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Accuracy Assessment of Measuring Linear and Areal Features in Aerial Imagery

I-Kuai Hung
Stephen F. Austin State University, hungi@sfasu.edu

David L. Kulhavy
Stephen F. Austin State University, dkulhavy@sfasu.edu

Daniel R. Unger
Stephen F. Austin State University, unger@sfasu.edu

Reid A. Viegut

Yanli Zhang
Stephen F. Austin State University, zhangy2@sfasu.edu

See next page for additional authors

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Accuracy Assessment of Measuring Linear and Areal Features in Aerial Imagery

Abstract

As part of natural resource education in the Arthur Temple College of Forestry and Agriculture at Stephen F. Austin State University (SFASU), students were instructed to take areal and linear measurements of grounds remotely using available platforms including aerial orthomosaic derived from UAS (unmanned aerial system) acquired imagery, Google Earth Pro, and Pictometry. The onscreen measurement was conducted at five different map scales, 1/1000, 1/2000, 1/3000, 1/4000, and 1/5000. Accuracy of the measurements was assessed by comparing the onscreen measurements to ground truth data verified with a measuring tape. Results show that measurements based on the UAS were more accurate than other platforms at all scales, resulting in lower RMSE (root mean square error). However, this advantage diminished when the scale approached 1/5000 where features were too small to identify onscreen. This scale related accuracy is more profound with Google Earth Pro. Overall, all three platforms performed its best at the 1/1000 scale, while accuracy decreased when an image was zoomed out to a smaller scale. All three platforms can be used with confidence at the 1/3000 scale or larger such as 1/1000 or 1/2000. For linear measurements, UAS was significantly more accurate than others. For areal measurements, Pictometry was significantly less accurate than others.

Keywords

Feature measurement, Aerial imagery, Accuracy assessment

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Authors

I-Kuai Hung, David L. Kulhavy, Daniel R. Unger, Reid A. Viegut, Yanli Zhang, and Nicholas C. Schiwitz

1 INTRODUCTION

Linear and areal measurements of Earth's surface features can be conducted remotely from individual aerial images or an orthomosaic map derived from the unmanned aerial system (UAS) (Viegut et al. 2018; Unger et al. 2019). As this technology is developed, the measurement at varying scales is important in the use of UAS for natural resource measurements. Linear and vertical measurements (i.e., height) are traditionally obtained in situ through GPS units and other measurement devices; however, these methods are labor intensive and costly when used over a large geographical range (Unger et al. 2013; Unger et al. 2014). Thus, remote sensing applications have been developed to efficiently obtain information about the Earth's surface. Multiple sources of aerial imagery are available to efficiently collect measurements of features on the Earth's surface. They can be used for planning purposes, such as estimating total area for a landscaping project, estimating the needed concrete for a pavement job, and estimating the number of tree seedlings needed for a new forest stand. Although not for replacing ground measurement by a professional land surveyor, accurate measurement on features with these imagery platforms is essential, and it is beneficial to quantify the differences in accuracy across the platforms so that an appropriate platform can be chosen.

There are multiple platforms with which high resolution imagery collected through remote sensing can be accessed. Orthophoto mosaics can be acquired in a matter of hours for use in both laboratory and field measurements (Viegut et al. 2018; Kulhavy et al. 2021). UAS data collection is becoming increasingly prevalent in the natural resource field (Shahbazi et al. 2014). While these images may be beneficial, some images may not be up-to-date resulting in certain features to be absent from these images (Unger et al. 2013). Thus, the use of UAS for surface measurements is beneficial to quickly acquire accurate and up-to-date aerial images that can be used for efficient data collection (Viegut et al. 2018). With the advancement in Deep Learning technology, more algorithms have been developed for geometric measurements on surface features with UAS data (Wang and Bryson 2023).

Google Earth Pro (Google, LLC, Mountain View, CA) is an internet-based platform that provides remotely sensed high resolution data to global users at no cost. Google Earth Pro imagery is acquired through multispectral sensor satellites that capture images of the Earth's surface. These images are used to create georeferenced, orthomosaic images available for users to access in the Google Earth Pro internet-based interface (Goodchild 2008; Henley et al. 2016). Google Earth Pro provides a user-friendly interface that is simple to navigate, allowing for easy data collection to individuals new to remote sensing (Viegut et al. 2018). On the other hand, Pictometry (Pictometry International Corporation, merged with EagleView Technologies, Bothell, WA) is a subscription based online platform that provides hyperspatial resolution multispectral and oblique data through a web interface. Pictometry data are acquired through the use of low-flying aircrafts that obtain images. The orthomosaic allows for estimation of land feature measurements within seconds through the use of the Pictometry web-based interface (Dailey 2008; Gerke & Kerle 2011; Wang et al. 2008). Pictometry was used to accurately measure surface features and integrated data into student-led measurements of natural resources (Unger et al. 2016; Kulhavy et al. 2018).

When viewing remotely sensed data, the scale of the image displayed on screen also plays an important role. This is coupled with the image resolution itself. Interest is increasing in the application of high-resolution and multispectral images acquired from UAS (Shahbazi et al. 2014). This study was aimed to compare the accuracy on linear and areal measurements between different platforms, UAS, Google Earth Pro, and Pictometry. As onscreen measurement can be conducted at different map scales that might affect the accuracy, different map scales, 1/1000, 1/2000, 1/3000, 1/4000, and 1/5000 were also compared across the different platforms. With the statistical analysis on the measurement errors, the results can inform users the accuracy level one can expect when choosing a platform to measure surface features remotely.

2 METHODS

2.1 Study Area

This study evaluated the use of UAS, Google Earth Pro, and Pictometry imagery to estimate the horizontal ground distance and ground area of lines and polygon features in the Stephen F. Austin State University (SFASU) Commuter Parking Lot in Nacogdoches, Texas (Figure 1). The parking lot was located at the intersection of East College Street and North University Drive on SFASU campus. The SFASU Commuter Parking Lot was chosen due to the proximity and accessibility to students and faculty, and having clearly defined lines that are consistent between the online aerial imagery, imagery obtained with the drone, and tape measurements on the ground.

The objective was to compare the ground distance and ground area of multiple lines and polygons in the parking lot estimated via UAS, Google Earth Pro, and Pictometry to the actual ground distance and area measured *in situ*. The UAS imagery was acquired by flying a DJI Phantom 4 Pro drone. A grid mission was planned on the Pix4DCapture app installed on an iPad. The flight height was set for 67 m (220 ft), with a front overlap of 80% and side overlap of 60%. Photos taken with the drone were processed in ArcGIS Drone2Map that resulted in an orthophoto mosaic with 2.7 cm spatial resolution. The onscreen measurement with the UAS data was conducted with ArcMap. The Google Earth Pro program was used for onscreen measurement with the available image closest to the time of ground measurement that had the highest resolution of 15.0 cm. The CONNECTExplorer web interface hosting Pictometry data was used for taking measurements on screen using its 15.2 cm spatial resolution imagery.

Figure 1. Commuter Parking Lot used as the study site on the SFASU Campus.

2.2 Length and Area Measurements

Field measurements using a measuring tape of the parking lot included recording the length of 30 lines and the area of 30 rectangles guided by lines already present in the parking lot. Measurements were recorded with a 300-foot (91.44-m) tape and were rounded to the nearest tenth of a foot (3.048 cm). These measurements served as the baseline measurements that all other records were compared to in the statistical analyses. Onscreen measurements were recorded in ArcMap with the drone derived aerial orthophoto mosaic loaded as the base map, as well as Google Earth Pro and Pictometry online interfaces. Lengths and areas were recorded through the measurement tools provided in each interface. The UAS, Google Earth Pro, and Pictometry feature distances and areas were measured on screen at the scales of 1/1000, 1/2000, 1/3000, 1/4000, and 1/5000, respectively.

3 RESULTS

Data were summarized for all 30 linear feature measurements and 30 areal feature measurements using the UAS derived data, Google Earth Pro data, and Pictometry data compared to in situ field tape measurements at each scale of 1/1000, 1/2000, 1/3000, 1/4000 and 1/5000. For each method at each scale, the measurement error was calculated by taking an onscreen measurement and subtracted the ground measurement of the same feature. Then the root mean square error (RMSE) was calculated using Equation 1, where $Z_{i,est}$ is an onscreen measurement and $Z_{i,act}$ is an ground measurement while n is the total number of measurement per onscreen platform at each scale (n = 30 for this study). Finally, the absolute measurement error values were used to conduct a two-way ANOVA to determine if there was any significant difference on accuracy between different imagery platform and onscreen map scale.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(Z_{i,est} - Z_{i,act}\right)^2} \tag{1}$$

3.1 Linear Measurements

Figure 2 shows a general trend of the error distribution on linear measurements across the three onscreen platforms. The errors were most clustered at the largest map scale (1/1000) and became more dispersed when moving to smaller map scales, with the scale of 1/5000 being the most dispersed. It indicates that when an onscreen image was zoomed out, the uncertainty in finding features increased. As expected, the average of the measurement errors was close to zero for each platform-scale combination, as the positive and negative error values were cancelled out. However, all of the three platforms tended to underestimate the length as a whole, with Google Earth Pro and Pictometry being more significant than UAS in underestimation. A few outliers of overestimation were found in Google Earth Pro and Pictometry. The distribution of linear measurement errors in relation to its accuracy can be verified by the RMSEs. The use of the UAS imagery had consistently higher accuracy at each of the 5 scales with the RMSE ranging from 0.1927 m at 1/1000 to 1.1904 m at 1/5000 (Figure 3). This was followed by Google Earth Pro with the RMSE ranging from 0.5741 m at 1/1000 to 1.9433 m at 1/5000. Pictometry was the least accurate at the scales of 1/000 (RMSE 0.8736 m), 1/2000, and 1/3000 but was superior to Google Earth Pro at the 1/4000 and 1/5000 (RMSE 1.5596 m) scales. Again, there is a general trend. When map scale was increased, accuracy increased.

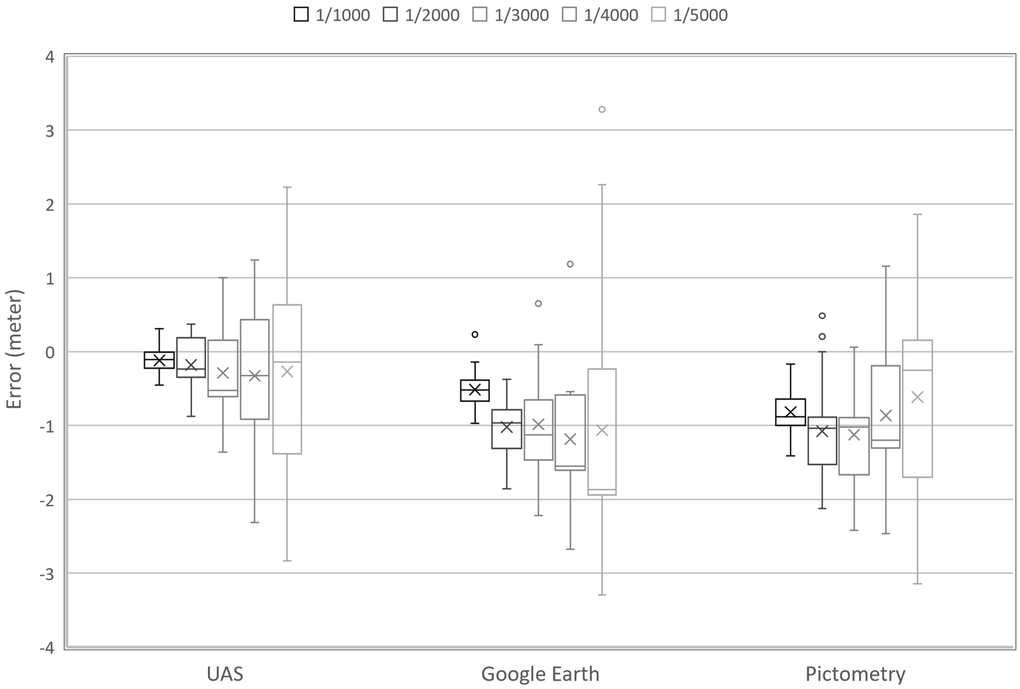

Figure 2. Measurement error distribution for line features by platform and scale.

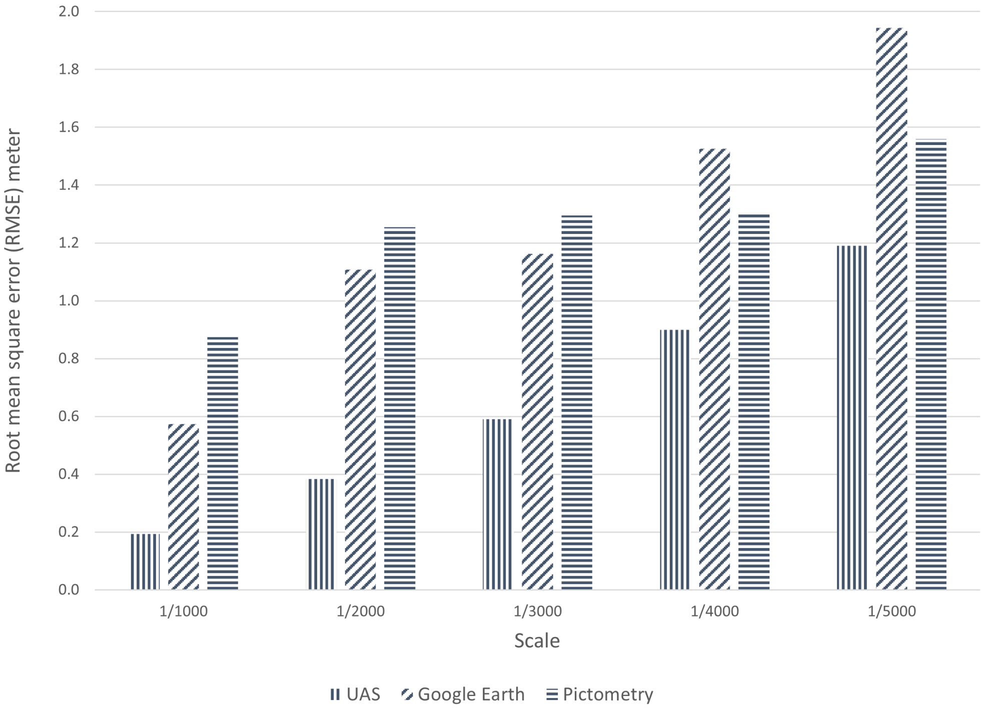

Figure 3. Root mean square error for the linear measurements by platform and scale.

Table 1. Two-factor ANOVA with replication on the absolute errors for the linear features. (Unit: meter)

SUMMARY	1/1000	1/2000	1/3000	1/4000	1/5000	Total
UAS						
Count	30	30	30	30	30	150
Sum	4.559445	9.9857	15.76057	22.17381	28.57423	81.05375
Average	0.151982	0.332857	0.525352	0.739127	0.952474	0.540358
Variance	0.014508	0.038072	0.074385	0.270911	0.52749	0.26134
Google Earth						
Count	30	30	30	30	30	150
Sum	15.91795	30.65128	31.05998	42.73294	55.57771	175.9399
Average	0.530598	1.021709	1.035333	1.424431	1.85259	1.172932
Variance	0.049684	0.190424	0.289103	0.310929	0.356378	0.43011
Pictometry						
Count	30	30	30	30	30	150
Sum	24.51773	33.70311	35.05914	32.67709	37.86148	163.8186
Average	0.817258	1.123437	1.168638	1.089236	1.262049	1.092124
Variance	0.098594	0.320854	0.323944	0.541694	0.868548	0.441567
Total						
Count	90	90	90	90	90	
Sum	44.99513	74.34009	81.87969	97.58384	122.0134	
Average	0.499946	0.826001	0.909774	1.084265	1.355705	
Variance	0.128112	0.303708	0.30171	0.445261	0.711999	

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Sample	35.55625	2	17.77812	62.37184	1.53E-24	3.016458
Columns	36.09554	4	9.023885	31.65892	3.67E-23	2.392445
Interaction	8.73401	8	1.091751	3.830243	0.000228	1.959689
Within	123.99	435	0.285034			
Total	2196.999	449				

In order to determine if the difference in accuracy was statistically significant, a two-factor (image platform and scale) analysis of variance (ANOVA) was conducted on the absolute measurement errors to compare the average values, with lower means deemed to be more accurate. Table 1 shows the ANOVA results on the linear measurements. The distribution of mean absolute errors revealed the same trend found in RMSE, where the accuracy decreased when the image was zoomed out to smaller scales. The only exception was Pictometry. Its accuracy was comparable at all scales. When comparing the three image platforms, UAS consistently performed better than Google Earth Pro and Pictometry at all scales (Figure 4). All of the differences, between the image platforms, between the different scales, and the interaction between the two factors, were statistically significant with a p-value less than 0.01 (Table 1).

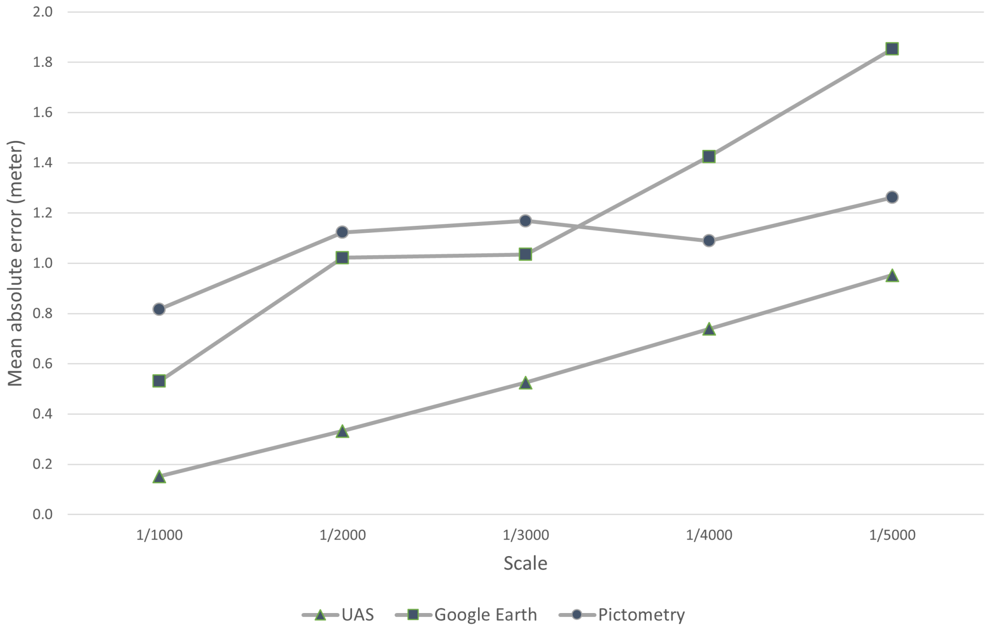

Figure 4. Mean absolute errors for length measurements by platform and scale.

3.2 Areal Measurements

Figure 5 shows a general trend of the error distribution on areal measurements across the three onscreen platforms, similar to what was found with linear measurements where the errors were clustered at large maps scales and dispersed at small map scales. However, Pictometry had a higher level of uncertainty across the different map scales when compared to UAS and Google Earth, except at the 1/5000 scale. When an onscreen image was zoomed in, the uncertainty in finding features is expected to decrease. It does not hold true for Pictometry when taking areal measurements on screen. Unlike linear measurements, the UAS tended to overestimate the area as a whole, while Google Earth and Pictometry were underestimating area. Google Earth and Pictometry were found to have more outliers than UAS. Those outliers were mostly on the underestimate side, revealing that Google Earth and Pictometry would not have the same level of precision and accuracy as UAS for finding features on screen and taking areal measurements. For areal measurements, the same trend was observed where UAS was more accurate than others at all scales, except at 1/5000 scale. Its RMSE ranged from 4.6910 sq m at 1/1000 to 33.0911 sq m at 1/4000 and 52.5548 at 1/5000 (Figure 6). On the other hand, Pictometry performed worst at all scales with its RMSE ranging from 37.7658 sq m at 1/1000 scale to 69.3387 sq m at 1/4000 scale and 53.9637 sq m at 1/5000 scale. At the 1/5000 scale, the accuracy was about the same among UAS, Google Earth Pro, and Pictometry. In general, UAS was found more accurate, followed by Google Earth Pro, whereas Pictometry was the least accurate.

When an onscreen image was zoomed in to display at a larger scale such as 1/1000 instead of 1/5000, the accuracy on linear and areal measurement increased.

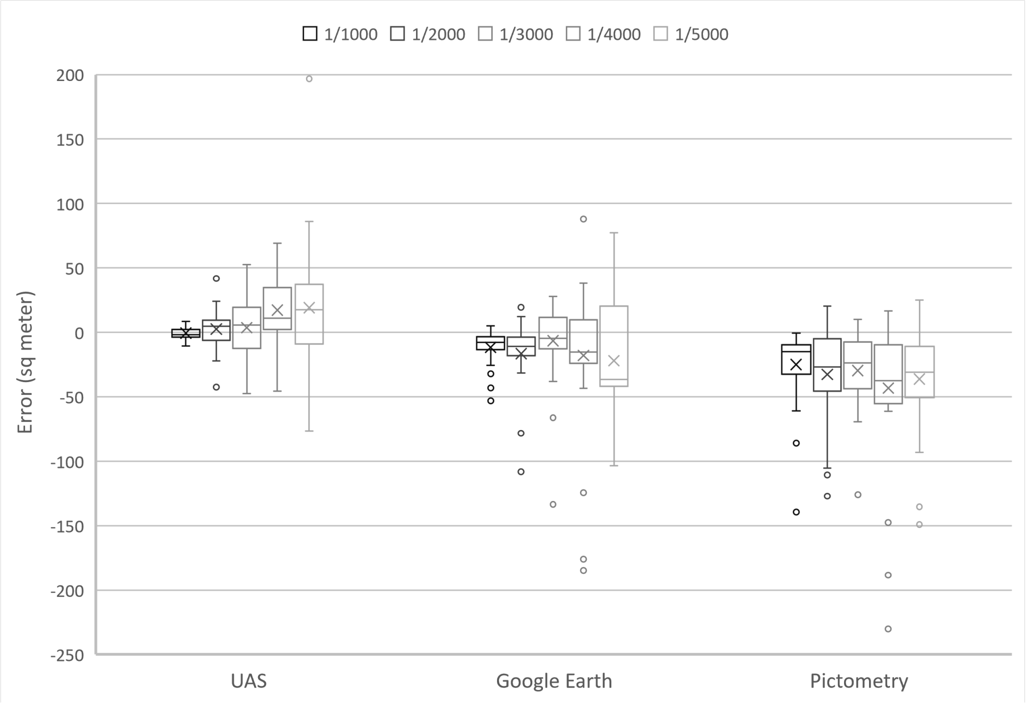

Figure 5. Measurement error distribution for area features by platform and scale.

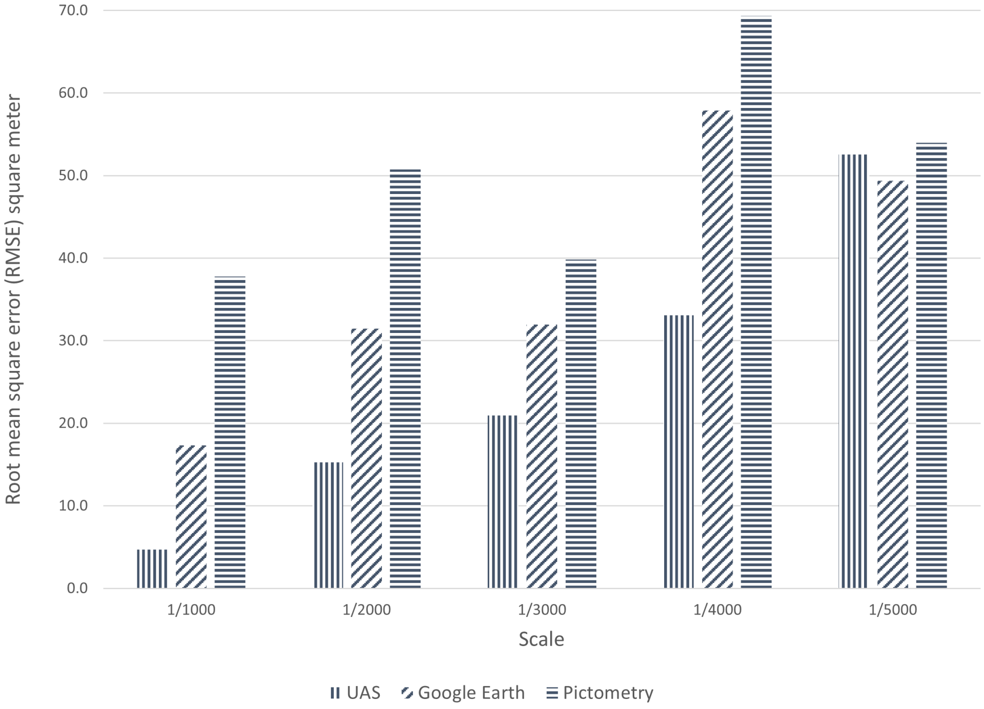

Figure 6. Root mean square error for the areal measurements by platform and scale.

Table 2 shows the ANOVA results on the areal measurements. Again, a general trend was observed, where the accuracy decreased when the image was zoomed out to smaller scales. This time, Pictometry was further apart from UAS and Google Earth Pro in terms of accuracy (Figure 7). However, when the online platform image was zoomed out to 1/5000, the accuracy among the three platforms was about the same. The difference between the image platforms and that between the different scales were found to be statistically significant with a p-value less than 0.01 (Table 2), but not the interaction between the two factors.

Table 2. Two-factor ANOVA with replication on the absolute errors for the areal features. (Unit: sq meter)

SUMMARY	1/1000	1/2000	1/3000	1/4000	1/5000	Total
UAS						
Count	30	30	30	30	30	150
Sum	1295.411	3703.982	5473.9	8412.665	11960.87	30846.82
Average	43.18037	123.4661	182.4633	280.4222	398.6955	205.6455
Variance	708.7628	12122.76	18217.52	49900.18	166612.4	63595.01
Google Earth						
Count	30	30	30	30	30	150
Sum	3872.31	6449.52	6490.37	11478.53	13809.84	42100.57
Average	129.077	214.984	216.3457	382.6177	460.328	280.6705
Variance	18799.3	70886.08	74034.91	250557.5	72965.44	109752.6
Pictometry						
Count	30	30	30	30	30	150
Sum	8059.22	11902.7	9824.62	14737.08	13101.2	57624.82
Average	268.6407	396.7567	327.4873	491.236	436.7067	384.1655
Variance	96293.19	145800.2	79277.5	326630.8	151750	161886.2
Total						
Count	90	90	90	90	90	
Sum	13226.94	22056.2	21788.89	34628.28	38871.91	
Average	146.966	245.0689	242.0988	384.7586	431.9101	
Variance	46462.05	87601.2	59771.83	211824.8	128163.1	

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Image platform	2410467	2	1205234	11.78093	1.04E-05	3.016458
Scale	4850062	4	1212516	11.85211	3.79E-09	2.392445
Interaction	597646.1	8	74705.76	0.730235	0.664824	1.959689
Within	44502138	435	102303.8			
Total	52360313	449				

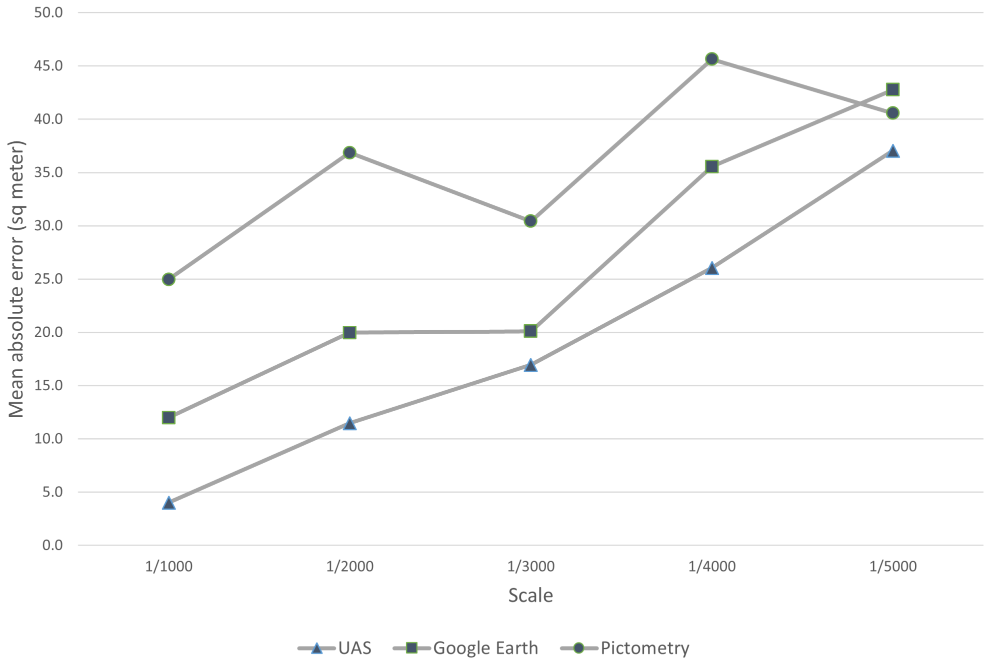

Figure 7. Mean absolute errors for the areal measurements by platform and scale.

4 DISCUSSION

The RMSEs were consistently lower for the UAS platform with imagery acquired through a DJI Phantom 4 Pro drone at all onscreen image scales, compared to both Google Earth Pro and Pictometry. This was attributed to the lower flight height of the drone that resulted in higher spatial resolution on the ground. However, when measuring areas on screen at 1/5000 scale, this advantage of UAS no longer exists as areal features become too small on the screen to be measured precisely. At the scale of 1/5000, all three platforms had consistent RMSE for areal measurements indicating the loss of measurement accuracy at this scale. Cautions should be taken when deciding on what scale to use when taking measurement on screen based on an aerial image. For Google Earth Pro, horizontal accuracy was reported at 1 m across images (Pulighe et al. 2016). For accident reconstruction, Google Earth imagery had an RMSE of 0.57 feet (0.17 m) compared to a total station (Wirth et al. 2015).

The scale related accuracy is more profound with Google Earth Pro. For both linear and areal measurements, its accuracy deteriorated significantly when the scale was reduced to 1/4000 or lower. Google Earth Pro had its best accuracy at 1/1000 and equaled at 1/2000 and 1/3000. As a free access platform, Google Earth Pro is an adequate tool for taking measurements with confidence in accuracy when the scale is set at 1/3000 or larger such as 1/1000 or 1/2000. For Pictometry, the errors for linear measurements were stable across different scales, whereas the errors for areal measurements varied significantly. As expected, Pictometry had its highest accuracy at 1/1000, while it can be measured from 1/1000 to 1/4000 with confidence for linear measurement. However, this confidence does not apply to areal measurements for

Pictometry, where its accuracy was the worst compared to other platforms and was not in line with the scale. When measuring linear features online with Pictometry, the large thickness of the measurement lines covering the feature being measure forced inaccurate measurement, regardless of the resolution of the source imagery. As a paid platform, Pictometry is not as good as an option for taking areal measurement.

Overall, all three platforms performed its best at the 1/1000 scale, while accuracy decreased when an image was zoomed out to a smaller scale. All three can be used with confidence at the 1/3000 scale or larger such as 1/1000 or 1/2000. For linear measurements, UAS was significantly more accurate than others. For areal measurements, Pictometry was significantly less accurate than others. When scales were allowed to vary and go larger than 1/1000, UAS had better accuracy due to higher resolution at these scales (Viegut et al., 2018). As the UAS can record measurements at any given time with a desired flight height below 121.92 m (400 ft), this method adds flexibility to both aerial and areal measurements.

5 CONCLUSIONS

All three methods for both linear and areal measurement were adequate for scales at 1/3000 or larger such as 1/1000 or 1/2000, with varying results at smaller scales such as 1/4000 or 1/5000. In this project, students were able to fly the UAS, construct orthomosaic, and measure distances and areas with little prior instruction. The use of the UAS follows the procedures of the Mentored Undergraduate procedures including UAS safety, UAS flights, use of software to download images to create an orthomosaic and use of the image to make decisions on management throughout the curriculum (Unger et al., 2016; Unger et al., 2019; Williams et al. 2023). The combined skills of onscreen digitization coupled with ground truthing measurements reinforced the concepts of “work outdoors, make a difference and use high end technology” for society ready natural resource managers (Bullard et al., 2014). Coupled with this are maintaining technical rigor, communicating relevant information effectively and building relationships to enhance use of the current technology.

If access to drone imagery is available, the UAS platform will achieve the highest accuracy due to its much higher spatial resolution compared to Google Earth Pro and Pictometry. As of today, even a low-cost drone such as DJI Mini 2 can conduct a preprogrammed flight using an app at no cost such Map Pilot Pro of Maps Made Easy. Images captured by the drone can be processed to produce orthophoto mosaic with freeware such as OpenDroneMap. If feasible, UAS will be the best option for measuring feature geometry remotely. Google Earth Pro is free to use and covers the entire globe. However, its image quality varies from place to place that limits the measurement accuracy, which is also related to the map scale used when taking onscreen measurement. The accuracy of Google Earth Pro is expected to increase as more high-resolution imagery becomes available, while the timing of the most current imaginary is still a limiting factor. Pictometry is a subscription-based service with timely imagery update. Although it allows for measuring height with its oblique imagery that comes with high spatial resolution, the accuracy of its planar measurement of length and area is inconsistent along different map scales. In most cases, its accuracy is not as good as Google Earth Pro.

Findings from this research provides some insights on the accuracy when using an imagery platform for taking measurement on screen. It is important to understand the benefits and limitations when choosing a platform for measuring surface linear and areal features remotely, while ground measurement might be prohibited. More research could be conducted to see how topography and cover type play as a factor that would affect the accuracy of the measurement outcomes.

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