Measuring Real-World Ground Distance Using High-Spatial Resolution Remotely Sensed Data: A Student-Focused Hands-on Study

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Abstract

Students under the direction of geospatial science faculty, 30 real-world distances were measured on the campus of Stephen F. Austin State University in the field with tape. Students were then instructed on how to measure all 30 real-world features remotely using drone imagery, point cloud data, pictometry data and the Google Earth Pro online interface. Real-world measurements were compared to remote sensing measurements taken by the students to calculate the root mean square error (RMSE). In addition, an ANOVA was conducted on the absolute errors to determine the statistical significance of the variation among the remotely sensed methods, while a Tukey test was performed to assess the statistical significance between the methods. Students discovered that the RMSE results indicate that the pictometry measurements were the most accurate, with an RMSE of 0.68 meters, and that the point cloud data were the least accurate, with an RMSE of 1.27 meters. The ANOVA results indicate that there was a significant difference in the mean absolute error among the methods, whereas the point cloud data, with a mean absolute error of 1.0423 meters, were significantly less accurate than those of the other methods, which was confirmed by the Tukey test.

Keywords: distance measurements, drone, LiDAR point cloud, pictometry, Google Earth Pro

1. Introduction

The focus of the geospatial science program within the Arthur Temple College of Forestry (ATCFA) at Stephen F. Austin State University (SFASU) is to train students on how to accurately quantify natural resources by cutting-edge geospatial science technology. The use of high spatial resolution data to measure real-world ground distance, which continues to advance within the broad geospatial science community, is a highly sought-after skill of employers in both civilian and government workforces.

Students during a semester long geospatial science class were introduced to the utility of using high spatial resolution raster datasets available from drone imagery, point cloud data, pictometry data, and the Google Earth Pro online interface through the use of a faculty-led student-focused hands-on undergraduate research study. The ability to measure real-world distances remotely, in lieu of on-site measurements, continues to show promise as an alternative to physically measuring distance in the field.

It is important that students in their educational endeavors understand the utility of each of these remotely sensed methods for measuring real-world ground distance. Distance measurements in the field can be time consuming and expensive. As an alternative, drone imagery, point cloud data, pictometry data, and the Google Earth Pro online interface may provide alternatives to in situ measurements.

The lengths of 30 real-world features on the campus of the SFASU were measured by undergraduate students in the field with tape. Students were then instructed on how to measure corresponding distances remotely using drone imagery, point cloud data, pictometry data, and the Google Earth Pro online interface. The undergraduate students then compared the real-world measurements to the remotely sensed measurements for accuracy.

2. Background

2.1 Real-World Surface Measurements

The actual surface distance between two real-world locations is important for effective natural resource management activities. Knowing the real-world length of objects on the Earth's surface is important for foresters or natural resource managers dealing with the management of the landscape and its surface features. For example, to create an effective management plan for a forest stand, knowing the real-world length of the sides of any forest stand is essential (Unger et al., 2013; Unger, 2014). Although real-world linear measurements can be measured in situ with tape, this approach can be time consuming and expensive for a large geographic area when a high number of real-world measurements are necessary (Unger et al., 2013; Unger, Kulhavy, Hung, & Zhang, 2014).

With the continued advancement of geospatial science within the last decade, imagery acquired from user-controlled drones, point cloud data, pictometry data, and the Google Earth Pro online interface has continued to show promise as an alternative to in situ measurements.

2.2 Measurements Using Drone Data

As drones continue to advance and become more affordable and prevalent within forest and natural resource communities, real-world measurements continue to be obtained from georectified drone imagery. However, the following questions remain: are the measurements obtained from drone imagery as accurate as real-world ground measurements? The main advantage of using drone imagery to obtain real-world measurements is that on-screen drone image measurements allow for the most recent imagery available to be used, making drone imagery measurements more temporally consistent than any other remotely sensed digital data source.

2.3 Measurements Using LiDAR Point Cloud Data

Point cloud data from light detection and ranging (LiDAR) data have been used in aerial scanning for heights and elevations of landscape features, including trees (Maltamo, Hyyppa, & Malinen, 2006; Gatziolis, Fried, & Monleon, 2010; Sibona et al. 2017). Trees in an urban environment were measured within 0.92 to 0.96 similarity, comparing LiDAR point cloud data to field height measurements (O'Beirne, 2012). Additionally, LiDAR has been integrated into height measurements in geospatial sciences coursework at the Arthur Temple College of Forestry and Agriculture (ATCFA) at SFASU. LiDAR point cloud data have been used to compare building heights with Pictometry hyperspatial imagery and a laser rangefinder; there was no difference in height between Pictometry and the laser rangefinder, but there was a significant difference between Pictometry and LiDAR point cloud data (Kulhavy, Unger, Hung, & Douglass, 2014). Point cloud measurements of heights from LiDAR data tended to be greater than actual heights, where the data source was from both UAV-LiDAR and aircraft LiDAR (Ganz, Kaber, & Adler, 2019). The intensity of the LiDAR dataset, collected at each point, is the strength of the laser pulse at that point based in part on the reflectivity of the object struck by the laser pulse. ArcGIS provides the ability to create intensity imagery from LiDAR data using the Create LAS Dataset geoprocessing tool to construct an LAS dataset.

2.4 Measurements Using Pictometry Data

The pictometry data used are hyperspatial resolution multispectral data available from Pictometry (Pictometry International Corporation, now merged with EagleView Technologies, Bothell, WA) in a web-based interface for linear measurements on the Earth's surface. Pictometry data are acquired using low-flying aircraft to obtain individual images that are merged to create a georeferenced orthomosaic image allowing for the estimation of surface object dimensions within a matter of seconds through the Pictometry web-based interface (Dailey, 2008; Wang, Schultz, & Giuffrida, 2008). Pictometry data, which can be assessed through a user-friendly interface for a small fee based on spatial location specificity, can be used to measure the height, length, slope, and area of real-world objects on the Earth's surface (Unger, Kulhavy, Williams, Creech, & Hung, 2015; Unger, Hung, & Kulhavy, 2014; Kulhavy, Unger, Hung, & Douglass, 2014; Kulhavy, Unger, Zhang, Bedford, & Hung 2016; Unger, Kulhavy, Hung, & Zhang, 2016; Unger, 2016).

2.5 Measurements Using Google Earth Pro Data

Google Earth Pro (Google, LLC, Mountain View, CA) is a free, internet-based platform that provides users with high spatial resolution remotely sensed data. It is accessible through internet connections and has no licensing requirements that other commercial applications may impose. Google Earth Pro provides a simple user-friendly easy-to-learn interface, creating a faster learning environment and facilitating its use for undergraduate students (Lisle, 2006; Hu et al., 2013; Patterson, 2007). Google Earth Pro imagery is acquired using multispectral cameras in satellites to capture images that are used to create global georeferenced orthomosaic images available for users (Goodchild, 2008; Henley, Unger, Kulhavy, & Hung, 2016; Viegut, Kulhavy, Unger, Hung, & Humphreys, 2018).

3. Methods

3.1 Study Site

The football stadium complex on the campus of Stephen F. Austin State University (SFASU) was chosen as the study site to evaluate the accuracy of distance measurements within corresponding drone imagery, point cloud data, pictometry data and the Google Earth Pro online interface (Figure 1). The SFASU football stadium was chosen because of its open space, its many clear ground markings and features and because it is easily accessible by the undergraduate students involved with this student focused hands-on study. In addition, distance can be easily measured on site, and the least distortion occurs in any remotely sensed image.

Figure 1. Football stadium complex on the campus of Stephen F. Austin State University

3.2 Real-World Measurements

Thirty real-world linear features within the football stadium complex were chosen by the undergraduate students. The participants were stratified at multiple locations within the football stadium complex and at various angles relative to each other to ensure that corresponding remotely sensed measurements were not dependent on one cardinal direction. Once identified, the students measured the lengths of all real-world features in the field to hundreds of meters long using tape.

3.3 Remotely Sensed Drone Measurements

Drone imagery of the SFASU football stadium complex was obtained using a DJI Phantom 4 Pro drone and flown by trained SFASU student drone pilots. The drone was flown to obtain images of the entire area using Pix4Dmapper software. Once obtained, the individual drone images were combined to create an orthophoto mosaic of the entire football stadium complex using Drone2Map software. The resulting orthophoto mosaic was uploaded into ArcMap software, where each corresponding real-world feature was identified and measured on-screen for length in meters (Figure 2).

3.4 Remotely Sensed LiDAR Point Cloud Measurements

A point cloud dataset was acquired in August 2017 using a small-footprint LiDAR system that captured discrete multiple return data with a density of 5.67 points/m^2. The point cloud data were viewed in the LP360 software program for the intensity of each point, where the linear features were identified. Then, on-screen measurements were taken for the length of each of the 30 features (Figure 3).

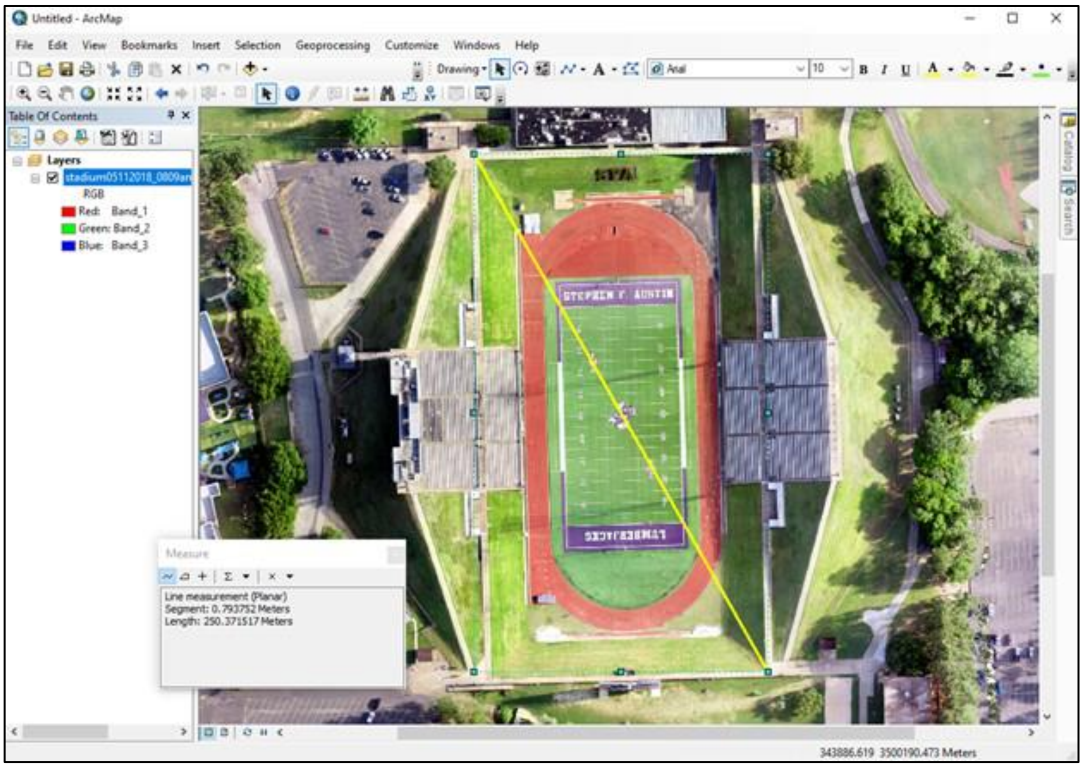

Figure 2. Distance was measured using drone imagery covering the football stadium complex of SFASU

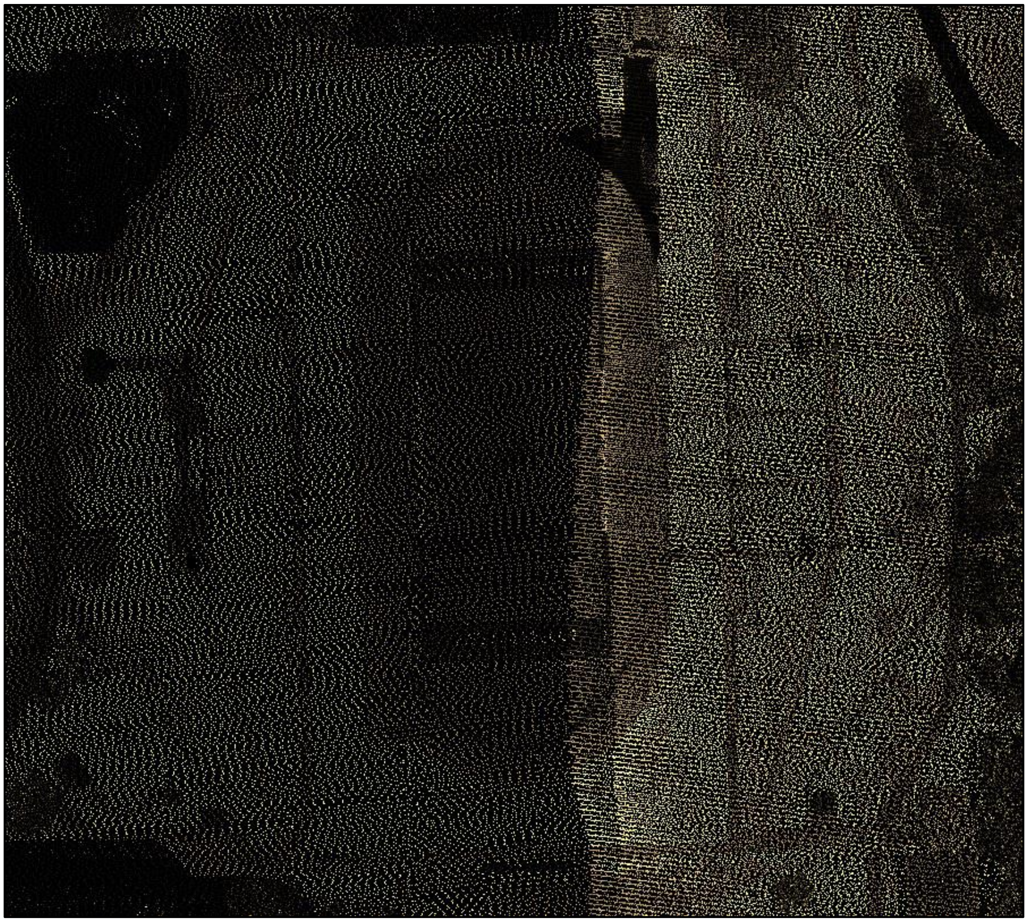

Figure 3. Distance was measured using intensity data from a LiDAR point cloud covering the football stadium complex

3.5 Remotely Sensed Pictometry Measurements

In 2013 and 2016, SFASU acquired the right to use pictometry data in partnership with the County of Nacogdoches 911 District, the City of Nacogdoches, Texas, and the Nacogdoches County Appraisal District. The purchase agreement includes pictometry data covering the city of Nacogdoches at a 10.2 cm spatial resolution in 2013 and the entire county of Nacogdoches at a 23.0 cm spatial resolution in 2013 and 2016. The undergraduate students were introduced to the online pictometry interface, which is very user friendly and allows users to measure height, length, slope, and the area of earth surface objects viewable within the online interface. Pictometry data, with the online user interface, were loaded onto a computer monitor, where the length of all 30 real-world features was measured by the students on the screen in meters (Figure 4).

3.6 Remotely Sensed Google Earth Pro Measurements

Google Earth Pro, which was developed by Google, Inc. (Mountain View, California), is user friendly and has an intuitive interface for learning and integrating into natural resource education for distance measurement (Viegut, Kulhavy, Unger, Hung, & Humphreys, 2018; Henley, Unger, Kulhavy, & Hung 2016). Google Earth Pro is a geospatial science-based software platform that students use on campus on a daily basis due to its ease of manipulation, powerful functions, and high spatial resolution imagery. Google Earth Pro was loaded into a computer monitor, and the lengths of all 30 real-world features were measured on the screen in meters (Figure 5).

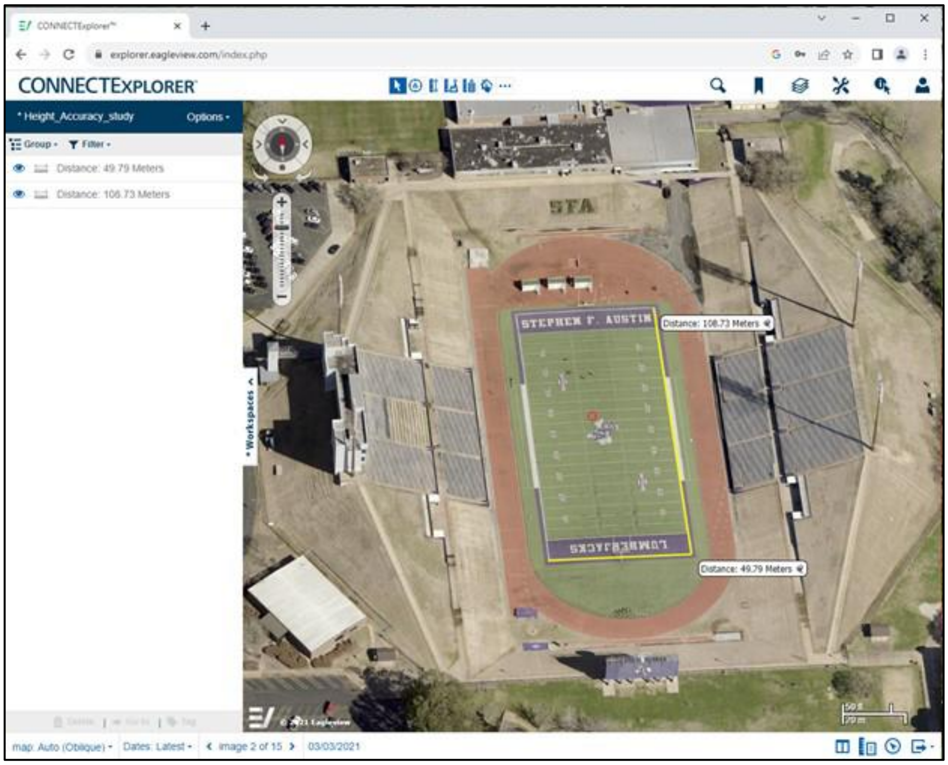

Figure 4. Distance was measured using pictometry data covering the football stadium complex

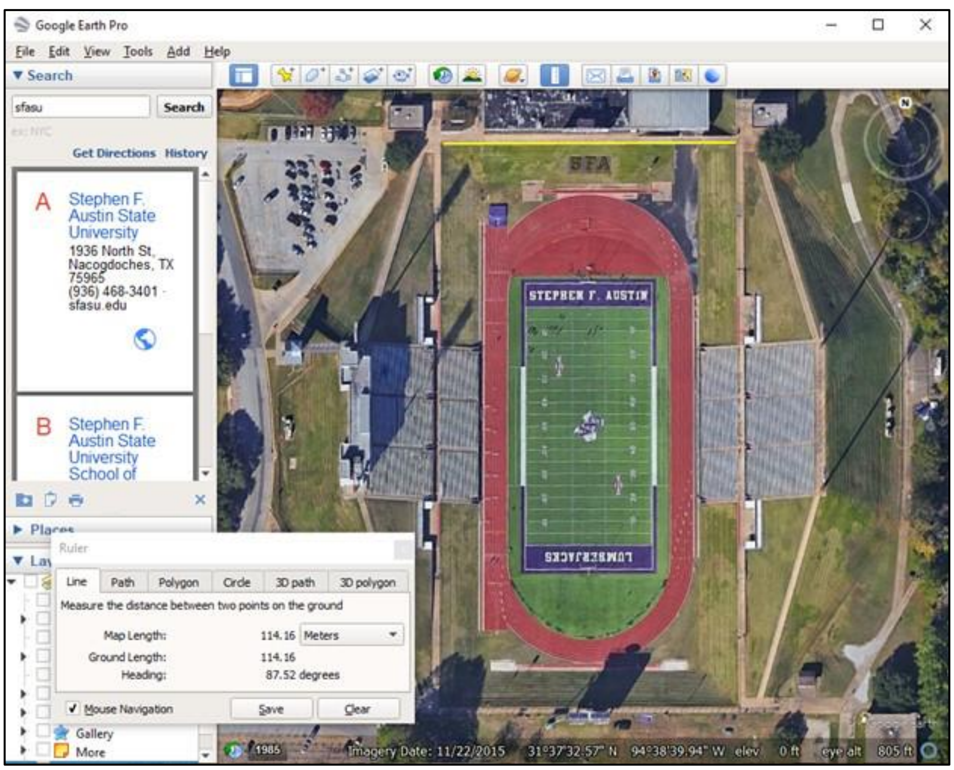

Figure 5. Distance measurement using Google Earth Pro covering the football stadium complex

3.7 Statistical Analysis

To assess the accuracy of the remotely sensed measurements, real-world measurements were compared to remotely sensed measurements to determine the measurement errors, that is, the difference between a remote sensing measurement and its actual length measured with a tape on the ground. Then, the mean error and the root mean square error (RMSE) for each remote sensing method were calculated. In addition, an analysis of variance (ANOVA) of the absolute errors was conducted to determine the statistical significance of the variation between the remote sensing methods. If a significant difference in the mean absolute error was found among the methods, a Tukey test was performed to assess the statistical significance of the difference between the methods.

Table 1. Linear measurements by methods used and their error statistics

Line Feature	LiDAR Intensity	Drone	Pictometry	Google Earth Pro	Ground Truth
(ID)	(Meters)				
L1	114.99	114.87	115.37	115.07	115.55
L2	49.30	48.69	48.56	48.68	48.70
L3	49.01	48.63	48.56	48.67	48.52
L4	84.86	85.14	85.51	85.41	85.11
L5	49.64	48.68	48.56	48.64	48.49
L6	216.18	217.00	218.91	217.18	218.2
L7	99.20	100.04	99.87	100.02	100.3
L8	77.33	77.88	77.64	76.09	79.11
L9	38.91	39.04	38.94	38.88	38.74
L10	61	59.53	59.66	59.47	59.61
L11	114.6	113.30	113.09	113.34	114.11
L12	244.76	245.74	246.66	245.6	246.91
L13	62.53	62.19	62.76	62.28	62.92
L14	75.27	74.17	74.76	74.22	74.03
L15	60.05	60.37	59.98	60.49	60.62
L16	87.58	87.52	88.08	87.41	87.51
L17	77.85	77.09	78.72	79.96	79.49
L18	34.62	34.07	34.16	33.97	34.07
L19	71.94	73.77	71.97	72.70	73.27
L20	73.86	73.77	74.84	73.55	74.38
L21	79.72	80.67	80.72	81.13	81.45
L22	57.37	60.19	60.41	60.42	60.38
L23	78.36	78.12	78.17	79.85	79.43
L24	48.56	45.73	45.70	45.74	46.00
L25	43.59	44.03	43.66	43.95	44.43
L26	77.80	78.13	78.62	78.52	78.63
L27	57.63	56.17	57.49	57.76	57.88
L28	47.31	50.11	47.47	48.62	48.5
L29	157.12	156.08	156.97	157.36	156.33
L30	44.43	44.12	45.07	45.00	43.89
Mean Error	-0.37	-0.39	-0.19	-0.22	
RMSE	1.27	0.84	0.68	0.77	

4. Results

All of the distance measurements are reported in Table 1, where the mean error and RMSE for each remote sensing method are included. While close to zero, all the mean error values are negative, ranging from -0.39 to -0.22 meters, indicating that all the remote sensing methods underestimated the distance as a whole. The RMSE results indicate that the pictometry measurements were the most accurate, with an RMSE of 0.68 m, and the intensity of the LiDAR point cloud data was the least accurate, with an RMSE of 1.27 m. ANOVA resulted in a p value of 0.00163, indicating that there was a significant difference among the mean absolute errors of the different remote sensing methods (Table 2). The following Tukey test revealed that the LiDAR point cloud is the least accurate, with a mean absolute error of 1.0423 meters, whereas drone, pictometry, and Google Earth Pro performed differently in terms of accuracy (Table 3).

Table 2. Analysis of variance of the absolute errors by method used (unit: meter)

SUMMARY						
Groups	Count	Sum	Average	Variance		
LiDAR Intensity	30	31.27	1.0423	0.537191		
Drone	30	17.96	0.5987	0.357715		
Pictometry	30	16.02	0.534	0.181866		
Google Earth Pro	30	14.82	0.494	0.353852		
ANOVA						
Source of Variation	SS	df	MS	F	P value	F crit
Between Groups	5.794869	3	1.931623	5.400781	0.00163	2.682809
Within Groups	41.48812	116	0.357656			
Total	47.28299	119				

Table 3. For pairwise comparisons, Tukey's test was used to evaluate the mean absolute error (unit: meter)

Method	Letters	Least Sq Mean	Std Error	Lower 95%	Upper 95%
LiDAR Intensity	A	1.0423	0.1092	0.8261	1.2586
Drone	B	0.5987	0.1092	0.3824	0.8149
Pictometry	B	0.534	0.1092	0.3177	0.7503
Google Earth Pro	B	0.494	0.1092	0.2777	0.7103

5. Discussion

Our results indicate that remotely sensed data collected within a focused hands-on study can be used to obtain accurate real-world distance measurements. Not only can remotely sensed measurements be accurate and comparable to real-world in situ measurements, but undergraduate students also realize that these measurements can be obtained in a timely and cost-effective manner. Students also learned how to use the intensity of LiDAR data measurements compared to in situ measurements and drone images. The intensity from LiDAR data increases with the number of autonomous vehicles, which senses the magnitude of the reflectance of lines on the surface of the road (Jeong, & Kim, 2018). Lane markings are essential in autonomous vehicle applications, and lane marking extractions are essential in transportation applications (Cheng, Patel, Wen, Bullock, & Habib, 2020). For ease of mapping, color point clouds can be developed from LiDAR point clouds (Peng, Hsu, & Wang, 2020). The close agreement of the pictometry, drone and Google Earth-derived data indicates that these remote sensing tools can be used as guides for obtaining point cloud intensity data from LiDAR. As the use of lidar point cloud intensity data for distance measurements increases, remotely sensed in situ data can be used as a guideline for ensuring the accuracy of the data. The students learned that their close agreement with the drone data from the DJI Phantom 4 Pro version 2, Pictometry and Google Earth Pro indicate the usefulness of drone-derived data in distance measurements.

6. Conclusions

The ease of remotely sensed length and area estimation demonstrated by undergraduate students using the web-based Pictometry interface, Google Earth Pro interface, and DJI Phantom 4 Pro data with ArcMap 10.5.2 software reinforces the use of these methods to remotely estimate length and area in lieu of in situ assessments. Tukey pairwise tests revealed that the accuracy of the linear length measurements was significantly the same for the remotely sensed Pictometry web-based interface, the Google Earth Pro interface, and the DJI Phantom 4 Pro data in the ArcMap 10.5.2 interface, while the accuracy of the LiDAR point cloud was significantly less accurate. The results indicate that linear estimates within the ready-to-use Pictometry web-based interface and Google Earth Pro could be used in lieu of time-consuming or more costly drone flights or even in situ linear measurements. Per the results, any of the three methods used in the study will achieve the same level of accuracy statistically for estimations of length measurements. When available, the drone can be user controlled and can fly at a given time and place at the discretion of the user.

The teaching methodology employed by faculty within ATCFA focuses on students learning geospatial science technology within an interactive hands-on environment. These results validate that the teaching methodology employed by faculty within ATCFA is highly effective in training undergraduate students in proper techniques to obtain accurate real-world measurements using high spatial resolution raster data. The field of geospatial science by definition is highly technical in nature and the effectiveness of instruction employed within ATCFA is displayed by this student led technical method paper. By integrating students in an interactive hands-on study, faculty at SFASU are able to train students to be more effective employees immediately upon graduation.

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