# Advances in LiDAR Processing for Change Detection

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There have been thrilling advances in LiDAR technology over the past year. Not only has LiDAR hardware grown in capability, there has been great progress in the difficult post-processing of the massive LiDAR data sets. In particular, there have been improvements in data classification, void filling, and data densification. The result is enhanced LiDAR data sets that are more easily used for change detection. In this paper we specifically examine these enhancements for appraisal data validation, change detection, and update.

## LiDAR Basics

Light Detection and Ranging (LiDAR) is a method of collecting coordinate data with a laser scanner. An airborne infrared laser sweeps the ground collecting billions of 3D measurements.

From the aircraft-mounted sensor, the laser pulse begins to spread from an initial width of about 0.1 centimeter (half an inch). By the time the pulse strikes the ground, the pulse can be a half meter in diameter. Sensor altitude affects the size of the beam strike.

With each feature the laser pulse strikes, the laser's reflection is bounced back to the sensor, where the distance between the sensor and the feature is recorded. Knowing the exact location of the aircraft and LiDAR sensor (from a GPS and IMU)[1] allows the computation of the ground XYZ coordinate struck by the laser.

Of course, not all laser pulses actually reach the ground. Many will strike rooftops and parked cars. Many laser pulses are captured in trees. In the case of trees, different portions of the laser pulse may be reflected from different features such as leaves, branches, and the ground underneath.

Multiple returns from the same pulse are recorded by the sensor and can be used to classify the feature (in this case a tree) as well as to compute the elevation of the ground beneath the tree.

*LiDAR Density*

LiDAR data density is critical to the resolution of features such as buildings and houses. Smaller features require more dense data for their resolution. The example below is a staggering 35 returns per square meter collected by a helicopter.

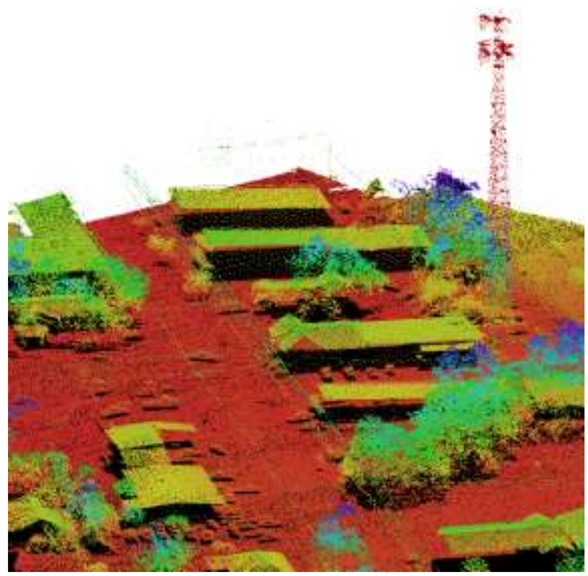

*Figure 1: Dense LiDAR – Note the Power Lines*

LiDAR vendors will collect LiDAR data according to a specification that states the density of the data to be collected. This density is expressed in terms of "postings" or "ground sample distance." A better definition is the number of pulses per square meter, which includes the understanding that some of these pulses will not include ground coordinates.

[1] GPS – Global Positioning System
IMU – Inertial Measurement Unit

| Vendor | Spec | Density | Average |
|---|---|---|---|
| S | 1.4m | $0.51/m^2$ | $0.44/m^2$ |
| W | 1.7m | 0.35 m | $0.16/m^2$ |
| M | na | $35/m^2$ | $41/m^2$ |

*Figure 2: Data Densities by Vendor*

To achieve greater densities, you can fly the aircraft slower and lower. You can have more side-lap in the aircraft flight lines. Some vendors have 50% side-lap effectively doubling the LiDAR data densities. Another option that is even better for feature extraction is to have perpendicular flight lines.

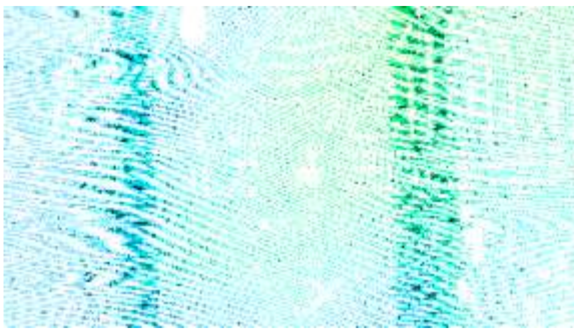

*Figure 3: Swath Overlap – Double Data Density*

*Data Noise*

In the LiDAR point cloud there is always data we don't want that we call "noise." This unwanted data is not needed in the users' end application, so it is removed. Noise may include transient features on the ground during the scan, such as cars in a parking lot or trucks on a road. More commonly, the noise being removed is vegetation, such as trees and shrubs.

Depending on the application, buildings may also be considered noise, as is the case for the digital elevation model (DEM).

There are other forms of noise. Some points have absurd z-coordinates and these are termed blunders. A blunder could be a point many feet below the ground surface, while others could be huge positive values. Other terms for these blunders are zingers and outliers.

## LiDAR Data Sets

There are a number of data sets created from LiDAR. The industry has often been sloppy with their proper use, often confusing their customers and users. County officials usually do not know the difference between a DEM and a Bare Earth file terming both files simply as LiDAR. The following are generally accepted industry definitions.

Point Cloud – The LiDAR data with all returns is the point cloud. The point cloud is a binary file in an industry standard file format. The LAS format is specified by the ASPRS[2], however, not all vendors follow the industry standard when preparing their LAS files.

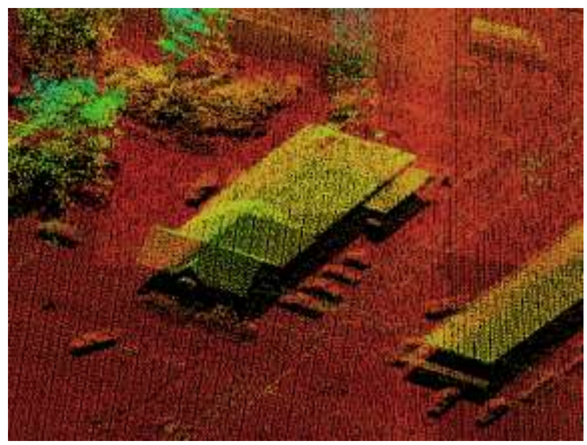

*Figure 4: Very Dense Point Cloud*

Bare Earth – The bare earth or bald earth file has all vegetation, structures, and other above-ground features removed. This file should only have XYZ coordinates that represent the surface of the ground. Sometimes the Bare Earth coordinates are called "mass points," which is a term borrowed from the ortho image production process.

[2] American Society for Photogrammetry and Remote Sensing

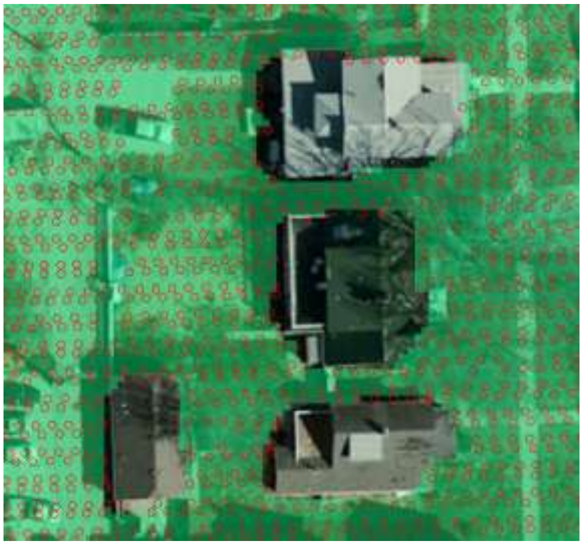

*Figure 5: Bare Earth as Red Circles*

Digital Elevation Model – This is a derivative from the Bare Earth data that averages and aggregates Bare Earth data into a regular grid. The grid is coarser than the starting LiDAR density to reduce the chances of voids occurring in the gridding process. The DEM will have coordinate values under buildings to represent the ground devoid of all vegetative and structural features. A DEM is used by surveyors and engineers to build terrain models that are inputs for contouring, hydrologic studies, flood plain modeling, and infrastructure development.

Digital Surface Model – This is similar to the DEM, but structures are included in the gridded data. This file is used for 3D building models, urban visualizations, architecture, noise studies, micro-climate research, and for locating wireless telecommunications antennae.

Digital Terrain Model – The DTM is a value-added product that augments the bare earth data with breaklines. The DTM is used in the ortho image production process to control the adjustment of blocks of pixels in the image. The DTM is also used to generate contours.

Breakline – A breakline is a linear feature used to enforce the accuracy of Bare Earth data or a Triangulated Irregular Network (TIN). Examples of Breaklines are planimetric features such as curbs, building foot prints, road crowns, and bridges.

Triangulated Irregular Network – The TIN is a detailed abstraction of the DEM or DSM data that renders XYZ coordinates as triangular polygons. Every polygon is flat and has a slope and direction. The TIN is useful in visualization by creating relief maps and for view shed modeling. TIN models are the most common format for processing LiDAR data within a geographic information system (GIS).

*Figure 6: Triangulated Irregular Network*

*DEM, DSM & TIN Limitations*

There are fundamental limitations with the DEM, DSM, and TIN. With the DEM and DSM, massive amounts of LiDAR data are discarded: as much as 95%. This is a substantial amount of abstraction and loss of detail due to data averaging and aggregation. In the case of the TIN, breaklines are absolutely required to enforce the slope direction of individual TIN planes to ensure the polygon's slope is in the correct direction and to locate straight edges. Otherwise, the spikes and zingers in the TIN will cause erroneous slope measurements. Ironically, the cost to produce breaklines can be higher than the costs of the LiDAR.

## Advances in LiDAR Processing

One significant issue with LiDAR is the amount of effort that goes into the data processing to create derivative products. The huge volumes of LiDAR data has actually been a limiting factor in making effective use of the data.

LiDAR data processing is not fully automated. Processing requires tuning various parameters to create the optimal data sets desired. Computer automation relies on iterative computation, evaluating the same LiDAR point many times before achieving a final result. This means there is the need for substantial computer processing time and for human supervision to classify billions of LiDAR points.

There have been several endemic problems with LiDAR data. The biggest problems have been void filling and data densification. The automated location of feature edges and corners is also an issue because of the nature of the data.

*Better Classification*

The raw LAS data can be classified better. Improved classification not only means more accurate data, but denser data because the industry approach has been to discard LiDAR returns that could not be easily classified.

| File | LAS | BE | BE + |
|---|---|---|---|
| 20852200 | 2,035,237 | 1,193,217 | 1,867,077 |
| 20852250 | 1,974,671 | 1,035,599 | 1,635,788 |
| 20902200 | 2,058,089 | 1,146,421 | 1,809,421 |
| 20902250 | 2,048,158 | 1,078,232 | 1,729,338 |

*Figure 7: Data Density*

The File column is the name of the LAS tile. The LAS column shows the number of returns in the full point cloud. The BE column is the number of bare earth points extracted by the LiDAR vendor from the LAS. The BE+ column is the number of bare earth points extracted using better classification technology.

*Data Overlap*

It is possible to quickly add data density by processing the flight overlap. Normally this data has been clipped by vendors to thin and reduce the data size. The overlapping data is located in the raw LAS files, not the processed bare earth, DEM or DSM data.

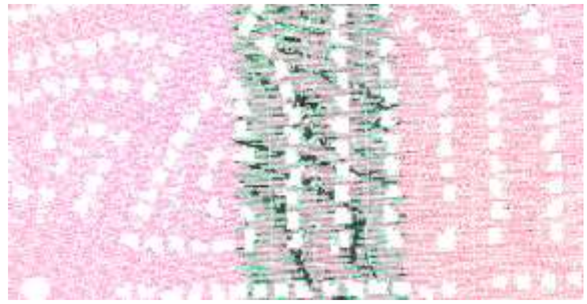

*Figure 8: Data Density and Feature Resolution*

*Void Filling*

Often there is missing LiDAR data called voids. Some of these voids are caused by the LiDAR sensor or result from a data processing step. Often software creates voids when large chunks of noisy data are removed, such as clusters of trees. Voids can be filled with classified data, indicating bare earth or structures.

*Figure 9: Densification from better Classification*

In the example above, the original data in red has been densified with better classified data in green.

*Synthetic Data*

A sophisticated solution for filling voids is the use of "synthetic" data. Synthetic data is information computed and classified by persons or software to minimize and eliminate data voids.

*Figure 10: Synthetic Ground points in Yellow*

Adding ground data under trees is another method of computing synthetic data. This is possible because of the multiple return data characterizing trees. The graphic above shows bare earth points as red circles and the synthetic points computed beneath a tree in yellow.

*ISM With Structures*

The Interpolated Surface Model is a concept similar to the DSM, except for the following:

- Data is better classified
- Voids are filled
- Data is densified
- Synthetic data is exploited
- Breaklines are not needed

The first step in building the ISM is better data classification. This means individual LiDAR return data is classified according to features that include bare earth, vegetation, structures, and others.

Vegetation and noise are removed from the ISM leaving only the bare earth and structure data. Noise removed typically includes cars. When these data are stripped, we then compute synthetic data to further extend the bare earth and structure classifications. This contributes to the void-filling and data densification process. This also helps minimize the occlusion issue caused by vegetation and shadow.

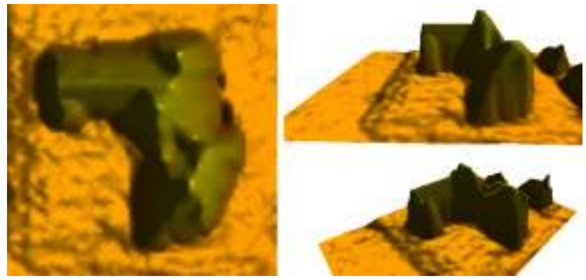

*Figure 11: Three views of a Church in a DSM*

*ISM Without Structures*

The ISM without structures, or what we call a mask, is very interesting because it is another value-add product that can be leveraged in other ways. The Mask is similar to the ISM in that it has better classified data, the voids caused by bad sensor measurements and much vegetation is removed, the data is densified, and we make much use of synthetic data. But the Mask is different from the ISM in that:

- We perform edge location
- We perform corner location
- We encode structure locations as mask data to enable later processing

The lidar mask is a tool used to better define the edges of foreground features and to block the view of other unnecessary background information. The mask is used primarily to assist in the delineation of feature breaks and later to locate their edges, such as for buildings and houses.

The rooftops and appurtenances are slightly dilated in the masking process because the LiDAR data spacing. If the returns average two meters apart, the dilation of the mask will also create about two meters of buffer around the structure.

*Figure 12: Mask is Missing Elevation Data*

The mask is prepared with the encoded elevation data. The colors in the ISM connote the elevation data. There is no color data under the structure. This resulting hole is called a mask or sometimes a blob because of their fuzzy shape.

## Sketch Change Detection

We use three input files in the change detection process. They are the LiDAR Mask, the fused parcel fabric, and the sketch data in a GIS format. The first step is to fuse the lidar data with the parcel information. This allows the software to understand what lidar data is included in the parcel.

*ISM / Parcel Fusion*

Next each mask is attributed with the parcel ID so the software will know what sketches should be compared to the mask. The parcel fabric should be a single GIS data layer with attribution including unique parcel identifiers. In the next figure, note how the parcel line cuts through the mask, creating two mask blobs, each with their own unique parcel ID. The sketch of the house could not be software-checked because of this fusion problem.

*Figure 13: Parcel Line in White splitting Mask*

There can be problems encountered when we fuse the parcel fabric to the ISM. Interestingly, we actually validate the accuracy of the parcel fabric by looking for locations where parcel lines bisect a mask.

*Figure 14: Parcel Fabric Error of 100 Foot*

*Mask Dilation*

The mask buffer is always larger than the actual structure. The LiDAR data only knows what LiDAR returns struck the ground or a structure. The points defining a structure include features in addition to the roof boundary. These appurtenances include awnings, decks, and attached car ports. For commercial structures, the mask may include loading docks and docked trailers. The mask does not necessarily represent the footprint of the structure.

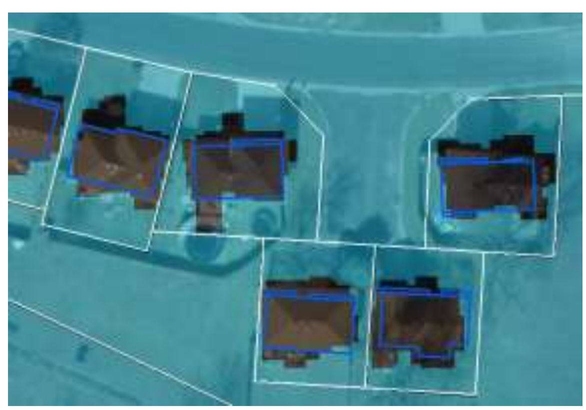

*Figure 15: Mask, Ortho and Sketches*

Note the special circumstance below of the attached condominiums. You can see their foundation in the image and the CAMA sketch in blue, but the LiDAR shows these have not yet been built. More importantly, notice how the parcels do not agree with the locations of the foundations.

*Figure 16: Foundations Do Not Match Parcels*

There can be more than one mask per parcel. This is true for more than one structure located on the same parcel, such as an out-building like a detached garage.

In the image below, note the voids in the mask where there is not a sketch. Some of these voids are outbuildings on the properties which are not sketched. In these cases the features are detached garages along the alleys

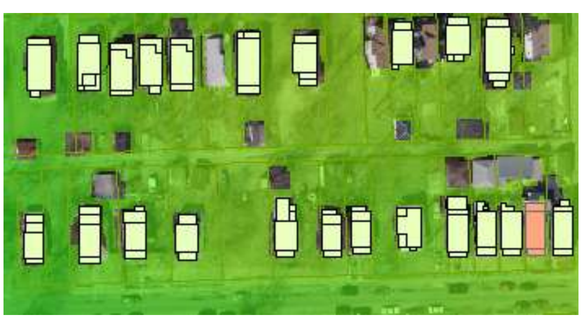

*Figure 17: Mask with Structures not Sketched*

*Sketch Preparation*

The property sketch from CAMA needs to be in a GIS vector format. If sketch data is stored in a CAMA system, the "strings" are converted into GIS vectors. If the sketches are on paper property cards, these will need to be digitized and stored as GIS data.

The sketches are all then stored as digital scale-accurate GIS polygons. In the case of this demonstration area, the polygons were created as an ESRI Shapefile[3]. We are also experimenting with 3D architectural drawings created using Google SketchUp[4] fused with the LiDAR.

*Figure 18: Google SketchUp in 3D*

But there are notable exceptions when there are no sketches for some properties. Examples include tax-exempt organizations, such as government buildings, schools, and churches.

*Software Logic*

The mask value for the structure has values of 0 for the red, green, and blue values. This makes it possible for the software to understand the mask locations. If there is more than one mask in the parcel, this technique simplifies the work of the software allowing it to form a hypothesis regarding what mask will be compared to a sketch.

Using an iterative estimation process, the software looks for a best fit between the geometries of the mask and the sketch. The best-fit process tries out different fits while adding some randomness. This allows us to "jiggle" the sketch until we achieve the best fit possible. There is a cost function that automatically determines the fit quality and keeps this score.

[3] Shapefile is a trademark of ESRI
[4] SketchUp is a trademark of Google

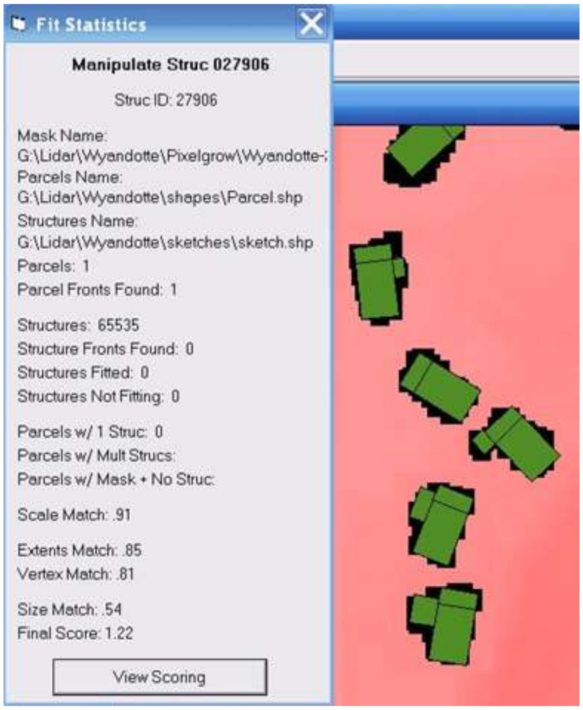


*Figure 19: Sketch Scoring Against LiDAR Mask*

Thus we are trying to assign a numeric grade to a qualitative estimate. It is the qualitative aspect of the scoring that is very subjective and different people will have different opinions about the score.

The sketch comparison algorithm anticipates this difference in mask and sketch, including the buffer zone. The sketch should be slightly smaller than the blob of the mask and have similar geometry. Similar geometry means the same number of corners and edges, with the equivalent dimensions. This means we are not solely using the square footage to calculate the fit.

In the next example, our scoring determined a difference between the mask and the sketch. In the top example, the mask shows a covered deck leading to the pool, but the pool does not appear in the mask because it is set in the ground. The bottom example has the mask indicating the above ground pool and the deck between the pool and the house. Interestingly, the parcel line is off about 15 foot to the south of the fence line.

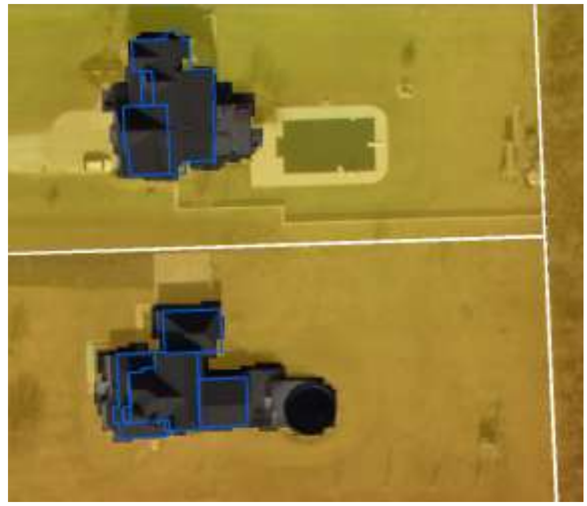

*Figure 20: Two Sketches not Fitting Mask*

When the sketch does not seem to fit the mask, it is flagged for follow up during the desktop review. The world is infinitely complex and software cannot handle all of exceptions. We want these outcomes to ensure that the time spent by people doing the follow-on desktop review are using their time most efficiently.

In the example below of these apartments, there are covered parking spaces with white roofs. Unfortunately, there are no CAMA sketches for these features so these masked features need to be manually inspected to determine that they are not false positives indicating possible missing sketch data.

*Figure 21: Covered Parking*

## IAAO Desktop Review

The desktop review is now performed on the sketches flagged as having change. The desktop review per the IAAO standard uses orthos, obliques, and street-level imagery.

The change detection process assigns a numeric score to the sketch based on how well it agrees with the mask. These numeric scores are then converted to a simple Yes/No flag indicating if the sketch should be inspected. By inspecting only those sketches flagged for desktop review allows the assessor to work more efficiently. Of course, some properties will still require measurements from the field.

*Desktop Review Limitations*

The IAAO desktop review is designed for the traditional "stare & compare" process of putting eyes on ortho photography, oblique imagery, and street-level imagery. This means the person performing the desktop review must be trained to understand the features they are analyzing for change.

Desktop Review is not automated because of fundamental limitations that are inherent to imagery. These limitations include requirements of similar imaging conditions such as look angles and lighting. The look angle and lighting affect shadows, which are difficult issues for software using radiometric data where color and intensity data are analyzed. These issues have forced vendors providing change detection services to rely on the "stare & compare" process of visually inspecting every feature in the image for change. This process is usually sent to inexpensive off-shore GIS shops.

*Relief Displacement*

An important issue to be aware of when comparing LiDAR to other GIS layers is that each layer will have its own spatial accuracy. This is common for parcels on ortho photography. It is also true for Lidar.

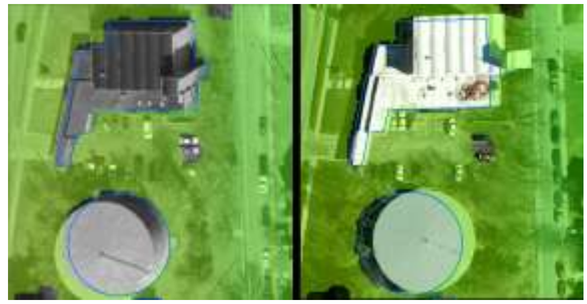

*Figure 22: Note the Structure Lean*

The example above show the disagreement of building roof tops relative to the LiDAR mask and their sketch. This error is termed "relief displacement" and it is inherent in all imagery and caused by the view angle creating the appearance of lean in tall structures.

Remember that it is the imagery that is spatially incorrect, not the LiDAR. Thus fitting the sketch to the LiDAR is more accurate than manually positioning the sketch over the imagery's rooftop.

*IAAO Standards*

The IAAO Desktop Review standard does not specify what constitutes change. Thus there is no definition or guidance regarding change in imagery or LiDAR.. This is an indication of the novelty of the technology in the assessment industry.

It would be difficult for the IAAO to provide guidance on what is change, as each taxing jurisdiction may define change in their own way. It is up to the jurisdiction to define what features are to be located in the orthos, obliques, and street-view images and then determine the nature of change in every scene.

Experts will have their own, differing opinions about what constitutes change. Within a jurisdiction, one technician will classify change differently from the next technician. A deck, above ground pool, or detached garage may be assessed in one jurisdiction, but not the next.

Just as it is not possible to determine grade and condition of a property from an ortho and oblique, the same is true for LiDAR. So the desktop review must rely on high-quality comprehensive street-level imagery to determine effective age and contextual criteria.

Immersive imagery is even better for this task because the user has more than one point of view to study the changes found by the LiDAR. Immersive imagery also helps the reviewer create the context of the property's value based on neighboring features, which is not possible from a one photo to one parcel context or with lesser quality video frames.

## Summary

LiDAR is another useful tool for automating the fusion of many data sets, including the sketch from CAMA into real-world space. The LiDAR mask also enables a significant degree of automated change detection of the sketch.

It is conceivable that this technology could be used by consultants to speculatively find properties and improvements missing on tax roles and the consultant only be paid a percentage of the value added to the rolls.

Using LiDAR it is also possible to create a change detection baseline to simplify and further automate later analysis. With a LiDAR baseline created, change detection utilizing future LiDAR data and updated sketches makes the change detection process simpler. In the future, change detection for CAMA sketch measurements will be possible in 3D, as well as from LiDAR on LiDAR data processing.

The importance of lidar in the field of change detection will grow, especially in updating CAMA data. Other uses of LiDAR are the determination of building elevations and flood plain mapping. These other applications will more tightly link the Assessor's office with the functions of land use, zoning, and perhaps code enforcement.

We are at the frontier of this technology's use. Change detection is just one of many uses for LiDAR data.

## About the Author

At Lidar Logic, Dr. Cunningham leads the exploration of new concepts and technologies for automated feature extraction utilizing LiDAR. Current LiDAR work includes assisting several counties with CAMA change detection, impervious surface modeling, and wetlands management.

Over the past twenty years, he has provided GIS, GPS & cadastral consulting on more than 150 county-level projects. This includes serving as a technical advisor to four states, several national organizations, and numerous projects overseas. He also consults with large spatial corporations where his knowledge of the human factors and process engineering is used to design better software and systems. He maintains his industry credentials with articles, classes, and editorial work for photogrammetry, GPS, and economic development.

Dr. Cunnigham received his PhD from Kansas University in 1997, with empahsis in artificial neural networks for automated feature extraction. While at the University of Kansas, he helped teach graduate seminars in advanced GIS, Urban GIS, and GPS for GIS. He also holds a BS in Geology and an MA in Geography from the University of Missouri.

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