The Use of Lidar for Change Detection and Updating of the CAMA Database

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A critical convergence of software, data, and data models is opening up a new frontier for computer-assisted mass appraisal (CAMA) management. This convergence will simplify CAMA updates, allow better integration with spatial data, automatically perform appraisal change detection, and allow for the creation of truly integrated management processes. A key to this convergence is the automated spatial registration of CAMA sketches with a new form of property imaging called lidar—light detection and ranging. Recent advances with lidar have led to new, powerful tools that accurately place the CAMA sketch in real-world space while simultaneously performing change detection.

Background

The job of the assessor is to estimate the monetary value of properties and maintain the CAMA database. CAMA is used to establish real estate appraisals for property tax calculations.

When possible and with the right tools, determining valuations from the office is more efficient than from the field. The new Section 3.3.5 of the recently approved *Standard on Mass Appraisal of Real Property* (IAAO 2006) states, "Jurisdictions may employ a set of digital image technology tools to replace routine cyclical field inspection with a computer assisted office review."

To perform this desktop review, various tools are available to the appraiser. Geographic information systems (GIS) have been utilized for several years. GIS data used by the assessor include parcel fabric, ortho imagery, and, occasionally, building footprints.

Often linked to the GIS parcel is a property image. Imagery began with a Polaroid stapled to a property card. The technology evolved to include digital imagery, first grabbed frame by frame from videotape and saved to a laser disk. As the technology matured, high-resolu-

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tion megabit imagery directly linked to parcels, and building footprints have become the norm.

Important to the reappraisal is the determination of the grade and the condition of properties. Obviously digital imagery can assist in this task. The better the composition of the image (framing, color balance, contrast, and depth of field) and the greater its resolution, the more useful it is for the desktop review.

Recently, oblique imagery has been demonstrated to be useful for determining building features and measurements. Some obliques produced by using detailed digital terrain models (DTM) can yield very accurate measurements in the horizontal (second) dimension, as well as on the vertical (third) axis.

Lately there has been a buzz in the appraisal industry about a concept called change detection. The concept of change detection is that two data sets can be compared and the differences noted. Typically a new air photo is compared with an old air photo, but unfortunately, this means the change is in the air photo, not in the CAMA database.

Recent work with lidar has led to new tools that allow the accurate placement of CAMA sketches in real-world space. With real-world coordinates and orientations, the georeferenced sketch from CAMA can be compared with the ortho photo and the oblique photo, thus performing simultaneous change detection with the CAMA sketch. Then the CAMA database can be updated directly.

Proactive versus Reactive Change Management

In communities where timely permits, inspections, and other regulatory processes are required, tracking change is a proactive process. In these communities, construction and other building activities affecting property values can be efficiently communicated from various government agencies to the assessor.

In most communities, especially rural counties, however, this proactive approach to monitoring change is not possible, partly because of limited technology and data sharing. A greater issue is the lack of a governing process with zoning, permits, inspections, and the like. Another contributing factor is the culture of the community, in which citizens think the government has no business knowing what improvements they are making to their properties.

In these communities, change detection is a reactive process. At best, jurisdictions can only play catch-up by updating their appraisal databases. Even after a new baseline of updates is created, the lack of proactive change management causes the appraisal database to begin to decay in both accuracy and completeness.

Change Detection

Change detection has many different meanings in other industries. A common use of change detection in the manufacturing industry is the robotic inspection of parts and pieces for defects. Some food products are inspected automatically to determine what fruits and vegetables on a conveyor are to be rejected. In medical imaging, change detection is used to assist the physician in identifying abnormal growth. In video surveillance systems, the movement of a person or object is considered change detection. The U.S. military is currently investing in a better understanding of how the human mind sees and understands change.

Even in the appraisal industry, change detection is loosely defined, with equipment vendors using different approaches and claiming different results.

The assessor's old-fashioned but reliable approach to change detection is to go into the field with the property record and to draw a sketch. This visual inspection and tape measure of all properties remains quite common and is performed on a cyclical schedule, with a complete canvas finished perhaps every few years.

Approaches to Change Detection

High-resolution street-view imagery is one approach to determining change. The latest street-view image is compared to the older image to determine whether the effective age of the property has changed and to update the condition. The street-view image also can note new construction on the home. This approach includes high-resolution megapixel digital imagery linked to a digital parcel fabric.

The evolving idea of street-view imagery is to allow the appraiser to review each structure in the office. Performing this task from the office is much more efficient than going into the field to make the same observations.

A limitation of street-view imagery is that the image may show only two sides of a structure. If there is a fence or hedge or trees blocking the view from the street or if the structure is located behind a locked gate or at the end of a long driveway, the image is not likely to be adequate for a desktop review.

Ortho Imagery

Another traditional approach to change detection is comparison of an older air photo with a new one. With the ortho photo becoming a commodity available to everyone, the process of comparing an old ortho to the current ortho is even simpler.

However, there are fundamental limitations to using orthos. First, the image is of the roof, which does not tell an appraiser whether that roof is covering the living space, a garage, a porch, or even a covered deck. Second, the ortho is not very useful for calculating the physical dimensions of each component of the structure because of the roof overhang.

A more critical issue in using orthos for change detection is *occlusion*. Occlusion is the technical term that photogrammetrists use to describe how a feature is hidden from view. In general, the term includes trees and their shadows that block the view of the feature being inspected. Even the most highly trained photogrammetrist has few tricks for dealing with occlusion. If it is this difficult for a photogrammetrist to make a decision about a building's dimension, imagine the problems that occur when a programmer attempts to automate the process.

Oblique Imagery

Recently, the oblique air photo has become a tool widely used by appraisers for desktop review. The oblique air photo has been around for more than 100 years, with the first pictures being taken from hot air balloons.

This side-angled view has inherent measurement errors caused by the perspective of the camera in the air. It was the effort to remove the perspective measurement errors that propelled the photogrammetry industry towards ortho-corrected aerial photography, so the air photo could be used to create scale-accurate measurements from the image.

Obliques are valuable in the appraisal process because they see under the roof eaves. When obliques are accompanied with accurate DTMs, the measurements made from the oblique can be very accurate. Not all obliques have an accurate underlying DTM to make this measurement process possible.

Obliques by themselves, however, are still incomplete tools for performing change detection. The same problem affecting orthos affects obliques—occlusion. The other problem with performing change detection with imagery is that a person needs to conduct the review.

The Human Factor in Change Detection

Even though robotic vision is used in many industrial and manufacturing processes, this automation is not easily applied to other forms of visual inspection. For example, a manufacturer of gears for automobile transmissions x-rays each part. Any variance from an expected norm, such as a small crack shown in an x-ray image, is sufficient information to reject that part.

In the industrial and manufacturing environment, inputs and defects are well known. Much more complicated, however, is an image of the real world. Because there are so many features with such variability, identifying changes caused by human activity can be a challenge of a totally different magnitude.

For example, consider two ortho images taken three years apart. In those three years, the trees around a house have grown taller and the shadows cast by those trees are longer. Even more important, the shadow is actually different in the two photos, because the photos are taken in different seasons and at different times of the day. Thus the shadow's intensity, direction, and length are different in the two images, causing differences in occlusion. Also, atmospheric conditions affect image clarity and contrast, creating more subtleties in the images being compared.

Stare and Compare

Change detection with the traditional ortho-on-ortho or oblique-on-oblique approach requires a great deal of manual labor. The human approach to change detection is colloquially termed stare and compare because a person has to visually inspect every detail in every photo.

Stare and compare is a tedious, tiring, and error-prone process. The person performing the change detection is subject to a variety of problems inherent in how the human brain functions. An obvious issue is the loss of focus and attention after staring at images for any length of time. Cognitive scientists term the loss of focus and attention *change blindness*, which reflects how people no longer can see change.

Change blindness cannot be avoided because it is built into human physiology. Eyes have two types of neurons: the cones located at the center of the retina specialize in detecting color and detail, and the rods are optimized for detecting motion.

To compensate for change blindness, the brain moves the eye around to keep the image updated in the brain, a process called *saccade*. The saccade allows the brain to focus on a detail in an image and actually allows the eye with its specialized neurons to create the image in the brain.

Training and experience also are very important for people working with change detection. With training and experience comes the ability to notice details that others would miss. For example, people from different social groups often miss details and changes about persons from other social groups.

Side-by-Side and Superposition

The traditional process used in stare-and-compare change detection is the side-by-side positioning of the old air photo with the new air photo. This forces the human eye and mind to go back and forth between the two images, looking for minute changes in the features.

Another approach is called *superposition*. This approach places the new and old air photos on top of each other. Then the top image is toggled on and off—an effect similar to animation. This approach actually utilizes the cone neurons on the retina to detect changes.

Human Economics

Because a highly trained and experienced human is used in change detection, the process is expensive. Some companies send the work off shore, where the labor pool is less expensive. But quality control becomes an issue, especially if the foreign culture does not have the same building features as the U.S. culture. Universities may have qualified and less expensive labor, but the quality control of their work can be a problem.

Ideally, change detection is performed by a review appraiser, who not only knows the community but also is skilled in air photo interpretation.

The CAMA Link

More importantly and still overlooked by most equipment vendors is that the change detection process must be performed with CAMA data, not by comparing ortho with ortho or ortho with oblique.

The obvious approach to determining change in CAMA is to overlay the sketch from CAMA on the ortho. When the sketch is overlaid, the review appraiser can visually determine whether the sketch generally fits the shape of the building's rooftop in the ortho. If the sketch does not match, there likely has been some change.

Determining the nature and extent of the change is another, separate task. If obliques are available, then comparing the sketch with the obliques can provide information on the nature of new construction, and perhaps even grade and condition. Megapixel street-view imagery also is a very useful supplement to the process. However, in some cases, a field visit to the parcel is necessary to determine the change.

Lidar

A maturing technology that can be used to fuse GIS, CAMA sketch, orthos, and obliques is lidar—light detection and ranging. With lidar, the sketch from CAMA can be linked to real-world coordinates, the edges of structures can be displayed against the ortho, and the user can visualize the change that is verified with obliques and street-view images.

Lidar also can help the review appraiser perform more efficiently and more accurately, because the lidar can actually be used to hide unnecessary detail.

Lidar Basics

Lidar is a way of collecting millions and millions of measurements using an airborne laser scanner. As a plane flies overhead, an infrared laser sensor continuously sweeps the land and stores the elevations of features on the ground. Elevations are actually determined by measuring the time between when the laser leaves the sensor and when it is reflected back, thus determining the distance between the sensor on the plane and the ground. When the plane knows its exact altitude and location from GPS, the elevation of the ground can be easily calculated.

A typical lidar scanner can burst 20,000 to 50,000 pulses per second. These pulses follow scan lines perpendicular to the flight of the plane. There can be as many as 200 of these scan lines per second, causing the push-broom sweeping of the aircraft's flight path.

The altitude of the plane determines not only the size of the pulse at ground level but also the breadth of the lidar sweep. Flying the plane at higher altitudes means the laser beam sweeps broader regions, resulting in larger lidar returns. Therefore, to see the greatest detail with lidar data, lower altitudes are desirable.

Lidar Returns

As the laser pulse leaves the sensor on the aircraft, it is about 0.1 centimeter (less than half an inch) in width. By the time the pulse strikes the ground, the beam is no longer as well focused and its diameter ranges from about 25 centimeters to 1 meter.

An aircraft altitude of 1,000 meters results in a 0.25-meter spread per pulse. An altitude of 2,000 meters causes the spread to grow to about 0.5 meter per pulse.

Each lidar pulse can yield several return pulses. In general, the sensor on the plane can measure about five returns per lidar pulse. Thus, if the sensor is 20 kHz, there can be as many as 100,000 returns per second.

Typically there is at least one return per lidar pulse. When there is more than one return, the last one is typically the ground, representing bare earth, grass, a road, or even a rooftop.

More than one return indicates other features that have been found in the spread of the lidar beam. A first return typically represents the crown of a tree. Between the first and the last return are other features such as tree limbs, shrubs, and even cars.

To most users of lidar data, much of this information is considered noise. Noise is actually a misleading term, however, because these other features reflecting the laser beam could be important to other users, such as appraisers.

Lidar Accuracy

Interestingly, lidar equipment vendors typically state accuracies in statistical terms that most people may not understand. Also, accuracies are specified in terms of “performance under system specification” or “system performance under optimal atmospheric conditions.” The accuracy of lidar also depends on the age of the sensor. The latest lidar sensors yield even better accuracies and classifications than sensors made only a year ago.

In general, vertical accuracies are on the order of 15 centimeters, or about a half-foot. Horizontal accuracy is generally worse because of the physics involved with the sensor. Also, horizontal accuracy is not consistent across the scan swath because perspective causes additional error across sloping ground.

Lidar Post-processing

One significant issue with lidar is the human effort called *post-processing* that goes into filtering data to create a final data deliverable. Post-processing is how noise and unwanted data are removed from the lidar returns. This post-processing can be completed with specialized software filters, but generally a person supervises the removal of the unwanted data.

In the preparation of lidar data for the ortho correction process, the bare earth data are the most important. Bare earth data represent the real terrain data used to create the DTM. Some lidar data can be sacrificed to create the DTM more efficiently.

Important to a lidar project is the error budget, which determines the accuracy of the lidar data being delivered. Part of this error budget includes the sample rate of the sensor and spacing of scan lines. This error budget also factors in the error from the scan pattern, sensor response times (latency), sensor (thermal) noise, and atmospheric error (fog, humidity, temperature, and refraction). Other sources of error are the airborne kinematic GPS and its ground control.

Lidar Data Sets

There are several lidar data sets describing the ”who, what, where, when, and how” of the data’s origin. The most commonly used data set is the bare earth file. There are also intensity files, the digital elevation model (DEM), and a file containing all the filtered returns. These data sets are typically available in binary LAS format and ASCII XYZ format.

There is no simple way to use the lidar data in off-the-shelf GIS. Because there is so much information, there are few existing tools available to easily visualize and analyze the data. In the case of Douglas County, Kansas, for example, there are more than 21 gigabytes of raw lidar data spanning 590 separate file sets.

GIS technology will eventually provide standard tools for utilizing the information, but for now, derivative products must be created. The following paragraphs describe several types of lidar data sets.

Feature Surfaces

All specialized lidar software allows the user to visualize the features in the data. This surface visualization determines surface locations based on similar elevation data. As a result, a flat roof of a warehouse can be visualized quite easily. But a problem with this approach is that the edges of the roof are not so well defined because of the irregular edge of the lidar returns.

Bare Earth

One benefit of lidar is its ability to penetrate the trees and shadows that typically occlude a feature in an air photo. This is the problem that vexes traditional photogrammetry, leaving important features hidden under foliage and its shadows.

The bare earth file has had the vegetation removed from the data, as well as data from buildings and other man-made features. The result is a file with only ground-level elevations.

DTM and DEM

When the bare earth data have been augmented by a photogrammetrist with mass points and break lines, the result is a DTM. The DTM is used in the generation of accurate ortho imagery. Some oblique products register each oblique image to the mathematical earth surface, thus ensuring accurate measurements from the DTM.

DEM is a filtered DTM that has removed many points, simplifying the file for computer processing. The DEM elevation points also can follow regular grid spacing. Some products use DEM data to create the orthos rather than a DTM.

TIN

The triangulated irregular network (TIN) is a set of triangular surfaces generated at irregular spacing from the DTM point data. The TIN often is used to create more detailed surface models that contain mass points and break lines. The TIN data created from the lidar DTM usually are used in the hydrologic and hydraulic models to determine flood risks.

Elevation Map

One of the first derivative products created in Douglas County was the elevation map. This is a compressed file, squeezing the 590 sets of lidar data measuring over 21 gigabytes in size into a single image of only 200 megabytes. This compressed image also preserves the elevation data while visually rendering it, so that the user can intuitively see changes in the elevation. With a custom tool created in ArcView, users also can see the elevation value as they move their mouse cursor.

In Douglas County, the elevation map was compared to the FEMA FIRM (Flood Insurance Rate Map) to determine how well the two data sets agree. Because the lidar has much more information and the data are accurate to about 6 inches, the lidar elevation map is more accurate than the FIRM. Indeed, when the FIRM data were overlaid on the elevation data, the two did not match. This is a good example of a change detection application using lidar.

Lidar Mask

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 determination of features that have changed.

The lidar mask filters the important features from the ground to the appraiser. This filtering or masking of the background helps eliminate visual noise from the ortho that would distract the review appraiser in the desktop review. The information seen by the review appraiser through the lidar mask includes homes, buildings, and other man-made features relevant to appraisers.

An advantage of the lidar mask over other approaches using orthos and obliques is its ability to penetrate occlusions due to foliage and shadow. This is a significant advantage when determining the edges of features.

Lidar Mask and CAMA Change

The lidar mask can be a useful tool in determining change, especially when users fuse the sketch with CAMA to the orthos and obliques.

The mask is an efficient tool in the automated georeferencing of the CAMA sketch. The mask represents the structure as a void in the background data, and then software can automatically determine the best fit of the sketch based on the geometry of the sketch and the hole in the lidar mask.

The same software also can determine the wellness of the fit. The lidar, like the ortho, actually reflects the rooftop of the structure, which is typically larger than the sketch because of roof overhang. The georeferencing software can calculate the amount of overlap. If there is too much overlap in the mask, it is likely that some form of additional construction is not accounted for in the sketch. So the sketch either fits or does not fit the mask.

Finally, when rendered transparent, the lidar mask allows the background orthos and obliques to be used more efficiently in the visual inspection of change. With the mask showing feature holes, the ortho and oblique can be viewed without any screening. The background information containing yards, shrubs, trees, and other distracting data is minimized with the screening process, allowing users to focus their attention on the features being inspected.

Lidar Mask and CAMA Benefits

Thus the lidar mask is a 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 against current lidar data.

Individuals performing the review appraisal from the office can now conduct their job more efficiently, achieve higher productivities, and be more confident that the changes they are identifying are correct.

In communities without a proactive CAMA change update process, the lidar mask allows for the creation of an accurate and complete baseline of CAMA information to ratchet up the accuracy and completeness of their revenue models.

Ideally a proactive CAMA change system would be implemented in conjunction with the maintenance of the CAMA system, keeping CAMA complete and accurate at all times.

Summary

The importance of lidar in the field of change detection will grow, especially in updating CAMA data. In communities with a reactive approach to database maintenance, the lidar mask is an effective tool for georeferencing the sketch in CAMA and for masking the ortho and oblique to more easily and accurately determine changes. Other uses of lidar are the determination of building elevations and flood-plain mapping.

Reference

IAAO. 2006. *Standard on Mass Appraisal of Real Property*. Kansas City: International Association of Assessing Officers.