EVALUATION OF LIDAR AND PHOTOGRAMMETRY FOR MONITORING VOLUME CHANGES IN RIPARIAN RESOURCES WITHIN THE GRAND CANYON, ARIZONA

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ABSTRACT

Elevation data from high-resolution photogrammetry and different resolution and replicate collections of LIDAR were compared with ground survey elevations of bare- and vegetated-sediment deposits within the Colorado ecosystem to determine their ability to map ground topography at an accuracy of =20 cm and to estimate sediment volume at an accuracy of =3%. We found high-resolution LIDAR and photogrammetry to meet this vertical accuracy requirement on bare-sand surfaces, but not on vegetated-sand surfaces. Photogrammetry and LIDAR second-return data produced the best vertical accuracies on vegetated-sand surfaces, but accuracies were only about 35 cm. Photogrammetry consistently produced the highest volumetric accuracies on bare (≤3%) and vegetated ground (4-9%). Overall, photogrammetry provides more accurate monitoring data than LIDAR, although more careful photogrammetric processing is necessary to attain monitoring accuracy requirements within vegetation.

KEYWORDS: LIDAR, Photogrammetry, Accuracy, Precision, Ecosystem, Monitoring

INTRODUCTION

The Grand Canyon Monitoring and Research Center (GCMRC) of the U.S. Geological Survey studies the effects of Glen Canyon dam water release on the Colorado River ecosystem between Lake Powell to Lake Mead, Arizona. One GCMRC program studies the effects of water release on terrestrial sediment deposits and routinely monitors the area, topography, and volume change relative to dam flow conditions to determine their relations to dam water release and to develop water-release protocols to restore, or at least to maintain, the ecosystem (Hazel et al., 1996). Collection of these data in this canyon system currently involves time-consuming (expensive) ground surveys. A recent increase in the number of study sites prompted an examination of alternative methods for data collection that might provide acceptable data over a larger region of the river corridor, in a shorter time frame, and possibly at a cost comparable to current ground surveys. For GCMRC monitoring purposes an acceptable range for vertical accuracy and precision is 15-20 cm (Schmidt et al., 1999). Sediment volume estimates derived from these topographic data need to be accurate to within 3% to meet current ground accuracy (Beus et al., 1992).

The most commonly used airborne technologies for topographic mapping are photogrammetry and LIDAR and several studies have evaluated their vertical accuracies. LIDAR assessments on large, uniform surfaces found vertical accuracies to be 15-20 cm (Krabill et al., 1995, 2000). Gomez Pereira and Wicherson (1999) found the vertical accuracy of LIDAR data to be about 14 cm on flat, homogenous surfaces, whereas vertical accuracy of (1:4,000-scale) photogrammetric data was about 25 cm. Blank (2000) found this same photogrammetric accuracy for a small area within the Colorado River ecosystem. Several studies have found LIDAR elevations to be offset from true ground elevations. Kraus and Pfeifer (1998) found LIDAR data to have a +20 cm vertical offset within the Vienna Woods, Austria: correction of the data for this offset reduced the mean square error from 26 cm to 10 cm. A LIDAR accuracy assessment of beaches along the U.S. Atlantic coast (Shrestha et al., 1999) found LIDAR vertical offsets to be +20 cm to -10 cm with LIDAR accuracies of 15-20 cm only obtained after offset correction. A more recent LIDAR evaluation along the Green River in Utah found an overall LIDAR offset of -44 cm on bare sand, cobble bars, brush-covered areas, and rock outcrops (Bowen and Waltermire, 2002). Adjustment of the LIDAR data by this offset resulted in a vertical accuracy of 22 cm.

Results from these studies suggest that LIDAR or photogrammetry might provide acceptable elevation data for GCMRC monitoring requirements, but these studies did not address some important issues for GCMRC monitoring.

These issues include: (1) the precision and vertical accuracy of these techniques for producing “bare earth” elevation data, not only on bare ground surface, but also within riparian vegetated zones, and (2) the ability of these airbome elevation data to accurately estimate sediment volume within the riparian ecosystem.

DATA SETS AND STUDY AREAS

To directly address these issues, we collected and compared the following data sets: (1) high- resolution RAMS LIDAR and moderate-resolution ALMS LIDAR data acquired at a spot spacing of 1.5 m and 3.75 m, a spot diameter of 0.5 m and 1.0 m, during August and March, 2000, respectively; (2) a second high-resolution RAMS LIDAR data set acquired over the same river reaches just two weeks (September, 2000) after the first high-resolution LIDAR collection, using the same LIDAR system and acquisition parameters, (3) high-resolution (25-cm C. I.) photogrammetric elevation data produced from 1:4,800-scale photography acquired between (September, 2000) the two high-resolution RAMS data collections; and (4) over 2,000 ground elevations obtained transect and stakeout surveys on bare and vegetated surfaces during these airborne data collections.

For this study we selected four large river reaches used by GCMRC for long-term monitoring of sediment. The four study areas are located within the northern 100 km of the Colorado River that flows through Arizona. All study areas have at least one debris flow and various types of vegetation stands. Bare ground in the river reaches consists of fine-grained sand bars and river terraces, talus slopes and associated cobble (25 cm) bars, and isolated 1-2 m boulders. Vegetation consists of patches of short (=25 cm) grass; low-lying (=2 m), scattered bushes and dense marsh vegetation; and individual stands and dense groves of high (?4-6 m) mesquite and *Tamarisk* trees. Elevations in our study region decrease downstream from 952 m AMSL (above mean sea level) to 818 m AMSL.

DATA ASSESSMENT

The photogrammetric DEM (25-cm cells) used in our analyses was produced from contour vectors using the GRID function in Arc/Info. LIDAR point elevations for each study area were converted to a raster image file of elevations having a 25-cm cell size. These uninterpolated elevation raster images were used in our assessments of vertical accuracy and precision; interpolated DEM versions were used in our assessments of the accuracy of the airborne elevation data for estimating sediment volume within each study area. Because there were very few spatial coincidences between the LIDAR points and our ground-transect points, we performed a 1-m radial search around each transect point to determine a corresponding LIDAR elevation. When more than one LIDAR point occurred within this radius for a particular transect point, we calculated a distance-weighted average LIDAR elevation for that transect point. High-resolution, orthorectified color-infrared imagery was used to create digital masks of bare ground and vegetated ground, which were used in our examinations of specific surfaces in each study area. Two measures of error were used to assess accuracy and precision: the *mean error* (which is the sum of the differences between the airborne elevations and the corresponding surveyed-ground elevations divided by the number of values) and the *mean absolute error* (which is the sum of the absolute differences between the airborne elevations and the corresponding surveyed-ground elevations divided by the number of values).

Vertical accuracy on bare ground

The lower resolution ALMS LIDAR data are less correlated with the true bare-sand surfaces than the two higher resolution RAMS LIDAR data sets, with standard deviations on the mean errors in the ALMS data being factors of 2 to 10 higher than those in the RAMS data. This is attributed to the larger spot diameter and hence higher positional uncertainty of the ALMS first return, which may have hit nearby bushes scattered about the sand surfaces. Least-squares regression lines for most LIDAR data sets are parallel to, but *offset above*, the true ground surfaces. Vertical offsets in the ALMS data show a wide range (–5 cm to +55 cm), whereas the August RAMS data have quite consistent offsets (+11 cm to +21 cm) with only one area’s offset differing more than 1 cm from a +20 cm offset. This RAMS consistency is encouraging for large-area topographic mapping large areas of the river corridor. However, the replicate (September) RAMS data show a more random, wider range in vertical offset (+17 cm to +48 cm), which argues against a regional offset approach.

The unadjusted mean absolute errors (vertical accuracies) of the ALMS (33-84 cm) and September RAMS (19-49 cm) data are consistency worse than the 15-20 cm accuracy generally purported by commercial vendors. Only the August RAMS data have vertical accuracies (7-22 cm) close to this advertised accuracy. Assuming offset adjustment is an operational necessity, we corrected the data sets for the observed offsets. The adjusted vertical accuracies for the ALMS data are still low (21-84 cm), but the adjusted vertical accuracies of the September RAMS data (12-26 cm) and August RAMS data (7-15 cm) are close to or within our level of acceptability. Thus, acceptable LIDAR accuracies for GCMRC monitoring of bare-sand deposits can be achieved by high-resolution LIDAR, but use of the data will require "ground control" areas within various river reaches and thus LIDAR has assumed one of the main disadvantages of the photogrammetric approach.

The mean error in the photogrammetry data for bare sand is -3 cm ± 33 cm, whereas the mean absolute error (vertical accuracy) is 17 cm ± 28 cm, which is close to the *preferred* vertical accuracy for GCMRC sediment monitoring and better than the 25-cm accuracy found in some previous studies (Blank, 2000; Gomez Pereira and Wicherson, 1999).

On cobble bars, we found the unadjusted vertical accuracies in ALMS and RAMS data to be 29 cm ± 25 cm and 18 cm ± 17 cm, respectively. The adjusted vertical accuracies (using bare-sand offsets) are not appreciably different. The RAMS data for cobble bars appear to be as accurate as the data obtained for smooth, bare-sand surfaces. Photogrammetric data on cobble bars were found to have a vertical accuracy of 11 cm ± 11 cm. This error is comparable to the photogrammetric errors found on bare-sand surfaces and is much lower than the LIDAR errors on cobble surfaces.

Vertical accuracy within vegetation

We examined photogrammetry and LIDAR elevation data within our vegetated terrain to determine the accuracies of these data for producing reliable bare-ground elevations. 475-700 surveyed ground elevations within vegetated parts of our four study areas were used in this evaluation. LIDAR elevations were adjusted for their bare-ground vertical offsets. Only one LIDAR survey (ALMS) in just one study area produced a vertical accuracy less than 20 cm. ALMS LIDAR provided higher vertical accuracies in the vegetated terrain than the RAMS LIDAR; a larger fraction of the RAMS elevations points fall far above the bare-ground surfaces than do the ALMS elevations. The higher ALMS accuracies in our vegetated terrain can only be attributed to its March acquisition date, when leaf-off conditions prevail in the upper Colorado River ecosystem. The vertical accuracy of the photogrammetry data within the vegetated terrain (37 cm) is not at our level of acceptable (≤20 cm) vertical accuracy. However, its vertical accuracy is 2-4 times better than that provided by the LIDAR data. The continuous, high-resolution imagery used in photogrammetry better samples bare ground within vegetated areas. Part of the photogrammetric error is due to a small, anomalous elevation mound erroneously produced by the contouring procedure.

One reason we selected the RAMS system for our tests was the detector's purported ability to distinguish multiple returns from a single laser pulse. However, within our four study areas only 0.2% of the RAMS first returns had corresponding second returns, even though a large proportion of the vegetation is 4-6 m high. We examined the RAMS second-return elevations to determine their ability to map bare ground in our vegetated regions. Because we did not ground survey the second-return data, we had to compare the second-return elevations with first-return elevations from nearby, unambiguous bare-ground. These data show that the average absolute difference between the second-return elevations and nearby first-return "ground" elevations is 32 cm. Although this error is greater than that found for the RAMS data on bare-sand surfaces (22 cm), it is significantly lower than the 147 cm error found for the RAMS first-return elevations in this vegetated terrain. This error is also comparable to the error found for the photogrammetry data (37 cm). This result might suggest LIDAR systems capable of recording multiple returns could compete with photogrammetry in vegetated terrain, however, many of the vegetation stands within our study areas average 5-6 m in height, but very few second returns were recorded within or even along the perimeters of these stands. The paucity of LIDAR second returns produced in this ecosystem suggests that LIDAR (at least the RAMS system) may not provide better ground topographic mapping than photogrammetry in this environment. In addition, the most ambiguous LIDAR results are obtained on sand surfaces with numerous, scattered willow and arrowweed bushes, which are common in this ecosystem. These bushes are ≤2 m high, have a low branch density, and are difficult to discern in the 18-cm to 30-cm panchromatic imagery that is commonly collected with LIDAR data. As a result, LIDAR topography in such terrain appears quite irregular, similar to that produced by a boulder field. Removal of the LIDAR points that *probably* hit the bushes is extremely time consuming due to the difficulty in unambiguously determining where the bushes are within low-resolution panchromatic image data. Photogrammetry generally collects very high resolution (about 5 cm) CIR or natural-color imagery for GCMRC monitoring purposes, in which the scattered bushes can easily be discerned and mass points can be unambiguously identified. Although more accurate ground elevations within riparian vegetation might be obtained by even higher resolution LIDAR data (e.g., spot spacing of ≤1 m and spot diameter of ≤0.25 m), such data will require a lower flight AGL, may preclude simultaneous image acquisition due to higher ground velocities, and will no doubt greatly increase collection costs.

Reproducibility

Reproducibility of topographic data is important for monitoring changes within the Colorado River ecosystem. We assessed the reproducibility (precision) of the high resolution RAMS LIDAR data that were acquired for the study areas at two separate times using the same instrument and flight conditions. On bare-ground surfaces, the unadjusted mean absolute differences between the two data sets are in the range of 10-34 cm, whereas the adjusted mean absolute differences are in the range of 9-26 cm. On vegetated surfaces, the unadjusted and the adjusted mean absolute differences between the data sets are in the range of 23-87 cm. In terms of monitoring ground topography within vegetation, the precision found in the RAMS data are unacceptable.

Brock and Sallenger (2001) determined that aircraft location and pointing need to be known to within 5 cm to obtain height accuracies of 10 cm. When we pressed selected commercial LIDAR companies to obtain *absolute* vertical accuracies of 15 cm, we were told that current IMU technology does not provide such accuracies and that significant ground control would be needed during the data collection to ensure this level of accuracy. This of course will significantly increase LIDAR collection costs.

Sediment volume accuracy

One reason topography is measured in the Colorado River ecosystem is to monitor the volumetric changes of the sediment deposits as a function of dam flow regime. To determine the effect that the observed airborne elevation accuracies have on estimating the volume of sediment, we selected sites with the densest ground surveys within bare-sand and vegetated-sand deposits. Our analyses addressed three questions related to estimating terrestrial sediment volume from airborne elevation data. (1) How do the volume errors differ between bare ground and vegetated ground? (2) What is the effect on volume error in ignoring elevation points within vegetation, where vertical accuracies are lowest in airborne data? (3) Do any of the data sets meet or even closely approach the 3% accuracy in volume estimates that is currently obtained by ground surveys?

For these assessments, two DEMs were generated from each LIDAR point coverage. The first LIDAR DEM excluded all first-return elevations in vegetated areas, but, in the case of the RAMS data, second-return data points were included in the DEM generation. The second LIDAR DEM did not exclude any first return data points, unless there was a second return. The average elevation along the lower-elevation shoreline of each DEM was used as the base datum for calculating sediment volume of each 25-cm DEM cell. The sediment volume from a particular DEM was determined by summing the cell volumes within that DEM. For each test site, the ground-surveyed volume was subtracted from a particular airborne-derived volume; this volume difference divided by the ground-surveyed volume produced the percent volume difference or error.

The results show that almost all LIDAR and photogrammetry data produce larger volumetric errors on vegetated ground than on bare ground. Volumetric errors for bare ground, vegetated ground, and total ground are mostly lower when both bare- and vegetated-ground data are used to estimate volume, which suggests that the topographic modulations in the vegetated terrain exceed the vertical elevation errors in the airborne data. Most of the LIDAR volumetric errors that are less than 3% were obtained on the bare-ground surfaces. On the other hand, the volumetric errors from the photogrammetry data in our bare-ground and total-ground assessments were less than 3% and the volumetric errors in vegetated terrain were in the range of 3.5% to 9.6%.

CONCLUSIONS

Considering the vertical elevation and volumetric accuracies provided by LIDAR and photogrammetry for both bare and vegetated ground, we have to conclude that photogrammetry provides better data for monitoring, but also requires more careful processing to satisfy the stringent GCMRC accuracy requirements for monitoring the sediment deposits within the Colorado River ecosystem.

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