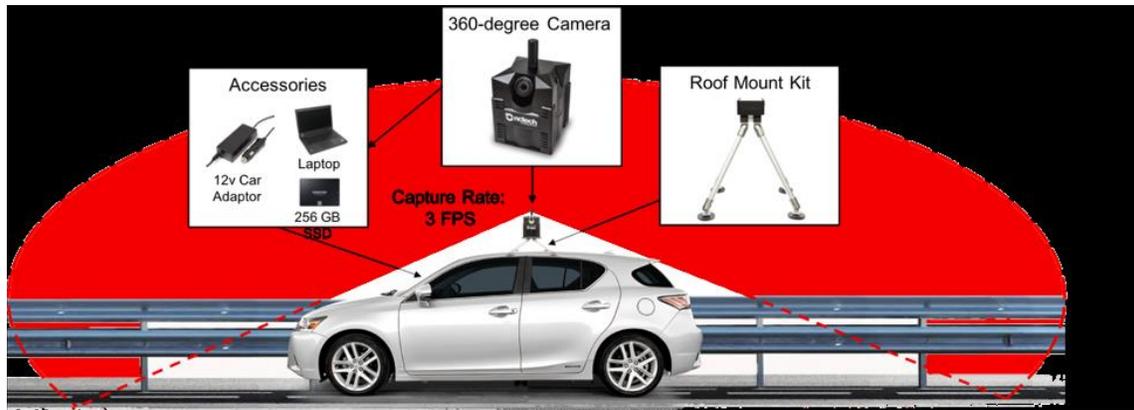

Figure 5. An example of necessary hardware setting for a video capturing platform

Expected Outcomes

The expected outcomes for this project will include the following items: a hardware framework for adequately collecting images and videos and images from highway assets; a manual for comparing point clouds generated by image-based and LiDAR techniques including quantitative procedures and a number of generated point clouds as the case studies. It is also necessary to mention that the outcomes of this project will be diseased and evaluated by UDOT personnel as the practitioners who will be benefited from this project.

Relevance to Strategic Goals

Primary strategic goal: State of Good Repair

This project is providing an easy to use and inexpensive tool to assist public transportation agencies and DOTs with managing their highway assets. Highway asset management is an important prerequisite for maintained, repair and replacing the assets in the future.

Secondary strategic goal: Economic Competitiveness

The proposed solution (using photogrammetry and image processing techniques) provides a very cost-effective option compared the current state of practice for highway asset management purposes. Considering the size and scope of asset management practices and costs within DOT, the project will provide significant amounts of savings.

Educational Benefits

The PI of this project is currently teaching a graduate level class called "CVEEN 6790: Advanced Computer Aided Construction". It is expected that the developed algorithms, methods, and case studies in this project will be directly converted into new course materials for this project. In addition, a number of selected undergraduate and graduate students will be participating in different steps of this project including data collection, processing, and validating the obtained results.

Technology Transfer

The technology transfer process for this project will take place through two major channels: 1) publishing (presenting) research results in scholarly journals (conference proceedings); and 2) direct interactions with UDOT personnel as the potential end users for the results of this study.

Work Plan

The project will include the following major tasks:

1) Literate review and initial evaluation of the existing photogrammetric software packages; Expected completion date: end of 2nd month

2) Developing necessary hardware settings and selecting case studies; Expected completion date: end of 5th month

3) Conducting experiments and data collection; Expected completion date: end of 8th month

4) Processing data and generating results; Expected completion date: end of 11th month

5) Preparing the final report; Expected completion date: end of 12th month

Project Cost

Total Project Costs: $54,000
MPC Funds Requested: $24,000
Matching Funds: $30,000
Source of Matching Funds: Utah Department of Transportation, financial support

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