SUPPORTING DESIGN WITH REALITY CAPTURE TECHNOLOGY

Bartley Wade Estes, CMS - LiDAR  
Geospatial Technologist  
CEC Corporation
Abstract— Developments in reality capture and geospatial technologies are rapidly enhancing the approach to engineering and design in the utility sector. As current design workflows shift from 2D to 3D, precise preliminary design requires highly detailed existing information. Projects are now being “virtually constructed” before ever breaking ground, drastically reducing construction conflicts, change orders, and other issues that come along with conventional design workflows. To help achieve this, reality capture technologies are being leveraged to provide comprehensive and high-precision existing models.

The general term “reality capture” encompasses many related technologies that capture the current state of something, like a project site. These technologies range from 3D laser scanning, photogrammetry, unmanned aerial systems, augmented reality, and many more. These new data capture methods are empowering designers to make more data-driven decisions.

There is not one single reality capture technology that fits every situation. Choosing the right tool in the toolbox is key. Many times, this can be a blending of multiple technologies to produce the critical and actionable data needed to create a comprehensive preliminary design. Understanding how these different technologies translate to the world of design is crucial to the overall approach to a project understanding.

INTRODUCTION

Infrastructure design of any type usually begins with an existing model – generally a survey. While the basic concepts of surveying are unchanging, the technology to acquire survey data is developing at a breakneck speed. Not only are these new technologies enhancing the acquisition of traditional topographic data, but also rapidly expanding the type of analyses that can be performed.

As designers face new challenges and are required to provide more comprehensive designs, a more complete existing model is required. Therefore, technologies such as LiDAR, unmanned systems, and augmented/virtual reality are becoming a common means to acquire the unique attributes of sites, structures, and other assets.

I. LiDAR

A. Introduction to LiDAR Technology

LiDAR, also known as 3D laser scanning, is an acronym for Light Detection and Ranging. This technology uses roughly the same concept as sonar, only rather than utilizing sound waves to sense objects, LiDAR sensors use laser pulses.

LiDAR data is commonly referred to as a “point cloud”. These datasets can appear like solid 3D models, though they are actually comprised of millions of individual survey points. Each individual point within a point cloud contains an X, Y, and Z coordinate. Along with the coordinate, each point can also contain an intensity (reflective) value, an RGB value, and/or a classification.

These sensors typically have sub-centimeter accuracy. So, combining the overwhelming point density with the high accuracy of each point results in a comprehensive, survey-grade representation of the acquired project area. LiDAR sensors are fairly platform agnostic. There are sensors for aerial, mobile, and static platforms – each with their own unique characteristics. However, the basic performance of the internal instrumentation is analogous.

LiDAR sensors are not only utilized in high-resolution mapping, but many other sectors as well. These include self-driving vehicle technology, gaming, historical preservation, archaeology, and forensics. It is obvious that the benefits of 3D scanning, often in real time, are valuable across a broad spectrum of applications.

The technology is still rapidly developing. Sensors are becoming smaller, lighter, more accurate, and consume less power. Point cloud data is becoming more common and more easily consumed by end users.

Fig. 1. Example of a LiDAR Point Cloud
B. Static LiDAR

Static LiDAR, sometimes referred to as “terrestrial LiDAR”, is one of the simplest forms of 3D laser scanning. The sensor is attached to a fixed-height or “tripod” and the scanner collects the surrounding area from a fixed position.

Due to the sensor remaining in a fixed position, the instrument does not undergo any external forces such as movement or inertia. Because the system is not required to compensate for these external forces, static LiDAR systems are often the most accurate. It is not uncommon for terrestrial systems to achieve +/- 2mm accuracies.

Laser scanning is inherently affected by line-of-sight issues. If there is not a direct path from the sensor to an object, the object will not be collected. More often than not, static LiDAR projects require multiple scans from multiple locations. The number of scans can be affected by the size and complexity of the project sight.

A real-world example would be a power plant. An intricate system of tanks, generators, and various piping networks presents a unique challenge when attempting to generate an accurate existing model. The intricacies of said system introduce many possible line-of-sight issues.

Therefore, scan locations must be planned ahead of beginning data acquisition to ensure best-case data coverage. Best-case data coverage contains overlap between multiple scans, while the different scans also “back fill” any data shadows of other scans.

The level of detail of information that can be extracted from point cloud data is quite impressive. The uniqueness of having the entirety of the project scene collected is that it is up to the end user to decide what data is vital and requires more detail.

For example, consider a piping network. Many times, as-built plans are not available or do not exist. However, precise as-built information is necessary to generate effective design plans for updates, new design, etc. Collecting pertinent information would be nearly impossible using conventional survey methods. Traditional survey methods would generate a great topographic survey. But the example project consists of much more than just the site topography. By integrating static LiDAR, existing information is collected for everything. Site topography, concrete pad sites, tank footprints, piping entry/exit locations, pipe/tank diameters, valve locations/heights – all captured in high-definition 3D point clouds.

However, most designers do not have experience or even the capability to use point cloud data. This lies at the feet of design software. While most design software packages are beginning to implement the ability to utilize point cloud data, the general consensus is that CAD programs are too cumbersome while referencing it.

While design programs are still developing support for point clouds, specialized software exists for extracting CAD features from LiDAR datasets. So, while the end-user may not directly utilize point cloud data, the benefit is still realized.

Feature extraction software allow for the point cloud to be used as a reference. Utilizing this reference allows the user to accurately model the scene using CAD features in 3D. In the case of the piping network, modeling each pipe as a solid with the correct diameter is crucial. It also provides an accurate representation of not only the location of assets, but also the size, condition, tie-in locations, and other fine details that are difficult to represent traditionally.

Static LiDAR is beneficial for many reasons. The data collection method is quick and safe. Utility sites are no stranger to the need for increased safety. The ability to spend less time physically on site and acquiring the required data remotely with no direct contact with site facilities is reason enough to incorporate this technology. However, the power of leveraging this data is the ability to virtually visit the project site while the point cloud data is translated to a traditional CAD as built.
C. Mobile LiDAR

Mobile LiDAR takes all the previously discussed system instrumentation and incorporates it with a terrestrial vehicle. The ability to continuously capture laser scan data as the vehicle travels introduces many additional benefits and potential issues that must be accounted for. By the introduction of motion to the equation, additional system instrumentation and sensors must be integrated to ensure the positional and ranging accuracy.

![Mobile LiDAR System](image)

**Fig. 4. Mobile LiDAR System**

Mobile LiDAR systems typically one, or multiple, LiDAR sensors mounted to the top of a vehicle that continuously scans the environment around the vehicle as it travels. These systems will normally also incorporate an imaging system. The imaging system can be on-board still images, video, or panoramic images. Many times, these imaging systems are calibrated to the LiDAR sensors, orienting each image pixel with a real-world coordinate.

Multiple additional instruments are also integrated to account for external forces the system undergoes, such as trajectory, GPS loss, and inertia.

The most rudimentary element is GPS. As a survey data collection tool, the sensor must know where geographically the data it is acquiring is located. These GPS receivers also communicate the heading of the vehicle, which is used in the post-processing of the vehicle’s trajectory.

Working in tandem with the GPS is the IMU, or Inertia Measurement Unit. As the vehicle drives, it and the LiDAR system are affected by external forces. Wind, potholes, etc. can all introduce motion that must be accounted for. The IMU, simply put, measures and accounts for these external forces.

Lastly, the DMI or Distance Measurement Instrument. What happens when the vehicle loses GPS? Simply driving under a bridge or next to tall buildings can result in limited or no GPS connectivity. This is where the DMI comes in. The DMI is calibrated to the circumference of the tires on the vehicle. When GPS loss occurs, the DMI begins counting the number of rotations the tires make. Once GPS signal is restored, the system uses the distance information and combines it with the inertia measurements from the IMU. This results in a smooth, accurate vehicle trajectory – necessary for accurate data – in GPS-denied areas.

As discussed previously, point cloud data offers a nearly unrivaled amount detail and precision for existing project models. In the utility sector, there are numerous assets that are vital and must be captured and accounted for. Structure location/type/height, phases, attachments points, sag, vegetation encroachment – these are just a few attributes that are challenging to acquire with conventional data collection methods. Point cloud data is a quick and accurate way to capture all of these features and either model or classify them for use in downstream design programs.

LiDAR data is a wonderful means to acquire accurate, existing project data. However, point cloud data alone is many times too cumbersome. Recent developments in panoramic camera integration have begun to bridge the gap between the data collector and the end user.

2D images are inherently more easily consumed by users. As mentioned before, these images captured by mobile LiDAR systems are many times calibrated to the LiDAR sensors. This small detail unlocks a powerful ability that seems somewhat insignificant on the surface – the ability to capture 3D measurements in a 2D image.

Utility inspectors are beginning to leverage this ability for inspecting long, detailed distribution systems. The system is captured in one mobilization. From there, an inspector may perform their inspection from a PC or tablet using only an internet browser. System condition, clearances, encroachment, etc. – all of these can be inspected and measured to generate quantifiable data.

![3D Clearance Measurement in a 2D Image](image)

**Fig. 5. 3D Clearance Measurement in a 2D Image**
D. Aerial LiDAR

Aerial LiDAR is one of the most common and flexible platforms, especially in the utility market. It is a widely accepted method of collecting topographic information for extended corridors. Aerial LiDAR platforms vary from fixed-wing aircraft, rotorcraft, and UAS. Each platform offers its own unique benefit depending on the application for which it is being implemented.

Fixed-wing aircraft can cover large distances quickly and acquire a vast amount of data – at the cost of mobilizing a manned aircraft.

Rotorcraft - like fixed-wing craft - can cover large distances, but with the ability to fly low and slow. The benefit to this is that lower altitude and slower speeds increase the point density and precise detail is captured in the resulting point clouds.

UAS (drone) LiDAR is a relatively new capability that offers its own strengths and weaknesses. Unmanned systems fundamentally cannot fly as far or long as manned aircraft. If the project is of any size, a UAS data collection is probably not the best approach. However, there are many projects that can benefit greatly. Sites, such as substations, or a focus on a set of transmission spans can realize the benefits of UAS LiDAR. Mobilizing an unmanned system is far less expensive than a manned aircraft. The agility of UAS also offer the ability to capture additional data, such as FLIR/thermal images and high-resolution inspection images. However, the use of UAS technology is highly regulated for commercial use. Projects can be slowed by regulatory red tape such as airspace permissions, regulation waivers, etc.

Unlike the high point density datasets of static and mobile LiDAR data, point clouds from aerial systems are many times more easily consumed by design software. Common design packages like PLS-CADD will ingest LiDAR data and can be directly utilized for design processes.

A common theme in aerial LiDAR data for utility design is that the data is classified. Classification is a process that takes a LiDAR point cloud and assigns classification to the points therein. These classifications act as layers or levels in CAD software. For example, the point cloud is filtered to bare earth, and the surface points classified as dirt or earth. Utility structures, individual phases, connection points, fences, houses, etc. all get classified and identified as such directly within the point cloud dataset.

II. UNMANNED AERIAL SYSTEMS

A. UAS Overview

Unmanned aerial systems are rapidly becoming a regular “tool in the toolbox” for geospatial data collectors. They come in many different shapes, sizes, and styles. Both rotorcraft and fixed-wing unmanned aircraft are available, and each can carry a wide array of payloads.

There are numerous regulations that UAS operators must follow which can limit the capabilities of these systems. Most commercial-grade UAS are capable of safely operating miles from the operator. However, FAA regulations prevent operators to fly a UAS beyond their visual line of sight (VLOS). This is not a problem if a project is a site or a short corridor, but if the goal is mapping or inspecting a multi-mile corridor, it will require multiple missions to achieve.

B. UAS Mapping

Early in the development of commercial UAS, geospatial professionals were eager to equip these platforms with mapping hardware. These payloads included metric photogrammetric cameras, multispectral

Fig. 6. Aerial Point Cloud of Transmission Line River Crossing

Fig. 7. Classified Aerial Point Cloud (Plan View)
cameras, and LiDAR sensors.

New photogrammetric processing software was developed alongside these platforms. Data capture applications were developed to automatically generate flight telemetry patterns in order to acquire the needed imagery to produce an accurate orthomosaic. The processing software also implemented simple image processing workflows. These ease-of-use capabilities have opened the landscape of users capable of generating accurate and actionable aerial photogrammetry.

Like most technology hardware, as LiDAR sensors advanced, their form factor was reduced. They have quite recently been reduced to a size suitable to be flown on unmanned systems. This has vastly reduced the cost associated with LiDAR data collection if a UAS platform is agreeable with the project area.

C. UAS Inspections

The most common payload on any UAS, commercial or otherwise, is a camera. The ability to put a camera in the sky is quite powerful. Assets can be inspected that may be inaccessible or dangerous.

The maneuverability and agility of unmanned systems make them a prime candidate for comprehensive inspection data collection. Structures are viewed from multiple angles and high-resolution payloads provide unparalleled detail.

In addition to true-color RGB cameras, many inspection UAS platforms are integrating FLIR or thermal imaging systems. Thermal images are used to identify hot spots, which if left unattended can lead to component failure or safety issues.

By identifying potential hot spots, the workflow moves from responsive maintenance to preventative maintenance. This results in an increase in safety, component efficiency, and ultimately a potential for overall outage reductions.

III. 3D VISUALIZATION

Previously discussed technologies are vital to creating a detailed existing model. This information is becoming necessary for designers as design is integrating more 3D components into traditional design processes. There are many benefits to be realized by translating conventional design to 3D.

Fundamentally, visualizing a design in 3D gives a better basic understanding of the plans by coordinating team members. Visual communication is a key component to understanding changes throughout the design process.

Typically, a 3D model is derived directly from the engineering plans. However, it is possible to blend existing data with proposed design to communicate how the project will affect the existing site.

Designers may also utilize 3D visualization to create project buy in. It can be difficult to communicate the design’s vision through 2D plans. Having the ability to show the public or stakeholders the completed project before construction can facilitate project approval.

Finally, visualization models can integrate directly into a BIM system. By introducing construction timing or phasing, designers can track project construction over time. This is crucial to catching flaws early in the design process. By virtually constructing the project, these issues are identified and remedied in the design process rather than during construction. Resolving construction conflicts are far more expensive than updating a preliminary design.

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