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Principles and Applications for LIDAR 3D Scanning

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Applications and Principles of LIDAR Surveying

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Course Description

This course provides an overview of applications for, and principles of LIDAR 3D scanning technology. One of the more promising applications of 3D scanning is for the quick and highly detailed act of performing as-built surveys. Thus the first chapter of this course is devoted to this particular application.

Subsequent chapters cover the principles of LIDAR 3D scanning technology, and 3D modeling, as well as other engineering applications for 3D scanning.

Topics

- Overview of as-built surveying
- Expectations from an as-built survey
- The role of an as-built
- Quality and standards
- When is one required, and what is needed
- Overview of 3D Laser scanning
- Equipment used in a 3D scan
- What are point clouds
- How to use a 3D scan once it is created
- CAD modeling programs which use the scanned data
- Digital terrain models (DTMs)
- As-built and 3D scanning applications
- Future needs and technologies in 3D scanning

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Chapter 1: As-built Surveying

Introduction

intro

In the relatively recent past, the bread and butter of a Professional Land Surveyor (PLS) was performing surveys of topographics, boundaries, routes and similar total station based surveying tasks.

Then along came GPS and GIS mapping and geo-spatial, geo-referencing technologies to open more lines of revenue for surveying firms to capital upon. The next step in the surveying profession's evolution was LIDAR and 3D scanning technologies.

Laser Scanning

Laser scanning is a relatively new technology, having been used as a precise surveying tool since 1998. Now, it is quickly becoming the new industry standard as a way to perform accurate and detailed measurements in complicated and difficult to reach environments.

3D scanning technology has been financially out of reach for many smaller surveying firms. However, as with all digital technologies, the prices have come way down, and manufacturer competition has increased, making this type of survey equipment reasonably affordable for many surveyors.

3D Scanning for As-Builts

The applications are endless, with a wider potential for obtaining new surveying clientele and streams of revenue; no longer being limited to niche markets such as homebuyers, mortgage companies, and municipalities.

One application which shows a good deal of potential is using 3D scanning technology to perform as-built surveys. Thus, the first chapter of this course will focus on performing as-built surveys.

What are As-built Surveys?

As-built Surveys

An as-built is a survey that verifies to a regulatory agency, and the engineering department, that a designed project has been built by the contractor according to the engineer's design specifications and plans. It is often the responsibility of the project surveyor to verify that the final construction is accurately portrayed in the engineering plans and specs.

A typical as-built would be performed on any of the following project types, and more:

- roadways, bridges, and railway corridors
- electrical and telecom infrastructure
- parking lots
- parks and campuses
- schools and universities
- retail and commercial buildings
- sub-divisions and PUDS
- industrial factories and plants
- (MSW) municipal solid waste landfill facilities
- municipal water mains and pump stations
- municipal sanitary sewer collection systems
- stormwater collection and drainage systems
- ore mine mapping
- hazardous sites (ex. - nuclear facilities and electrical substations)

Usually when an as-built survey is requested, the surveyor will locate not only the physical features that were built, but also verify that boundaries are correct and monuments or markers are in the ground and properly located.

Scope and Definition

The scope and definition of a project's "as-built" plans and specs differ from one firm or municipality to the other, based on the particular design process followed within an engineering department, and the construction process followed by the contractor.

Most drawing sets include the following:

- ***Ready for Construction Drawings (RFC)*** - Construction drawings completely designed 100%, and ready to be used for construction. They are the basis for the as-built drawings.
- ***As-Built Additional Drawings*** - Drawings generated during the as-built process indicating new or additional work constructed.
- ***As-Built Drawings Construction*** - Drawings modified to reflect design changes and actual conditions of construction, conformed from field and design changes directly from the Ready for Construction (RFC) drawings.
- ***As-Built Revised Drawings*** - Drawings generated during the as-built process for the purpose of providing clear and concise as-built correction information, but contain with no new or additional work added.

Plus these other typical drawing types:

- ***Preliminary Drawings*** - Drawings prepared during the preliminary phases of the design process.
- ***Preliminary Engineering for Procurement*** - Preliminary engineering that demonstrates technical feasibility and constructability for procurement.
- ***Bid Package*** – drawings which are prepared for soliciting bids from potential contractors.

- ***Contract drawings*** **-** Drawing files that are specific to a particular project and contract. Contract drawings include preliminary design drawings and construction drawings.
- ***Construction Drawings*** **-** Drawings furnished by the contractor representing the post preliminary design project delivery, from final design through completion of construction. Construction drawings include Final Design drawings, Ready for Construction (RFC) drawings and As-Built drawings.

Accuracy and standards of quality in an as-built Survey

Level of Accuracy

Having an accurate as-built survey is vital to the maintenance and future development of a construction project or site. They confirm that the engineering plans and specifications were vetted through the regulatory permitting and inspection phases, and will account for any variations, which may have occurred during the construction, from the original plans.

As-built surveys can help engineers and architects see what was actually built and to make sure it was built correctly and within applicable tolerances.

As-builts performed at various stages

As-builts must document the site changes and feature additions or removals at various stages throughout a construction project:

- occurring during the construction process
- following completed construction
- verifying that improvements meet the design expectations
- verifying that improvements comply with regulatory criteria

During some projects, the inspectors or the client may require one or more as-built surveys to ensure that the construction is proceeding according to expectations.

These surveys will need a high level of accuracy to satisfy the requirements of local or state regulations and to help the contractor sufficiently measure the progress of improvements.

Prevalence of substandard survey work

There are some contractors that do an excellent job of providing clear, accurate and concise as-built records; however these contractors are in the minority. Most others perform somewhat adequate work at best, though their as-built surveys may tend to be sloppy, incomplete, or hard to read, with Xeroxed documents stapled to drawings and similar examples of haphazard shortcuts.

Other contractors may tend to submit contract drawing sets as as-builts with no accompanying notations on them. While others may perform only a portion of the survey, and assume that no one will verify their completeness.

Reasons for not providing a set of As-builts

When contractors do not provide an acceptable set of as-built documents, it can appear to be a cover-up of substandard or incomplete construction work.

It's likely that there are other reasons at fault though, such as:

- a lack of resources to dutifully perform the as-built stage
- the perception of not being properly reimbursed by the client for the added work load
- the fact that multiple contracting parties are responsible for providing as-built information for their portion of the project (any contractor would resent having to provide as-builts for another contractor's work)
- lack of clarity and communication as to who is supposed to perform the as-built survey, as well as the degree of detail and thoroughness required

With these considerations, the only sure way a client can ensure the building's existing conditions is to conduct verification field surveys and double check the contractor's as-built documentation, until an adequate level of trust exists between the client and the contracted party.

Roles of an As-built Document

Documentation

An as-built is a single reliable source for verifying the changes which have occurred. An as-built document serves as a single reliable source for all directed changes. This way, the general contractor and all subcontractors are hopefully working from the same updated documents as the design and construction progress.

The contractor usually bears the responsibility to update the records as the work progresses and to do so routinely, in order to make them trustworthy for all design and construction parties.

Post Construction Record of Final Product

An as-built serves as a record of what the post construction project actually consists of, serving as the contractor's certified record verifying their finished product. Thereafter the drawings can be turned over to the owner or operator as an official reference, for the life of the project or improvement.

This allows the owner to locate unseen site features, aids in troubleshooting, and provides additional insight when planning for changes or expansion.

A "fluid" record of ongoing site uses

As-builts serve the owner, as a 'fluid" document, to be used as an ever-changing record upon which to archive subsequent minor modifications which have been performed.

Demo record for Future Development

As-builts can eventually become demolition records, in addition to being construction records. These records can be updated, repackaged, replicated and integrated into a new bid package, saving the owner the time and expense of developing a new bid set from scratch. As-builts can be used over the complete life cycle of a site.

Historical Archive of past site conditions

An as-built can serve as a historical archive of the previous land use or condition, recording what features formally existed at the site. This information can be of great benefit for subsequent land uses. In some future situations, it may be necessary to research what gad existed previously, such as stubbed-off utilities or buried foundations.

In addition, many times a re-purposed site may need to have an environmental assessment to determine if any contamination might exist from previous land uses.

As-builts become a value tool when performing geotechnical or environmental assessments of a potential commercial or industrial site for what may become a multi-million, or possibly multi-billion dollar venture; being the last testament to what once existed.

Checks and Balances for Accounting

Thorough as-built documentation provides the benefit of an accounting check and balance system for both sides in a construction contract.

Change orders are a constant occurrence in most large construction projects, and sometimes the client or contractor may lose track of what has been requested, and completed.

If changes are properly executed and referenced, an as-built can provide valid proof of work which was requested and paid for, but not completed, or work which was performed, but not billed or paid in full.

When is an As-built Required?

When are As-Builts needed?

An as-built survey of a construction site will differ from a typical land or boundary survey, which measures the boundaries or features of the land itself. An as-built survey is performed to show all changes, modifications, or improvements made to the site at a given time.

A construction or improvement project begins with a site plan showing the location and dimensions of the proposed work. At various stages of the project, as-built surveys will measure these improvements as they're being built to ensure they are conforming to the proposed site plan.

Depending on the size and scope of the project, as-built surveys may be necessary numerous times throughout construction, and again at the final completion, to ensure all aspects of the project have been constructed as designed.

An as-built drawing serves as a close-out document, verifying that the work authorized was completed as designed and in compliance with all relevant standards and regulations.

While other surveys provide details about the parcel of land itself, an as-built survey provides details about structures being built or recently completed upon the property.

A client, contractor, engineer, or inspector may need this survey for any of the following purposes:

- to explain to zoning authorities that the structures or improvements are in compliance with local codes
- to obtain a Certificate of Occupancy (CO) from the local jurisdiction, verifying that a structure is deemed to be inhabitable
- to verify that the structure(s) has/have been completed according to design specifications
- to provide proof to a lending agency that the structure has been built according to approved plans
- many agencies require as-built surveys for the actual locations of underground improvements
- to verify that no potential conflict may occur with existing features (such as underground utilities)
- to prove the location of a structure at a point in time; and as a historical record
- to measure what has been completed to date, so that contractors can remain on the completion schedule
- to be used for accounting purposes, to record which portion of a project has been completed, so the workers or subcontractors can be paid

Often, local or state zoning authorities will request a certain number of as-built surveys to be performed during the course of a construction project, in order to verify that all improvements are complying with applicable regulations, as well as with any proposed plans already existing on file.

The guidelines for these as-built surveys as to the amount of detail and their frequency may vary according to local regulations.

Catching and correcting design mistakes or oversights
The real world presents construction restraints that are sometimes overlooked within the design phase of a project. Sometimes a contractor is left to provide an immediate "on-the-fly" solution to an engineer or designer's oversight. Properly documenting these types of existing as-built conditions and project constraints are essential to providing a complete design.

Catching construction mistakes early

Even when local authorities do not request them, a diligent contractor may call for an as-built survey several times during the course of the project to ensure that the work is proceeding according to the design, as well as to measure the progress of construction against the projected timeline for completion.

If mistakes or design variations have occurred during construction, it's much easier and cheaper to correct them along the way, rather than after the project has been completed.

Many construction projects can run in the tens of millions of dollars. Given the financial losses that could occur from the most innocent of mistakes, accuracy and due diligence can be critical when performing as-built surveys.

Comparing present work with past construction

When applicable, a surveyor should compare the present construction work against any previous plans submitted to zoning or inspection officials to ensure the work has been completed in accordance with those plans. Some issues with a present job, may only become apparent through the study of past construction projects.

Markups (redlines)

As built surveys are often presented in red or redline and laid over existing plans for comparison with design information.

Performing Hazardous As-built Surveys

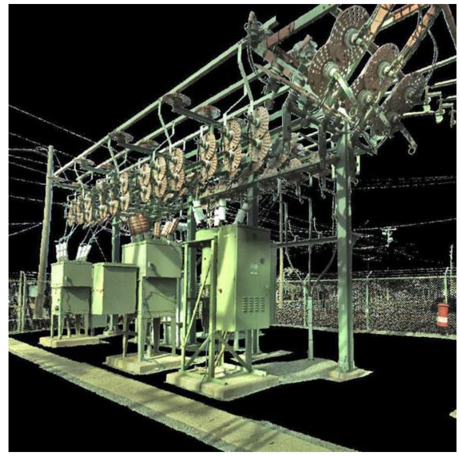
Hazardous Sites

There are a number of hazardous sites which, in the past have put the lives and well-being of survey personnel at risk. This has always been a part of the job description, and surveyors have always been required to do what was necessary to complete the surveying task.

New technologies such as high resolution, 3D scanning are allowing surveyors to perform as-built surveys at a safe distance from dangerous environments.

Ground based scanners

3D scanning technology allows surveying personnel to now perform many of these surveys entirely from the safety of the ground, at a healthy distance from potentially hazardous sources.



Hazardous examples which surveying personnel may encounter can come from high elevations, high voltage electrical (see image), and toxic sources, or from automotive traffic.

Some of the survey scenarios which require putting survey personnel in harm's way are:

- ***HV electrical infrastructure*** - transmission towers, high voltage air-insulated and gas-insulated substations
- ***Nuclear facilities*** - high radiation, nuclear waste facilities
- ***Mining*** - natural gas intrusion, mine subsidence
- ***High elevation sites*** - cell towers, bridges, other tall structures
- ***Transportation*** - heavily traveled bridges and roadways

Drone based, (UAV) Unmanned Aerial Vehicles

Using industrial grade drones for aerial scans, and robotic crawlers for ground access can put a 3D scanning unit in positions which are totally inaccessible by human personnel.

Drone-attached units can be used for applications such as:

- Scanning tall objects and structures at elevated positions
- Minimizing shadowed areas
- Complementing terrestrial laser scanning
- High-resolution topography and vegetation mapping
- "Bird's eye" scanning where a direct line of sight is not available from the ground

In the image below, this drone unit is capable of handling a payload of 15 kg, or 33 lbs, and can maintain flight for a duration of up to 35 minutes before requiring grounding for a recharge.

Robotic crawler transport based

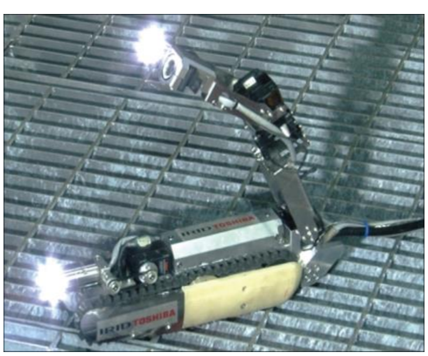
3D scanners can be mounted on robotic crawler units for scanning hazardous areas which are inaccessible to humans. Radio controlled, industrial grade crawler units similar in nature to those used for law enforcement, military recon, or bomb disposal can easily handle a 3D scanning unit.

These can be used for applications such as gas infused mine cavities, or radioactive zones in nuclear facilities.
Specially designed scanners in hazardous environmental applications such as highly radiated zones, special design considerations are required to shield the electronics for the entire robotic crawler and scanner unit.

Extreme Radiation Conditions

In 2011, a meltdown at the Fukushima nuclear plant was triggered by an earthquake and subsequent tsunami. Radiation levels reached far beyond the limits of human survival, so engineers began using specially designed robotics to survey the area.

These "scorpion" robotic units, while specifically designed for high radiation environments still encountered problems, failing at a rate five times faster than was predicted.



This image is of a Toshiba “scorpion type” robotics crawler used for high radiation scanning task.

The robot should have been able to deal with 73 sieverts (unit of ionizing radiation dose) of radiation. However, a recently recorded level in the reactor was rated at 530 sieverts.

Seivert

One sievert can cause radiation sickness, while five sieverts can kill half of those exposed within a month, and 10 sieverts can kill in weeks. The levels in Fukushima's unit two reactors were so extreme; they would kill a human within two minutes of exposure.

Chapter 2: LIDAR (3D Laser Scanning)

What is LIDAR?

LIDAR (LIght Detection And Ranging)

is an optical, remote-sensing technique which uses laser light to densely sample the surface of physical objects such as the topography of the earth or the detail of structures. LIDAR produces highly accurate, geospatial, 3 dimensional (x,y,z) measurements.

Distance Technology

LiDAR is fundamentally a distance technology. An airborne LiDAR system actively sends light energy to the ground. This light emitted is known as a pulse. The LiDAR measures reflected light back to the sensor. This reflected light is known as a return.

So pulses of light travel to the ground. They return and are detected by the sensor giving the range (a variable distance) to the Earth. This is how LiDAR earned its name – Light Detection and Ranging.

Point Cloud Datasets

LIDAR is emerging as a cost-effective, quicker alternative to many traditional surveying techniques such as many types of total station surveys, and photogrammetry.

Lidar produces mass point cloud datasets that can be managed, envisioned, analyzed, and shared using most 3D modeling and mapping platforms such as ESRI's ArcGIS, Autodesk's Land Development Suite and Revit (BIM), or Bentley's GeoPak.

Optical Sensor/Receiver

LIDAR is an active optical sensor that transmits laser beams toward a target while moving through specific survey routes. The reflection of the laser from the target is detected and analyzed by receivers in the LIDAR sensor.

These receivers record the precise time from when the laser pulse left the system to when it is returned to calculate the range distance between the sensor and the target.

Positional Data

Combined with the positional information (GPS and INS), these distance measurements are transformed to measurements of actual three-dimensional points of the reflective target in object space.

The point data is post-processed after the LIDAR data collection survey into highly accurate georeferenced x,y,z coordinates by analyzing the laser time range, laser scan angle, GPS position, and INS information.

LIDAR (LIght Detection And Ranging) is an optical remote sensing technology that measures properties of scattered (or reflected) light to find range and/or other information of a distant target. The method to determine distance, speed, or even composition of an object or a media surface uses one of the following forms of a laser beam.

Types of Laser Beam Emission:

- ***pulsed*** **-** rapid change in amplitude then a return to the baseline value
- ***CW*** **-** continuously emitted wave
- ***modulated*** **-** varying one or more properties of the periodic waveform

Like the similar radar technology which uses radio waves instead of light, the distance to an object is determined by measuring the time delay between transmission of a light signal and detection of the reflected signal, either in discrete amounts or by using the beat note resulting

3D Scanning Surveys

3D Laser Scanning is a surveying process which is non-contact and non-destructive, that digitally captures the surface contours of the topography and structures using a line of laser light on a transit base or .

The scanning unit creates a three dimensional spatial cloud of digital points or a "point cloud" of data, from the laser feedback received when scanning the surface of an object. The scanner then transmits the raw point data to a digital data collector, such as a laptop.

Easy to use in CAD modeling

3D laser scanning is a means to easily and quickly survey a construction project, turning it into a digital 3-dimensional representation to be incorporated into applications such as 3D modeling (CAD) software programs.

Modeling Programs

Most modeling programs have out of the box functionality to easily import and modify raw point cloud data files.

Accuracy of 3D scans

Depending upon the settings, production process, equipment type, ranging and stability of the scanner, 3D laser surveys can be accurate to within millimeters.

Solution for a As-Built Backlog

All too often, for practical and financial reasons, construction occurs at a feverish and accelerated pace, causing the as-built stage to be overlooked or put on the "back burner" until time permits. Unless an as-built is required to sign off on a project, a client may forego the time, hassle, and expense of performing the as-built surveys.

> **AutoDesk and Bentley Software**
> Two of the more commonly used land modeling packages, Autodesk's "Land Development Suite" and Bentley's "Geopak", for example have numerous commands to manipulate raw point cloud data. And with the recent popularity of BIM, Autodesk's "Revit" is becoming the industry standard for architectural applications. Revit, of course has a great deal of functionality for utilizing point cloud data in all forms for residential, industrial, or commercial construction.

This can cause many problems down the road when there is no historical, or completed and accurate record of a project.

With 3D scanning technology, it has become much more convenient and affordable to maintain as-built documentation. This opens up a whole new branch of potential revenue for surveying firms.

LIDAR (continued)

Laser Light

LIDAR measures properties of scattered or reflected light, to find range and/or other information of a distant target. The method used to determine the distance, speed, or composition of an object or surface uses a pulsed, CW (continuous wave) or modulated laser beam.

Measure of Time Delay

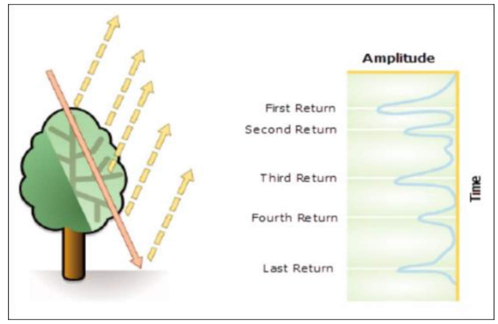
Similar in nature to radar technology, which uses radio waves instead of light beams, the distance to an object is determined by measuring the time delay between transmission of a light signal and detection of the reflected signal.

This is either in discrete amounts or by using the beat note resulting from the interference with a reference laser in coherence. This method was first demonstrated in 1970.

Lidar Laser Returns

The laser pulses which are emitted from a LIDAR system will reflect from objects both on and above the ground surface, such as hardscapes, landscapes, structures, and similar features.

One emitted laser pulse can return to the LIDAR sensor as a single or multiple returns. An emitted laser pulse which has encountered multiple reflective surfaces as it travels is split into the same number of returns as there are reflective surfaces encountered (see image below.)



Multiple Laser Returns

First Return

The initial return laser pulse is the most significant return, and will be associated with the first feature point encountered, meaning the highest feature in the landscape; such as the top of a tree or the top of a building.

The first return might also represent the ground, in which case it would be the only return registered by the LIDAR system for that pulse.

Intermediate Returns

Multiple returns are capable of detecting the elevations of several objects within the laser footprint of an outgoing laser pulse. The intermediate returns, in general, are used for vegetation structure, and the last return for bare-earth terrain models.

Last Return

This is usually the pulse return from the ground. However, multi-return LIDAR is not always consistent and predictable, and the last return may not always be from the ground.

For example, when the beam goes through a tree and the pulse reflects a large branch. The pulse would not reach the ground, thus the final return would not be from the ground but from the density of the branch that reflected the entire remainder of the laser pulse.

Lidar Point Attributes

Additional attributtal or meta data is stored in the database with each set of x, y, and z positional values, or grouping of values. This allows for easier customization and manipulation of the point cloud points using database commands and tools.

The following LIDAR point attributes are maintained for each laser pulse recorded:

- Intensity
- return number
- number of returns
- point classification values
- points that are at the edge of the flight line
- RGB (red, green, and blue) values

- GPS time
- scan angle
- scan direction

Advances in LIDAR
Over the years, the advances in LIDAR technology have closely followed advances in laser technology. Rather than superseding and replacing microwave radar technologies, laser radar has exposed new potentials.

Radar vs. LIDAR
The primary difference between the two technologies is that LIDAR uses much shorter wavelengths, or the higher frequencies of the electromagnetic spectrum. This is in the form of a low divergence laser beam, (in the optical wavelengths 0.2– 12 µm) allowing it to generate very short pulses.

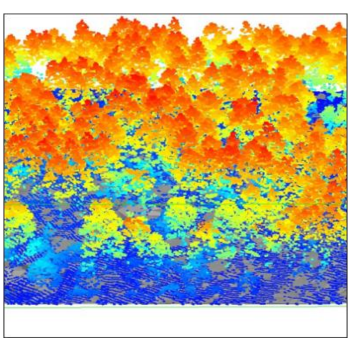
This enables the imaging of features or objects which are comparable in size to the wavelength, or larger. Because of this, LIDAR units are capable of higher accuracy and greater resolution than microwave radar devices, providing many advantages in a variety of applications.

Canopy Height Model (CHM)
LIDAR can attain highly accurate data for the ground surface, as well as attaining highly accurate data concerning objects above the ground.

This is accomplished with a Digital Surface Model (DSM). A Canopy Height Model (Normalized Digital Surface Model (nDSM)) gives the true height of topological features on the ground.

To obtain the true height of features on the Earth, begin with the first return, including topology such as the trees and buildings. Then the last returns should be subtracted which are the ground hits or bare ground.

For example, taking the top of the tree height and subtracting the ground height; then interpolating the result, gives a surface of the feature's real height on the ground.



LIDAR Canopy Height Model

Four Primary LIDAR Technologies
Over the years, four different forms of LIDAR technology have emerged:

- (TOF) Time Of Flight LIDARs
- (CDH) Coherent Doppler Heterodyne LIDARs
- (FMCW) Frequency Modulated Continuous Wave LIDARs
- (DIAL) DIfferential Absorption Laser LIDARs

The following pages will address the most important aspects to consider, when selecting the most appropriate laser type for a given application.

Time Of Flight (TOF) LIDAR

Time-of-Flight (ToF)
This is a highly accurate distance mapping and 3D imaging technology, and is the simplest form of LIDAR. This type of LIDAR is often used in conjunction with other technologies for detecting multiple types of data simultaneously.

Time-of-Flight sensors emit a short Infrared light pulse and each pixel of the camera sensor measures the return time. Time-of-flight cameras have a huge advantage over other technologies as it is able to measure the distances within a complete "scene" in a single shot.

Range Imaging
ToF is one of many techniques known as "range imaging." The sensor device that is used for producing the range image is sometimes referred to as a range camera.

Other range techniques are:

- Stereo triangulation
- Sheet of light triangulation
- Structured light
- Interferometry
- Coded aperture

Time-of-Flight cameras can sense the time that it takes light to return from any surrounding objects, combine it with video data and create real time 3D images which can be used to track facial or hand movements, completely map out a room or even remove or overlay 3D objects or backgrounds from an image, plus much more.

The Principle of Time-of-Flight Technology
Time-of-Flight (ToF) is a method for measuring the distance between a sensor and an object, based on the time difference between the emission of a signal and its return to the sensor, after being reflected by an object. ToF is scannerless, meaning that the entire scene is captured with a single light pulse, as opposed to point-by-point with a rotating laser beam.

Time-of-flight cameras capture a whole scene in three dimensions with a dedicated image sensor, and therefore have no need for moving parts.

Three measurements are performed with ToF:

- ***Distance to target*** – With two known variables, the time and the propagation speed of light, it is possible to calculate the distance
- ***Target speed*** - the derivative of distance vs. time
- ***Target surface profiling*** - By measuring the distance of the various surficial points on a target, it is possible to map its surface profile

The typical applications of ToF LIDARs are:

- Range finder
- Vehicle or particles speed measurement
- Aerial land profiling
- 3D object scanning

Drawback to ToF LIDAR

With ToF LIDAR, one major drawback is that the time measurement resolution will limit the distance measurement resolution considerably.

Coherent Doppler Heterodyne LIDAR

Uses the Doppler Effect

This type of LIDAR uses the Doppler Effect for making measurements. The "Doppler Effect" is a subtle but measurable shift in the center frequency of scattered light returning from a moving object.

This shift in frequency is directly proportional to the speed of a moving object, and is therefore very effective for the measuring of speed.

What is the Doppler Effect?

When there is an increase (or decrease) in the frequency of a sound, light, or other wave, as the source and observer move closer or further from one another, the effect will create a sudden change in pitch, (such as is noticeable when observing a passing siren, as well as the redshift observed on subtly moving planetary bodies.)

The Doppler Effect was used to prove the theory of the "big bang," as the redshift was observed on planetary bodies, showing that all were moving away from one point in space.

Heterodyne Detection Scheme

The simplest way to measure the shift in the scattered light's center frequency is by using a "heterodyne detection scheme." This consists of mixing the laser light scattered from a remote target with a reference local coherent laser oscillator (LO).

Heterodyne detection will output an electrical RF beat note (a signal with the difference of the optical frequencies) which provides feedback on the frequency of the signal field. Coherent Doppler Heterodyne detection has a high sensitivity, providing detailed phase information which facilitates accurate velocity measurements.

Measuring Distance and Composition

By combining the pulsing of the laser source, then precisely timing the moment when the Coherent Doppler heterodyne detection is performed, it is possible to measure the distance of the moving target whose speed is being measured.

Additionally, the polarization state can be derived from the backscattered signal, providing data about the target's composition.

Typical applications of Coherent Doppler Heterodyne LIDARs are:

- fluid measurement
- vehicle speed measurement
- wind measurement
- industrial, military and aerospace applications

Applying CDH LIDAR to Wind Measurement

The use of Coherent Doppler Heterodyne LIDAR remote sensing processes is now becoming commonplace for determining:

- wind speed
- turbulence
- wind veer
- wind shear data

This is a means for measuring wind in a more practical and cost effective way than through the use of traditional mechanical anemometers.

Some of the specific applications are:

- wind surveying and analysis at potential windmill installation sites
- windmill anemometer (an instrument used to measure the speed of the wind, or a current of gas)
- for detecting wind shear conditions surrounding airports
- for monitoring wind on offshore platforms

Indirect operation for capturing airborne particulate matter

The operation of LIDAR-based wind measurement systems is indirect, used for detecting atmospheric aerosol particles such as:

- dust
- water droplets from clouds and fog
- pollution aerosols

- salt crystals
- biomass burning aerosols
- etc.

Select the Proper Laser Frequency

This particulate matter is assumed to be traveling at the same velocity as the air mass which is transporting them, so the basic concept is to measure their speed of travel.

To do so requires carefully selecting a laser frequency that is transparent to air, while still being highly reflective to the particulate matter. The velocity measurement of the aerosol particles will then show a "Doppler shift" on the frequency of the back-scattered laser light.

Used in Conjunction with ToF

When TOF analysis is combined with the coherent Doppler Heterodyne measurement scheme, this provides the ability to measure wind speed at different distances in front of the LIDAR.

Adding a Rotating Mirror to the System

By adding a rotating mirror to the LIDAR system, this will provide multiple lines of sight that allow the measurement of wind speed and direction at a variety of angles around the instrument.

This will provide data about the winds which are circumventing a wind energy system, hence helping to increase the efficiency, by pre-determining the most appropriate angle and pale pitch to catch the wind.

It also can prevent damage to the expensive wind system by foreseeing strong and potentially damageable wind turbulences.

Frequency Modulated Continuous Wave (FMCW) LIDARs

FMCW Systems

The principles of operation for a FMCW detection system are similar in nature to the coherent self-homodyne LIDAR system presented on the previous page.

The optical output of the laser is frequency modulated and the outgoing light wave is divided into two parts:
First part is transmitted toward the target
Second part is used as a local oscillator (LO)

The light scattered or reflected by the target is then mixed with the local oscillator signal, producing a beat note (whose frequency is the difference between the two light signals.)

So when the modulation signal is shaped to a linear function, such as a saw tooth shaped function, the beat note frequency is directly proportional to the distance between the source and the target.

The main advantages of the FMCW LIDAR over the two previously mentioned types are:

- The target does not need to be in motion in relation to the laser source, which is the case with Coherent Doppler Heterodyne types of LIDARs
- when the target is moving, its speed can be calculated from the phase variation of the beat note
- For profiling applications, FMCW provides faster acquisition (two orders of magnitude) than the TOF method
- Better resolution (two orders of magnitude) than the TOF method
- Better dynamic range, providing longer distance measurement capability
- Can be used to measure very small distances, (which isn't possible with the ToF method, as the time delays involved become difficult to measure)

FMCW LIDARs are more complex and expensive; normally used in high end systems such as:

- Large area metrology systems (high res 3D Laser scanners)
- Facial recognition systems
- Range finders
- Wind speed measurement systems
- Landing speed and distance measurement systems

(DIAL) Differential Absorption LIDAR

Principles of Operation

Differential Absorption LIDAR consists of a simultaneous measurement in the same direction, of two LIDARS tuned at two different specific frequencies.

The two frequencies correspond to spectral lines of molecules or gases, to be detected and measured in order to measure the difference of some key parameters of the two backscattered light beams.

For Oceanic (bathymetric) Surveys

When used along with the ToF type of LIDAR technology, DIAL can be used to measure oceanic depths or to profile the ocean's bed by airborne remote sensing. When one laser is tuned at a wavelength which is highly reflective from the surface of the water, and another laser is tuned to be highly reflective to the ocean bed, both can be captured in one pass.

Measuring Atmospheric Gases and Molecules

Another type of application for which DIAL technology is well suited, is to measure the concentration relative to the altitude, of a specific gas (such as ozone) or a specific molecule (such as carbon dioxide) in the atmosphere.

This is done by measuring the difference in the amplitude of the two backscattered light beams compared to the distance between two ToF or FMCW LIDARs.

One laser beam would be tuned to the reflective spectral line of a specific gas or molecule being detected, while the other would be tuned to a frequency for which no reflection occurs.

Based on Light Absorption

Light is absorbed by many of the gaseous components in our Earth's atmospheric. The absorption of light by molecules is the basis for which DIAL LIDAR is used when measuring the atmospheric concentrations of gases such as water vapor and ozone.

Analyzing Atmospheric Water Vapor

In regards to analyzing the weather and climate, atmospheric water vapor readings are one of the most important atmospheric constituents to measure and record.

The distribution of water vapor in the air is highly variable and inconsistent, and being able to accurately determine how much water vapor is where, is vital in climate monitoring and weather pattern predictions.

Water vapor has various discrete absorption lines. In water vapor, DIAL laser pulses are transmitted at two differing wavelengths.

One is transmitted on a water vapor absorption line, while the other wavelength is offline. If the two wavelengths are close to one another, then for both wavelengths the scattering by molecules and particles are fairly equal.

Thus, any measureable difference in the laser returns between the two wavelengths is due entirely from the absorption by water vapor molecules. Therefore, measurement of the ratio of the backscatter at the two wavelengths as a function of range can be used to calculate the water vapor concentration profile.

Measuring Ozone

The measuring of ozone using DIAL technology requires a less precise laser frequency than water vapor, because ozone has a broad absorption band instead of the narrow lines of water vapor.

This requires that the on/off wavelengths be chosen with sufficient enough separation between wavelengths to ensure a significant difference in their absorption.

Requires Three Wavelengths

Uncertainties in the changes of aerosol scattering and patterning between the wavelengths can introduce error. The difference in aerosol scattering at λon and λoff can be extrapolated from a third measurement taken at a longer wavelength, λa.

Therefore, DIAL measurements with three wavelengths can be used to determine ozone concentration profiles to a suitable degree of accuracy.

Components of a LIDAR System

Components of LIDAR system

The major hardware components of a LIDAR system include:

- Vehicle, aircraft, vessel or mount (airplanes, helicopter, UAV, robotics, automobile, boat or tripod)
- laser
- scanner and optics
- receiver circuitry
- INS (inertial navigation system)
- GPS (Global Positioning System)

Lasers

Types of LIDAR lasers:

- **600–1000 nm lasers (focused)** - These are the most common types used for non-scientific applications. They are inexpensive, but since they can be focused and easily absorbed by the eye, the maximum power is limited by the need to make them eye-safe. Eye-safety is often a requirement for most applications.
- **1550 nm lasers (non-focused)** - These are an eye-safe alternative at much higher power levels because this wavelength is not focused by the eye. Though with these types of lasers, the detector technology is less advanced, and the wavelengths are generally used at longer ranges with lower accuracies. They are also used for military applications as 1550 nm is not visible in night vision goggles, unlike the shorter 1000 nm infrared laser.
- **1064 nm diode pumped YAG lasers** - are typically used in airborne topographic mapping LIDAR units.
- **532 nm frequency doubled diode pumped YAG lasers** - are typically used in bathymetric or underwater depth research systems, because a 532 nm laser beam penetrates water with much less attenuation than a 1064 nm laser beam.

Laser Settings:

- ***laser repetition rate*** - which controls the data collection speed
- ***pulse length*** - is generally an attribute of the laser cavity length, the number of passes required through

the gain material (YAG, YLF, etc.), and Q-switch or pulsing speed

- ***target resolution*** **–** improved resolution is achieved with shorter pulses, depending on whether the LIDAR receiver detectors and electronics have sufficient enough bandwidth

Scanner and optics

LIDAR uses these light spectrums to image objects:

- ultraviolet
- visible
- near infrared

LIDAR light wavelengths are varied to match the target; ranging from about 10 micrometers to the UV (approximately 250 nm). Typically light is reflected by backscattering, as opposed to the pure reflection found with a standard mirror.

Different types of scattering are used for different LIDAR applications.

The most common types are:

- Rayleigh scattering
- Mie scattering
- Raman scattering
- fluorescence

Suitable combinations of wavelengths can allow for remote mapping of atmospheric contents by identifying wavelength-dependent changes in the intensity of the returned signal.

The speed at which images can be developed is affected by the scanning speed. There are several options to scan the azimuth and elevation, including dual oscillating plane mirrors, a combination with a polygon mirror and a dual axis scanner.

Optic choices affect the angular resolution and range that can be detected. A "hole" mirror or a beam splitter are ways to collect a return signal.

Receiver Circuit

The receiver circuit receives the diffusely reflected laser light, then converts this light into an electrical signal and amplifies the signal to suitable levels. It also measures the phase difference between this signal and the transmitted one with some specified degree of accuracy.

Photodetectors (a part of the receiver circuit)

Photodetectors are sensors which convert optical power to electrical power, using the photoelectric effect. One of the basic properties of a photodetector is its photosensitivity, which describes its response when exposed to (photons) or light.

Another basic property of a photodetector is its frequency response, or bandwidth (BW), which describes the behavior of the device when the optical signal is time dependent.

Types of Photodetectors:

- ***Photoresistors*** **-** A photoresistor is a device whose electrical resistance decreases as incident light intensity increases. Photoresistors are mainly used for detecting the presence of light, rather than to perform accurate light level measurements.
- ***Phototransistors*** **–** In its simplest form a phototransistor is a homo-junction bipolar transistor (BJT) that has been optimized to perform as a photodetector.
- ***Photomultiplier tube (PMT)*** **-** This is a class of highly sensitive and fast photoreceivers, often used in research to measure extremely low levels of light or to register single photons.
- ***Charge Coupled Devices (CCD)*** **–** With a CCD, the sensor area is divided in smaller parts called pixels, and each pixel works as a small photodetector.
- ***Detectors arrays*** **-** Instead of using a single detector of the types above, it may be advantageous to use multiple detectors in an array.

Front-end Amplifier

The front-end amplifier converts the current signal produced by the photodiode to a voltage and amplifies it. An amplifier of this type is called a transimpedance amplifier (TIA).

Second stage Amplifier

There is insufficient gain (a measure of the ability of an amplifier to increase the power or amplitude of a signal) achieved in the front-end amplification stage. Therefore, a second stage amplifier is used to boost the gain received from the front-end amplifier.

Position and navigation systems (for mobile data collection)

When a LIDAR sensor is mounted on a mobile platform, (such as a train, plane, automobile, UAV, robotics or satellite) it will require the aid of additional instrumentation. This instrumentation determines the absolute position and orientation of the sensor throughout the surveying process.

These types of devices generally include a Global Positioning System receiver, and an Inertial Measurement Unit (IMU) or Inertial Navigation System (INS) for airborne scanning.

Accelerometer sensory chips are typically incorporated into these devices to monitor and react to inertial forces. An INS system measures the roll, pitch, and heading of the LIDAR system (for airborne), allowing for proper tracking of the flight path.

Terrestrial Data Acquisition

Airborne and Terrestrial Applications

LIDAR has a wide range of practical applications which can be divided into two groups: airborne and terrestrial types.

These different types of applications require scanners with varying specifications based on:

- the proposed use of the data
- the size of the area to be captured
- the range of measurement desired
- the cost of equipment
- etc.

Terrestrial LIDAR

Terrestrial LIDAR collects extremely dense, highly accurate points, which allows for precise identification of objects.

Dense point cloud datasets can be used for a wide span of applicable operations:

- as-built surveying
- facility management
- robotics and automated industrial processes
- reverse engineering
- conduct highway, bridge and rail surveys
- design of interior spaces and space planning
- exterior planning
- and much more

Terrestrial LIDAR is broken down into two sub classes:

- ***mobile acquisition*** - (where the LIDAR system is mounted on top of a moving vehicle), and
- ***static acquisition*** - (where the LIDAR system is typically mounted on a tripod or other stationary device).

Mobile LIDAR

This refers to the collecting of LIDAR point clouds from a moving system platform. Mobile LIDAR systems can consist of multiple LIDAR sensors mounted on a moving land or sea based vehicle, (such as vehicles, trains, marine vessels.) This excludes planes and UAVs.

Mobile systems typically consist of:

- LIDAR sensor
- cameras
- GPS (Global Positioning System)
- INS or inertial navigation system, (same as those used with airborne LIDAR systems)

Mobile LIDAR data can be used for many applications, including:

- to survey, inventory, and analyze roadway and railway infrastructure
- to locate and inventory overhead wires, light poles, and road signs near roadways or rail lines
- to analyze roadside drainage conditions
- to analyze unsafe road conditions such as improper superelevation, poor line of sight distances, or locate roadside obstructions

Static LIDAR

This is the collection of LIDAR point clouds from a static or stationary location. Normally, the LIDAR sensor is mounted onto a tripod mount and is a fully portable, laser-based ranging and imaging system. These systems can collect LIDAR point clouds inside buildings as well as exteriors.

Common applications for this type of LIDAR are:

- land development
- civil engineering
- construction applications
- surface and subsurface mining
- topographical surveying
- archaeology and historical site archives
- forensics and the archiving of crime and incident scenes

Airborne Data Acquisition

Airborne LIDAR

In the past, an airborne LIDAR system was installed on either a fixed-wing aircraft or a helicopter. However, with the recent proliferation and advancements in UAV technology, and more standardized and accommodating regulatory oversight, these are now becoming the norm for airborne data acquisition.

They are much cheaper to operate, safer to use, and can be set on pre-determined flight paths, making them somewhat automated. With airborne data collection, the beam is emitted toward the ground and returned to the moving airborne LIDAR sensor.

There are two forms of airborne sensors:

- ***Topographic LIDAR*** - can be used to build surface models for use in a variety of land based applications, such as forestry inventory, hydrologic analysis, coastal geomorphology, urban planning, landscape ecology, coastal engineering, survey assessments, and volumetric calculations (such as earthwork, cut and fill).
- ***Bathymetric LIDAR*** - is airborne data acquisition that is able to penetrate through water to the water body's bed. The most common use for bathymetric LIDAR systems is to survey the bottom (bed), for navigational purposes.

Also these LIDAR can collect elevation and water depth simultaneously, providing an airborne LIDAR survey of the land-water interface.

With these types of bathymetric LIDAR surveys, multiple returns are required. The initial beam is reflected back to the aircraft from the land and water surface, while the additional green laser travels through the water column.

Analyses of the two distinct pulses are used to establish water depths and shoreline elevations. Bathymetric information is very important near coastlines, in harbors, and near shores and banks.

Bathymetric information is also used to locate objects on the ocean floor. This is very helpful for a number of applications: such as locating shipwrecks, searching for unexploded ordnances, or marking navigational hazards.

Chapter 3: Using 3D scan datasets in 3D Modeling Applications

Point Cloud Datasets

3D Modeling

Three dimensional modeling is becoming the industry norm for all forms of scientific and engineering design and analysis.

Where manual drafting practices and traditional surveying techniques were gradually replaced with digital drafting (2D CAD) and total station surveying, 3D scans and 3D modeling are becoming another step in the digital design evolution.

What is a point cloud?

Point clouds are the data output from the 3D scanning process. These point clouds are used for a number of practical applications.
These include creating 3D CAD models for:

- architectural applications (residential, commercial, industrial facilities)
- manufacturing and industrial uses
- metrological and environmental analysis
- hydrological evaluation
- earthwork volumetric calculations
- and a large number of other three dimensional modeling applications

LIDAR point datasets require post processing and "spatial organizing," in order to be properly utilized by the 3D modeling software programs. The initial pre-processed point cloud dataset consist of large unorganized sets of three dimensional elevation points, with their related attributtal data, such as the x, y, and z location, and GPS time stamp of each individual point in the "cloud".

Raw point cloud data consists of elevational data for the ground surface, buildings, forestry features, highway bridges and overpass sections, and other surface features that the laser beam encounters in the LIDAR survey.

Specific surface features such as those just mentioned, are classified following the initial stage of collecting LIDAR point cloud raw data, during the post-processing stage.

LIDAR point cloud data, in the context of GIS applications is most commonly represented as a:

- series of rasters
- TIN
- LAS dataset
- terrain dataset
- mosaic dataset

LAS (ASPRS) Point Classification

LAS (ASPRS) point classification

Each individual LIDAR point can have a classification assigned to it, defining the type of object that has reflected the laser beam pulse.

Lidar points can be classified into a variety of data type categories including:

- bare earth or ground
- forest canopy
- hydrological features
- roads, bridges

LAS Specification Standards

LAS (ASPRS) point classification is defined using numeric integer codes in the LAS files. These classification codes were defined and standardized by the American Society for Photogrammetry and Remote Sensing (ASPRS) for the LAS formats 1.1, 1.2, 1.3, and 1.4.

LAS version 1.4 is the latest LAS standard established, adding additional point classification and data. Only LAS 1.1 and later have a predefined classification system. The LAS 1.0 specification has no predefined classification scheme, and the data files neglect to identify what class codes are used by the points.

Classification "flags"

When LIDAR data is classified and organized in the post processing stage, the points may wind up qualifying as more than one type of classification. In this case, classification flags are used to provide a secondary descriptor for dual purposed LIDAR points.

With the first LAS version, a LIDAR point could not be assigned two classification attributes at the same occurrence. For example, a LIDAR return from a tree's top may need to be removed from the final output dataset, but still remain and be managed in the LAS file as a collected LIDAR point. Using LAS version 1.0, this point could not be set as forest canopy and be withheld from the analysis.

Classification values and their associated definition

These are classifications found in the LAS version 1.4:

0 - Never classified
1 – Unassigned
2 – Ground
3 - Low Vegetation
4 - Medium Vegetation
5 - High Vegetation
6 - Building
7 - Low Point
8 - Reserved
9 - Water
10 - Rail
11 - Road Surface
12 - Reserved
13 - Wire - Guard (Shield)
14 - Wire - Conductor (Phase)
15 - Transmission Tower
16 - Wire-Structure Connector (Insulator)
17 - Bridge Deck
18 - High Noise
19 through 63 - Reserved
64 through 255 - User Definable

In the versions following LAS 1.0, classification flags were used to remediate this issue. These classification flags were added to designate those points with information which is in addition to the primary classification of the point or point group.

Types of classification flags which can be set for each LIDAR point or point grouping are:

- synthetic
- key-point
- withheld
- overlap

These flags can be set to coincide with the classification codes. For example, a bridge deck record could be given a classification code as a bridge deck, in addition to a "withheld" flag. The point will remain in the dataset but will be withheld from any additional analysis on the LAS files.

When working with LAS specifications, the predefined classification schemes defined by the American Society for Photogrammetry and Remote Sensing (ASPRS) for a specific data category should be used.

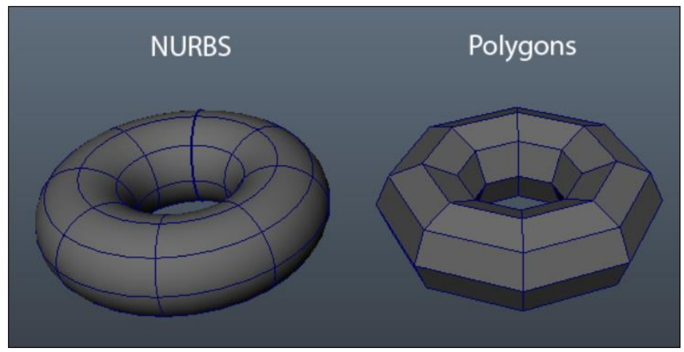
The LAS dataset is a stand-alone file, which is usually residing in its own separate folder within the 3D model's project file hierarchy. This file references LIDAR data in the LAS format along with optional surface constraint features that define the dataset surface characteristics.

The LAS dataset can be quickly generated by using a 3D modeling tool with the title "Create LAS Dataset" or a similarly named LAS manipulation command.

Surface Mesh Models

Mesh models

A point cloud can be directly rendered and inspected without being converted into a surface. However, point clouds in raw form are usually not usable in most 3D applications, and are therefore converted into polygon mesh or triangle mesh models, NURBS surface models, or other types of CAD surface models using a process referred to as "surface reconstruction".



NURBs vs Polygons

Surface Conversion Techniques

There are a number of techniques used, for converting a point cloud into a 3D surface model. Certain techniques, such as Delaunay triangulation, alpha shapes, or ball pivoting, will build a network of triangulated shapes over the existing vertices of the point cloud.

Other techniques convert the point cloud into a volumetric distance field, and then reconstruct the implicit surface, (defined through a "marching cubes" algorithm.)

Point Cloud Post Geo-Processing

Point Cloud Data

Point cloud data is in a raw data format directly from the scanner. In order to use this data, the points must be converted into a format which is usable by the modeling software. Most of the post geo-processing is implemented either in the 3D modeling program itself or some other 3rd party program.

Raw Data Import

The first step is to import the raw point cloud data into the modeling program. When the data is imported, a database will be created to store the coordinates for the individual points of the cloud. These databases can be quite large, as some scans can contain millions of individual points.

Filtering and Styling the Points

In the next step, styles are created to view the point cloud object in different ways, as well as to filter the display of imported point cloud data. Some point cloud styles display point cloud points as a specified color, based on their elevation value.

The point cloud points can be separated into classifications showing color-coded point cloud classes. This is a useful way to see different features that were captured during the scan. The point cloud style can be adjusted to filter unwanted features from the point cloud.

Some other types of post-processing:

- Aligning
- Cleaning
- Registration
- Classifying
- Meshing
- Separating into specific datasets
- Ortho-rectification
- Importation and file format conversions

Point Cloud File Formats

Point Cloud Data File Formats

This can come is a variety of file formats depending on the intended use, and the software package in which it is used.

ASCII files (plain text)

These are plain text files which can be read with any word processor or text file program such as Microsoft's Notepad. Formats may be: .txt, .asc, .csv and many more.

Comma Separated Values (.csv)

CSV files are plain text files as well, but the point cloud data is structured in an array or table format (as with an Excel spreadsheet), and is separated into rows or lines and columns.

- columns - are delimited by commas, tabs, or semicolons. 2D and 3D point features are supported as well as a limited number of point descriptors. It is good practice to make the first line of the CSV file a header, identifying each data column.
- features - are identified as: "x", "y", and "z" if the point cloud in 3D.
- descriptors - are divided into columns (these must be appropriately identified)

LAS dataset file Types

There are up to four file types created on disk that are associated with a LAS dataset:

- LAS dataset file (.lasd)
- LAS auxiliary file (.lasx)
- projection file (.prj)
- optimized LAS file (.zlas)

Digital terrain modeling (TIN's data)

DTM or DEM

Digital terrain modeling (DTM), or digital elevation modeling, is the creating of a digital representation of the surface topography and terrain.

Uses of DTMs:

- water flow and drainage analysis
- delineate watersheds
- perform avalanche or landslide simulations
- for land-use studies
- transportation system planning
- geological and geotechnical applications
- perform earthwork volumetric calculations
- GIS layers (overlays)
- physical raised-relief maps

Creating DTM's

There are a number of ways to collect information shown in a digital terrain map. This data is often obtained using remote sensing equipment rather than direct surveying methods, such as Radar and LIDAR sources. There are several governmental satellites dedicated to creating remotely sensed models of large areas of terrain. These satellites often have a lower resolution (of about ten meters.)

Even so, they can collect data on an area tens of miles wide in a single pass. Also, pairings of airborne images acquired at differing angles can be used to create the terrain. The first digital terrain models using this method were created in 1986 for a large portion of the planet using data taken with the SPOT 1 satellite.

Filling the gaps in regular contour mapping

In many cases, a DTM is generated from contour maps which were produced through direct surveying of the topography. The contour line data was obtained through a number of surveying methods, such as: LIDAR, Doppler radar, Theodolite or total station surveying processes.

While traditionally created contour maps can illustrate the equal elevations points on a terrain, they can't provide data for the intermediate points not shown on the contour map. DTMs are able to provide continuous elevational data across the model, filling in the gaps within the inter-contour terrain.

And, unlike contour maps which are 2D, a digital terrain map provides 3D imaging. In many cases, a "fly thru" or similar program can allow the user to manipulate the map to view all areas and angles of the terrain.

DTM variations and glitches

A DTM usually only illustrates the Earth's surface, leaving out vegetation, buildings and other man-made features. This is sometimes referred to as a bare-earth model.

However, a digital surface model shows these other types of features along with the natural terrain. One issue which arises with some surveying methods used to create these models such as radar is that they reflect the highest elevation point captured at a given location, whether it is the top of a tree or building or bare ground.

This will wind up skewing the rest of the model, usually requiring some manual cleanup and post processing to make it correct.

DTM and DEM Data Sets

Digital terrain and elevation data sets

There are numerous sources of digital terrain and elevational data sets available to the public from a variety of governmental and private agencies.

GTOPO30

A free, low-resolution digital elevation model (DEM) of the earth, known as GTOPO30, is available to the public. GTOPO30 is a digital elevation model developed by the USGS. It has a 30-arc second resolution (approximately 1 km), and is split into 33 tiles stored in the USGS DEM file format.

Terra Data Sets

A much higher quality DEM is available from the ASTER instrument of the Terra satellite.

Terra carries a payload of five remote sensors designed to monitor the state of Earth's environment and ongoing changes in its climate system:

- ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer)
- CERES (Clouds and the Earth's Radiant Energy System)
- MISR (Multi-angle Imaging SpectroRadiometer)
- MODIS (Moderate-resolution Imaging Spectroradiometer)
- MOPITT (Measurements of Pollution in the Troposphere)

Data from the Terra satellite aids scientists in better understanding sources and migration of pollution around the earth, examining global pollutant trends such as carbon monoxide and aerosol pollution. The data collected and compiled from Terra will one day become a new, 15-year global data set.

Other data sets from the USGS

The US Geological Survey also provides the National Elevation Dataset, which depicts seamless elevation data for the contiguous United States. However, for explicit applications, specifically created DEM, DTM, or Digital Surface Models may be needed.

Models of this type are usually requested by public agencies or large corporations, and must be created with the help of a professional in the field.

Digital Elevation Model (DEM)

These are bare earth, or topology models of the Earth's surface. Digital Elevation Models (as with Digital Terrain Models) can be derived by using the ground hits from LIDAR, (the last return of the LIDAR.)

With a DEM, one can generate products like:

- slope (the rise or fall, expressed in degrees or percentages)
- aspect (the direction of the slope)
- hillshade maps (shaded relief maps using illumination angle for contrast)

Filtering Bad Hits

Occasionally, the last return may not reach the bare ground. This may take some manual dissecting of a data set to distinguish which cloud points are actually bare ground hits.

There are ways to filter out the bad LiDAR points, by taking the ground hits (topology points only) meaning the last returns from LiDAR, and using the 3D model software's filter command. This filter interpolates unknown or missing ground points based on known points.

Light Intensity data

The strength of a LIDAR return varies according to the composition of the surface object which is reflecting the return.

These reflective variations are known as LIDAR intensity, with a number of different factors having an effect on it:

- surface composition
- receiver
- range
- beam
- incident angle

As the LIDAR pulse is tilted further away, the return energy will likewise decrease. Light intensity is of considerable use when distinguishing features in land use and land cover. Impervious surfaces, for example, will stand out in light intensity imaging.

Extraterrestrial Topography Datasets

And for possible future reference, there are DTM's, DEM's, and other datasets which are available for planets such as Mars!

These can be found on the USGS website's Planetary GIS Web Server, PIGWAD (which stands for: Planetary Interactive GIS on the Web Analyzable Database).

BIM (Building Information Modeling)

Benefits of using 3D scanning during a major BIM project

3D scans and models are a great point of beginning for any BIM project of existing facilities and structures. By using 3D laser scanning and modeling during a major commercial or industrial design, the savings which are realized can been substantially above the cost of the initial 3D laser scanning services.

Complex design and engineering changes to existing facilities are improved by scanning existing architectural features and importing them into the BIM model. The time to design and construct is reduced, thus reducing overall costs substantially.

Also, it is much easier to deal with any future remodeling, expansions, and structural integrity analyses with a BIM model already created.

The time and expense involved in building a BIM model from scratch can be quite a drain on the project budget, as well as a delay on the design and construction schedules, waiting for the model to be laid out, and go through the markup process.

Many errors and omissions which occur from rushed and overworked BIM personnel can be avoided with a scanned BIM model.

As-built data sets

This as-built data is the basis for the BIM process on existing facilities or newly constructed facilities.

Metadata

Completed solid models based on 3D scans provides architectural, structural, electrical, plumbing, HVAC and other 3D as-built information for importation into BIM models.

A variety of metadata specifications can be attached to the 3D objects, such as MEP specifications, manufacturers, part numbers or other information necessary for classification of an object.

This information can then be queried by database management systems and automatically inserted into bill of materials and other tabular reports.

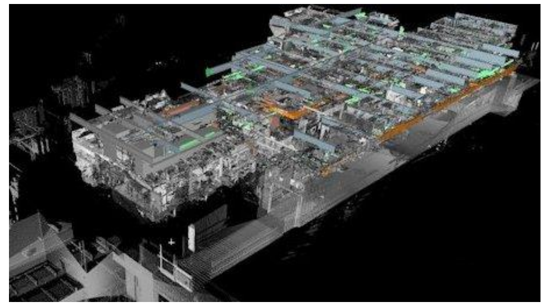


Image: Model and Point Cloud – Phoenix Mayo Clinic Hospital

Land Development Modeling

Land Development Modeling

Land Development 3D modeling software applications are used for a number of civil, environmental, geotechnical, architectural site, transportation, earthwork and other land use design purposes.

Popular programs such as Autodesk's Land Development Suite, and Bentley's Geopak, are two of the most common programs used.

Many DOT roadway design projects tend to use "Geopak" to model roadway corridors. While the "Land Development Suite is used by many private engineering and architectural firms for site work design.

Platform for cross discipline collaboration

Land Development modeling is kind of like BIM for the land, where the many different disciplines of design and analysis can all be incorporated into the primary model, such as drainage, stormwater control, impervious covers, landscaping, earthwork, utilities, environmental delineations, and more.

3D modeling and land planning

3D land development modeling is useful for all types of land planning. Whole district or whole cities can be laid out in a 3D modeling project folder.

In land planning, decision makers have hundreds of decisions to make concerning the long term land use within their boundaries.

Having 3D visual representations of the proposed and existing cityscape can be immensely helpful. For example, when looking at a proposed bypass, an added cell tower or electrical substation, or a complete urban renewal project through a 3D visual representation provides land planner with the tools to explain their concepts to city officials, council members, or financiers.

3D scanning allows for these types of presentations to be compiled in a fraction of the time that conventional surveying methods would require.

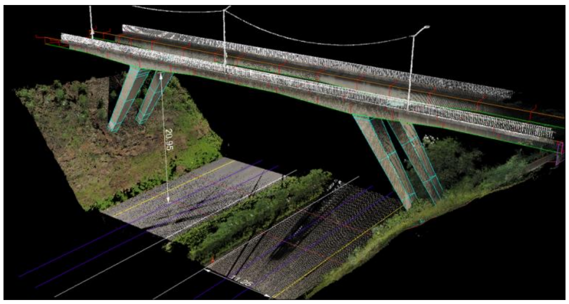
GIS shapefiles for an urban area

Chapter 4: 3D Scanning and Applications

Transportation

Roadway and railway corridor surveys

During the course of a roadway project, obtaining a 3D scan of the existing topography of a proposed roadway project is vital. From this scan, many measurements and site observations can be made from the safety of the engineer's desk. After the project is completed, as-built scans help to document and record the work which was performed.



Scanned roadway and bridge section
Image Source: mhpsurvey.com

Bridge Surveys

With the huge number of bridges which are falling into states of disrepair throughout the country, 3D scanning becomes a valuable tool in the analysis of bridge conditions. Various hazards such as cracking, spalling, scour (at water crossings), corrosion, settling and deformation can be uncovered in a high resolution scan survey.

Tunnels

Scanning of roadway and railway tunnels can highlight structural defects and issues, such as moisture or water seep, shifting at joints, and concrete cracks or spalling.

Volumetric Measurements and Calculations

Earthwork (Cut and Fill Volumetric Analysis)

3D models are essential to performing volumetric measurements of earth cut and fill in land development applications.

When regrading and excavation tasks are performed, it is necessary to maintain a balance and record or the amount of soil which is removed and where it can be added. In roadway design, 3D models help in building cross section details of along a road's center alignment, showing the required amount of cut and fill between each set of adjacent station points.

Hydrologic volume measurements

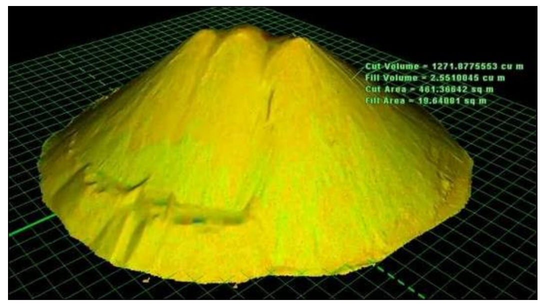
Obtaining areal measurements of stormwater and drainage systems, watersheds, or impervious cover, all aid in the calculating and estimating of the volumetric quantities of rainfall which will occur on a developed site.

Using modeling analytical tools, a wide variety of hydrologic calculations can be performed on a 3D land model when parameters such as soil type, regional rainfall, and runoff/infiltration rates are known.

Aggregate and soil stockpile measurements

3D scanning can be used to measure the volumes of aggregate or soil stockpiles. Meshing of a scanned point cloud is used to obtain the model, upon which the estimate of the pile volume is based.

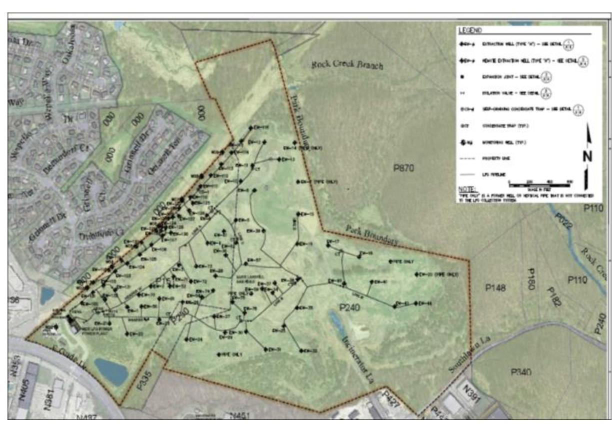
Using modeling analytical tools, highly precise measurements can be obtained of these irregularly shaped earth piles.



3D model of an aggregate stockpile

(MSW) Landfill Accounting

From the beginning when municipal solid waste landfills are built, they are in a constant state of volumetric change. 3D scans help to record the various stages of construction and earth removal, as well as the progression of MSW fill re-added to the site.



As-built site plan for LFG Monitoring at the Gude Landfill in Derwood, Maryland
Image Source: Montgomery County

Mining

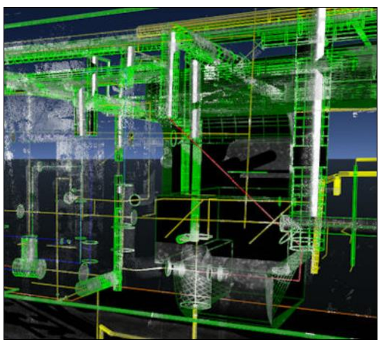
3D scanning is a valuable tool for quickly assessing the volumetric differences in mining operations over time. Performing periodic scans of active mining zones, allows for before and after imaging and analysis of ore productivity.

Industrial Facilities

There are a number of uses for 3D scanning at commercial or industrial facility locations. Scanning helps in taking stock of what exists and where at a given facility or commercial building.

MEP (mechanical, electrical, plumbing)

The use of scanning helps to accelerate the process of as-built surveying of the intricate and detailed piping, electrical and HVAC networks which exist throughout an industrial facility or commercial/retail building. As-builts obtained through scanning are created at a fraction of the time, making them cost-effective and less timely.



Post processed point cloud data from a piping scan
Image Source: topa3d

Property Accounting

Performing a scan of an existing facility or building is a quick and affordable means to take stock of what furnishings, equipment, and other non-stationary properties are on site.

Some administrators require an annual accounting of the property that exists on a premise. This helps in creating future budgets, provides proof of purchases, and helps in taking account of potential thefts of property which may go unnoticed.

Space Planning

This is a fundamental component of the interior design process. It helps in analyzing how interior space is being utilized, and verifies that furnishings and equipment are placed properly. With the high cost of some leased office or industrial spaces per square foot, effective space planning ensures that every square foot is being efficiently used.

Tower Structures

Communication and Cell Towers

The construction of a communication tower is a complicated process requiring a number of surveys to verify that the construction is built according to design plans, and is in full compliance with local, state and federal regulations. These surveys help to catch mistakes which can be extremely costly if not caught early enough in the construction process.

Towers are either designed as latticed structures or single monopoles, both requiring perfection in their erection and alignment. Insuring that the structure is erected with a perfect vertical alignment and is correctly centered on the foundation is vital to the safety and longevity of the tower.

HV Transmission Towers

When it comes to the construction of transmission and distribution power lines, the term “as-built” refers to more than just a record of the site conditions.

Creating as-built surveys for high voltage electrical infrastructure requires a specific knowledge and awareness concerning certain features, such as:

- the right of way corridor
- fencing
- grounding
- the latticed or monopole structures
- structure foundations
- insulators and hardware
- cabling and tensioning
- and more

Some members of the as-built surveyor team may need to be specially certified in areas such as NACE (corrosion control, coatings, and cathode protection), or OSHA (Occupational Safety and Health Organization).

Structural Deformation Analysis

Finding Structural Deformations

3D scanning is a good tool to use for measuring the degree of structural deformation which occurs in a multitude of structures, such as:

- latticed structures (such as communication and electrical transmission towers)
- ships and aircraft
- boilers, and other pressurized vessels
- bridges
- an automobile chassis
- trusses and building support structures

Causes of Deformation

In materials science, deformation refers to a change in the shape or size of an object due to:

- an applied force (the deformation energy in this case is transferred through work)
- temperature change (the deformation energy in this case is transferred through heat)

Due to applied force

Deformation due to applied force can be a result of tensile (pulling) forces, compressive (pushing) forces, shear, bending or torsion (twisting).

Due to temperature change

With deformation due to temperature change, the most significant factor (determined by the temperature), is the mobility of the structural defects, such as: grain boundaries, point vacancies, line and screw dislocations, stacking faults and twins in both crystalline and non-crystalline solids.

The movement or displacement of such mobile defects is thermally activated, and limited by the rate of atomic diffusion (transport of atoms).

Bridge structural integrity

Periodic scanning of an existing bridge helps in the recording of progressive structural issues such as steel deformation, concrete cracking and spalling, as well as scour and erosion around the bridge piers.

These structural irregularities may not always be visible to the human eye, but can sometimes become apparent when a progressive series of images is analyzed.

3D scan survey of the west span of
the San Francisco-Oakland Bay Bridge

The Mapping of Mining Operations

Mine Safety

Safety is a main concern in any type of mine, whether the ore is gold, coal or other. Performing 3D laser scans of the tunnels can identify and record any cracks and fissures, compare these data to previous scans, and identify areas of concern. This is an enormous contribution to the safety of the mine workers and promotes a safer work environment.

Consistent 3D documentation of the mine's structural integrity, can prevent a potential mine collapse, as it instantly detects alterations in local rock strata, so that appropriate measures can be implemented prior to a disastrous situation.

Material Assessments

For all applications of surface and subsurface mining, 3D scanning is a powerful tool to use to document the progressive removal of ore from the ground. It can provide an ongoing record of what has been removed from the site, and where it was removed from; allowing for a digital and visual accounting of a mine's production.

Assessing mine conditions virtually

By using 3D surveying technology to survey the existing condition of a mine, mining engineering personnel are able to visualize what presently exists in all of the hard to reach places of the shafts and tunnels, and make determinations as to how to plan for future ore extraction. 3D scans show fissures and cracks, structural support, mechanical and electrical systems, and more.

Avoiding hazardous conditions using robotic crawlers
By combining 3D scanned surveying units with robotic crawlers, hazardous conditions can be avoided by personnel.

The mine can be surveyed from a safe distance; eliminating the need to place people and equipment in potentially dangerous situations should a mine subsidence, gas intrusion, or slope failure occurs.

Mining Applications

All types of mining operations can benefit from the use of 3D scanned surveys.

Surface mining operations:

- Open pit
- Quarrying
- Placer
- Strip
- Dredging
- Hydraulic
- Mountaintop removal

Subsurface mining operations:

- Hard and soft rock classes
- Directional tunneling
- Stoping (room and pillar, longwall, retreat)

"Underground soft rock" mining

is a group of underground mining techniques used to extract coal, oil shale, potash and other minerals or geological materials from sedimentary ("soft") rocks.

"Underground hard rock" mining

refers to various underground mining techniques used to excavate hard minerals, mainly those containing metals such as ore containing gold, silver, iron, copper, zinc, nickel, tin and lead, but also involves using the same techniques for excavating ores of gems such as diamonds.

Directional Tunneling

- ***Shaft mining*** – or shaft sinking, is excavating a vertical or near-vertical tunnel from the top down, where there is initially no access to the bottom.
- ***Slope mining*** – A sloping access shaft tunnels downwards toward the ore materials, with the entrance being at an incline.
- ***Drift mining*** – the horizontal working of coal seams, accessed by adits (horizontal entrances) driven into the surface outcrop of the coal bed. Access is above the water level and generally on the slope of a hill, driven horizontally into the ore seam.
- ***Borehole*** – mining by use of boreholes and high pressure water jets
- ***Bell Pit*** – primitive method of mining which uses an open pit, with bucket and winch for ore removal.

Stoping

This is the process of extracting the desired ore or other mineral from an underground mine, leaving behind an open space known as a *stope*.

"Room and pillar" mining

is a system in which the mined material is extracted across a horizontal plane, creating horizontal arrays of rooms and pillars.

"Longwall" mining

is a form of underground coal mining where a long wall of coal is mined in a single slice. "Retreat" mining refers to the final phase of room and pillar mining, where room or chamber is excavated while leaving behind pillars of material for support. This excavation is carried out in a pattern advancing away from the entrance of a mine.

Utility As-builts

Locating and documenting underground utilities

3D scanning is a line of sight technology, meaning it can only scan those surfaces which cast a reflection for the laser beam. Because of this, it is well suited for above ground utility scanning, but is not usable for underground utility documenting and locating.

For these types of utilities, other technologies are required which can penetrate through solid matter, such as ground penetrating radar, electromagnetic devices, acoustic sounding devices, hydro excavation, or even dowsing (for locating buried water mains).

High Voltage Electrical Infrastructure

3D scanning is an ideal solution for performing as-built documenting of high voltage electrical infrastructure. Most surveying can be performed using ground-based stationary scanning units. However, some applications may require an airborne approach.

Additionally, there are underground components as well such as duct banks, and underground services which require other means for location and documentation.

Water and Wastewater Infrastructure

The distribution portion of this infrastructure is usually built out of sight and beneath the ground. However there are still a number of components such as pump stations, valves, the treatment plant, and more which are still accessible and able to be scanned.

Combining scan technology with other locating technologies such as those mentioned above, can provide a complete picture of the entire water and sewer distribution or collection system.

Oil and Gas Infrastructure

Similar to water and sewer systems, oil and gas distribution systems are both above ground and beneath, requiring a combination of technologies in order to fully locate and record the complete infrastructure.

Forestry and Landscapes

Landscaping and Hardscaping Plans

In commercial and high-end residential construction, landscaping and hardscaping have become quite technical and sophisticated features. Landscape Architects, Design Architects, Interior Designers, and Civil Engineers all realize the visual impact that a well-designed exterior has on the aesthetic appeal of a property.

3D scans are useful in documenting a well laid out exterior. When incorporated into a BIM model, a 3D as-built scan of trees, walkways and other exterior features is necessary in recording the final construction product for future reference.

Forestry Inventory

When deciding on forestry resources, sound judgment relies on the precise information that is collected using forest inventory techniques. There are various kinds of forest inventory techniques that can be used depending upon the goal, scale, resources and the level of accuracy required.

Most forest inventory work is based on field sampling. The accuracy of the forest inventory depends on the quality and quantity of the field sample. Traditionally, a field sample was measured using simplified, manual methods. However, remote sensing methods will likely become the preferred and required means of collecting field sample data.

Terrestrial laser scanning (TLS)

provides a measurement technique that can acquire a level of detail (LOD) in the millimeters. This data is acquired from the surrounding area, which allows for a quick, automatic and routine estimate of many important forest inventory parameters.

As specific data processing software becomes available and more affordable, standardized best practices become commonplace, and industry acceptance becomes more wide spread, TLS will be the normal method for data collection.

The wide spread use of UAV-based scanning will also likely follow, as the industry standard for forest inventory.

LIDAR imaging comparing old-growth forest (right) to a new planting of trees (left)
Image Source: Wikipedia

Forensic Applications - Accident and Incident Scene Reconstruction

Accident Reconstruction

Some law enforcement agencies around the country have begun using laser scanning at traffic crash sites to quickly document and record the site, instead of having to painstakingly log all pertinent points of interest hoping to not miss key evidence.

The 3D laser is mounted on a stationary tripod, taking a 360-degree image of the crash site, recording a cloud of up to 30m separate data points with a resolution of less than a millimeter. Each sweep can take roughly four minutes to complete, and typically four scans are captured from each site.

These images can then be used to extract measurements and survey evidence over a broader area than was once captured using strictly digital photographs.

This digitally scanned image of the site can then be viewed, rotated, zoomed in, and otherwise manipulated within various modeling programs, enabling investigators to analyze where vehicles are in relation to one another and other bits of vital evidence.

More benefits of 3D scanning over traditional accident reconstruction:

- Lines of sight can be analyzed from a variety of vantage points.
- The scan data may be compared with OEM CAD files from the vehicles manufacturer to perform a vehicle deformation analysis.
- The scan data can also be used to create accident animations to simulate the actual event for use in the courtroom.
- Time spent at the accident scene can be reduced greatly, thus improving officer safety while minimizing traffic congestion and bottlenecking.

Advanced physics analysis can be performed on the 3D model, reconstructing unknown vehicular parameters such as braking distances, line of travel, speed of travel, and more.

Forensics and Crime Scenes

Crime scene investigation is a popular use of 3D scanning technology. The ability of the scanning unit to accurately record millions of measurements along with panoramic imagery at a crime scene is a powerful tool in investigative technology.

Because the scanner measures everything within its line-of-sight instead of just what an investigator may believe to be of the most importance at the time, it is a controlled crime scene.

Investigators are no longer limited to making all of the “important” measurements while the crime scene is initially measured.

A competent investigator will diagram the obviously important evidence at a crime scene such as a body, weapon, cartridge casings, etc.

However, in the early hours of an investigation the investigators do not know what is of importance and what is not. It may a month later that an investigator realizes the importance of a critical measurement from the scene.

Through 3D scanning, the investigators can virtually return to the crime scene multiple times, and examine the viewpoint or find a critical measurement required for the investigation.

Hydrology, Geomorphology, Glacial Movements

Hydrology

The use of 3D scanning allows for quick and easy surveying of surrounding site topographies when delineating surrounding contributory watersheds. When performing hydrologic analysis of a developing site, 3D scans provide a level a detail never before available with older topographic survey applications.

Geomorphology

This refers to the scientific study of the origin and evolution of topographic and bathymetric (underwater topography of the river/ocean beds) features. It is a study of the dynamic changes in the Earth's surface created by physical, chemical or biological processes upon the terrain.

Geomorphologists seek to understand why landscapes look the way they do, to understand landform history and dynamics and to predict changes through a combination of field observations, physical experiments and numerical modeling.

3D scanning provides a detailed picture of the highly complex process of geomorphology. When multiple geo-referenced scans are overlain over various periods of time, the progressive and often subtle changes in the topography can be envisioned, and extrapolated to create predictive models of future events such as beach erosion and scour.

Glacial and tectonic progression

With the degree of detail available in 3D scanning, time progressed scans can show the subtle progression in glacial and tectonic movement, which are not otherwise evident.

Analytics - Clash Detection

Clash Detection

Clash detection is a vital and integral step in the BIM modeling process. In BIM modeling, it allows the right hand to know what the left hand is doing, during the design and build process.

In BIM, there is not just one model being digitally built, but several, that are integrated into a composited master model. Each design discipline: structural, MEP, environmental, landscaping, interior design, etc. are all creating models, usually independently of one another.

Most ancillary design is usually based on the architects' original conceptual model, which is the starting point for all the other disciplines to build upon. After each of the disciplines have completed their separate designs, clash detection is performed to discover where the models are in conflict.

There are a number of scenarios where clashes occur, such as when separate design models occupy the same space, when there are design parameters that are incompatible or a sequence of design and build events which are out of order.

Finding these conflicts is vital, to maintaining a well-orchestrated construction process, preventing delays, causing excessive design changes, the wasting of expensive materials and non-skilled or skilled labor time. Unforeseen construction conflicts can seriously cause a slew of headaches and budget overruns.

Previous Methods of Clash Detection

Clash detection is not a recent stage of the design process, which followed the advent of BIM technology. However, in the past, clash detection was performed by overlaying drawings on a light table to visually see the clashes, or at the construction site, in a more rudimentary and haphazard fashion.

For example, when a support beam that the structural engineer designed is square in the path of the HVAC ductwork which is being installed, either the structural support member or the HVAC ductwork is going to need to be relocated.

This would usually entail on the fly workarounds to make the ductwork fit. This onsite change can cause cascading conflicts to occur with other professions such as plumbing, electrical, or the interior designers.

And sometimes engineers or architects may design things in a certain way that is unclear to the contractors building their design. Time delays and costly budget overruns would be common, especially on larger more complex projects.

Early BIM and CAD

In the early days of CAD design, computers had barely enough power to perform basic 2D CAD drafting functions, and certainly not enough computing power to process true 3D functionality. In those early days prior to 3D modeling, 2D CAD design was no help with finding conflicts.

Even after 3D modeling became possible on a typical, out of the box computer, there was still the technological lull in software capabilities (analytical algorithms). Detecting clashes in the earliest stages of 3D modeling was often performed visually by the designer or engineer. Even the automated commands returned meaningless clash returns.

Newer Method for Clash Detection

Now in BIM modeling, true clash detection takes place during the design phase, resolving conflicting issues prior to construction commencing; saving money and time, while producing a better quality structure.

With true BIM modeling and the clash detection search capabilities of the software, the detection process has greatly enhanced the ease, speed and accuracy of the detection process.

Clash detection is a vital component of BIM modeling. Each identified clash saves hundreds, if not thousands of dollars on a project. On large construction projects, there can literally be thousands of these clashes which may occur.

Best Practices (for effective laser scanning)

Establish the intended use of the scanned dataset

It's important to identify the intended use for the scanned data, as well as how the data will be used, and at what stage of the project the data will be needed. It's helpful to know whether the data is being used to verify construction quality and stage of completion, being used as as-built data, or verifying that the construction is meeting regulatory compliance.

Communicate Clearly with the Client

Scanning can have its limitations, and sometimes clients may not understand this, due to a lack of knowledge concerning scanning technology. The client needs to be fully aware that laser scanning is line-of-sight technology, and cannot scan through solid objects.

Additionally they must be aware that the scanning process consists of multiple stages; collecting of the data, scan registration, post-processing, and model generation. When a client doesn't fully understand the limitations and full purpose of scanning they may be unhappy with the results and dispute payment for the services.

Research the scanned environment

Predicting any unknown contingencies helps a survey contractor avoid losing money on a project. There may be site-specific issues which can hinder a scan. The site may have employees or other occupants which can prevent a successful scan. There might be debris, or erroneous objects which need to be moved such as heavy equipment or vehicles. There could be snow on the ground, or other unforeseen obstructions which need to be removed or possibly added prior to the scanning.

Establish a clear scope of services for the project
Fully communicating with a client as to the full scope of services helps tremendously. It's not possible to foresee every contingency when accepting a scanning contract. However, having a clearly defined outline of the client's needs in writing helps protect both parties from getting "burned" due to misunderstood project goals.

Determine the type of deliverable product needed
Different clients have differing needs. It is always best to discuss the format for the deliverable scan data with the client to make sure it is feasible. Most software used in engineering and architecture is proprietary and very pricey.

Some clients may require a bit of post processing of the raw scanned data prior to the dataset being delivered. Without having a copy of the software the client is using, it may be impossible to perform the post processing to their satisfaction.

Establish survey control prior to commencing the scans

Establishing the project survey control prior to scanning, links the laser scan data to an established project control. This allows for additional scanning using the same coordinate system, should addition scans be required.

It ensures the accuracy of the scan relative to the space, and provides a common point for all contractors to adhere to, during construction.

Gather more data than is required

It usually takes far less time to perform an additional scan or two, while set up at the site; rather than having to return to the site, and set up to rescan missing gaps of point cloud data.

Establish a schedule and appropriate time table for the project's completion

Determine the time requirements and the client's expectations of the deadline for completion, prior to beginning the scan. Some sites may only accessible during after-hours, or weekends. It helps to know when the best time for scanning may be, to avoid missing deadlines due to inaccessibility.

CAD and 3D modeling capabilities

As the improvements in digital hardware continue to occur, so too will the software industry continue to adapt and innovate, accordingly. CAD firms such as Autodesk (Autocad) and Bentley (Microstation) will continue to add features to their modeling software, finding bigger and better uses for raw point cloud data files.

Bibliography

This course is based on information obtained from the following governmental and private sources:

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