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## Accuracy Assessment of Pictometry® Height Measurements Stratified by Cardinal Direction and Image Magnification Factor

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August 2016

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# Accuracy Assessment of Pictometry® Height Measurements Stratified by Cardinal Direction and Image Magnification Factor

## Abstract

The aim of this project was to ascertain if Pictometry® estimated height could be used in lieu of field-based height estimation. Height of a light pole measured with a telescopic height pole was compared to Pictometry® hyperspatial 4-inch (10.2 centimeters) multispectral imagery estimated light pole height on the campus of Stephen F. Austin State University, Nacogdoches, Texas. Average percent agreement between light pole height and Pictometry® estimated light pole height summarized by Pictometry® image magnification factors at 100%, 125%, 150%, 200%, and 300% magnification were within 98% of light pole height with percent disagreement ranging from 1.37% to 1.90%. RMSE between light pole height and Pictometry® estimated light pole height summarized by Pictometry® image magnification factors at 100%, 125%, 150%, 200%, and 300% magnification ranged from 0.14 meters to 0.17 meters. The results of Kruskal-Wallis test indicated that Pictometry® estimated light pole heights measured at the cardinal directions of north and east were more accurate than the directions of south and west, while increasing the magnification scale did not increase light pole height accuracy significantly. Pictometry® estimated height can be used in lieu of field-based height estimation for vertical features in a landscape and has the potential to revolutionize remotely sensed height measurements. This confirms the precision and accuracy of height measurements previously found for use of Pictometry® for tree, pole and building heights, slope distance, and height measurement by unmanned aerial systems.

## Keywords

Pictometry®, accuracy, height, remote sensing, web

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## 1. INTRODUCTION

Estimating the height of vertical features in a landscape has been a component of *in situ* assessments and remote sensing applications for decades. Numerous methods to estimate height have been developed and proven successful and typically fall into the categories of traditional field measurements, use of remote sensing data acquired via an airplane or satellite platform, or the use of remotely sensed aerial or satellite platform based digital data within a web-based GIS environment.

### 1.1 TRADITIONAL FIELD MEASUREMENTS

The traditional method of estimating height for a vertical feature such as an open grown individual tree or average height of a stand of trees has been carried out with a clinometer (Kovats 1997; Williams et al. 1994). Coefficient of determinations between actual tree height and estimated tree height using a clinometer has ranged from 0.9462 to 0.9501 (Williams et al. 1994). Clinometer estimated tree height was within 0.93 meters of actual tree height when estimating loblolly pine tree height (Rennie 1979).

Height can also be estimated with a laser range finder allowing the operator to stand at any distance from a vertical feature with the clearest view of the top and bottom to increase the accuracy of height estimates (Asner et al. 2002; Williams et al. 1994). The operator uses the laser range finder to visually shoot and record the bottom and top of an object with the laser range finder providing the resulting height without a need for mathematical calculations by the operator. Linear correlation coefficients between actual tree height and estimated tree height using a laser range finder have shown to be accurate and have ranged from 0.9250 to 0.9293 (Williams et al. 1994). In recent years, laser and ultrasound combined hypsometers are available for field height measurement.

### 1.2 REMOTE SENSING

The use of aerial photography to estimate height has been available for decades (Avery 1977). Aerial photos, acquired along a predetermined flight path, are typically acquired with a side lap of approximately 30% to ensure complete coverage and overlap of 60% to allow for three dimensional assessments of surface features. Aerial photographs have proven successful in estimating height by converting parallax displacement measured along a flight path into a height estimate (Paine 1981; Titus and Morgan 1985).

LiDAR (Light Detection and Ranging) data are a relatively new form of remotely sensed data as compared to traditional digital imagery obtained from satellites or an aerial platform (Maltamo et al. 2006; Means 1999). LiDAR uses laser-scanning to measure the height and elevation of the landscape's physical attributes (Maltamo et al. 2006). Height measurements obtained from narrow-beam LiDAR data were within 0.43 meters of actual tree height and within 0.56 meters of actual tree height using wide-beam LiDAR data (Anderson et al. 2006). In western Oregon LiDAR data error exceeded 10% of tree height for 60% of trees measured at leaf-on and 55% of trees measured at leaf-off (Gatzolis et al. 2010). O'Beirne (2012) found an  $R^2$  of 0.92 to 0.96 when comparing LiDAR data to field height measurements of trees within an urban environment. Kulhavy et al. (2015)

found an absolute mean height error of 0.07 m using LiDAR and Pictometry® data when estimating height of buildings. Although LiDAR data are capable of distinguishing height of surface objects and bare ground elevation, it can be quite expensive and provides only a one dimensional vertical perspective of a landscape.

### **1.3 PICTOMETRY® WEB-BASED GIS ENVIRONMENT**

In 2013 the Arthur Temple College of Forestry and Agriculture (ATCOFA) at Stephen F. Austin State University (SFASU) purchased 2013 Pictometry® multispectral imagery (Pictometry International Corporation, 100 Town Centre Drive, Suite A, Rochester, NY 24623) (United States Patent Application 2013). The purchase included 4-inch (10.2 centimeters) spatial resolution multispectral imagery for the City of Nacogdoches, Texas (69.96 square kilometers). The Pictometry® imagery was acquired in late February and early March of 2013 for the City of Nacogdoches. This leaf-off season better differentiated surface features than a leaf-on season. The high positional accuracy of Pictometry® imagery allows for integration with existing spatial data and creates a powerful comprehensive spatial analysis tool for tasks that often require field data collection (Wang et al. 2008). Pictometry® data are classified as hyperspatial resolution remotely sensed data. Hyperspatial resolution data are defined as remotely sensed data having a spatial resolution finer than an object of interest. For a more complete review of Pictometry® including its uses in an urban setting and measurements of images, please refer to Kulhavy et al. (2016) and Unger et al. (2016).

### **1.4 PICTOMETRY® URBAN MEASUREMENTS**

The purpose of this study was to evaluate the use of Pictometry® imagery to estimate height of a light pole in an urban environment while accessing height accuracy relative to cardinal direction and image magnification factor. Expansion of the use of Pictometry® in both education and research indicates that methods are needed to evaluate this tool for accuracy in natural resource measurements. Unger et al. (2014) found Pictometry® was significantly more accurate than both clinometer and laser range finder for light pole height estimates. It was found that Pictometry® was accurate for both slope distance estimate (Kulhavy et al. 2016), tree height measurement (Unger et al. 2015), and building height measurement compared to LiDAR and a laser range finder (Kulhavy et al. 2015). Height measurement using Pictometry® was also compared to height measurement using an unmanned aerial system (drone) (Unger et al. 2016).

## **2. METHODOLOGY**

This study evaluated the use of Pictometry® imagery to estimate height of a light pole on the campus of SFASU in Nacogdoches, Texas. The objective was to compare the height of a light pole on the SFASU campus estimated via a Pictometry® web-based interface to the actual height of the light pole measured with a height pole in the field. The Pictometry® estimated height was measured onscreen repeatedly for four cardinal

directions and five different image magnification scales at 100%, 125%, 150%, 200%, and 300%. For accuracy assessment, the percent disagreement and average percent disagreement of the absolute value difference between field measured height and Pictometry® estimated height for each cardinal direction and all cardinal directions combined per magnification scale were assessed. Also, the absolute differences between light pole height and Pictometry® estimated light pole height were compared to determine if any Pictometry® height estimate is statistically more accurate per magnification scale or cardinal direction.

The light pole was located along the side of E. College Street on the residential campus of SFASU. A light pole within a small town urban environment was chosen to provide a full view, both top and bottom, of a vertical feature clearly identifiable from all four cardinal directions and to ensure no change in height between *in situ* measurement and Pictometry® oblique image acquisition during February and March, 2013. The actual height of the light pole was measured during September, 2013 *in situ* with a telescopic height pole in 2.54 centimeter increments (1 inch increments) by a graduate research assistant within ATCOFA (Figure 1). The actual height of the light pole was confirmed as 7.47 meters. Then, the height of the same light pole was estimated onscreen using Pictometry® imagery via a web-based interface during September, 2013 by an ATCOFA faculty member.



Figure 1. Measuring light pole height with a telescopic height pole on the campus of Stephen F. Austin State University, Nacogdoches, Texas.

Multiple images embedded with the Pictometry® onscreen web-based interface, which were taken at different times during the image acquisition date, were utilized to estimate light pole height and ensure robustness of the height estimations regardless of

shadow length or time of day. The height of the same light pole was measured in Pictometry<sup>®</sup> onscreen eight times per cardinal direction and recorded to 0.003 meters (0.01 feet). This same process was repeated on five different Pictometry<sup>®</sup> image scales at 100%, 125%, 150%, 200%, and 300% magnification (Figures 2-4). It totaled to 160 Pictometry<sup>®</sup> light pole height measurements, with 8 replicates on each cardinal direction and each image magnification factor. Onscreen Pictometry<sup>®</sup> light pole height measurements were recorded prior to measuring actual light pole height *in situ*, and by two separate individuals, to eliminate light pole height estimation bias.

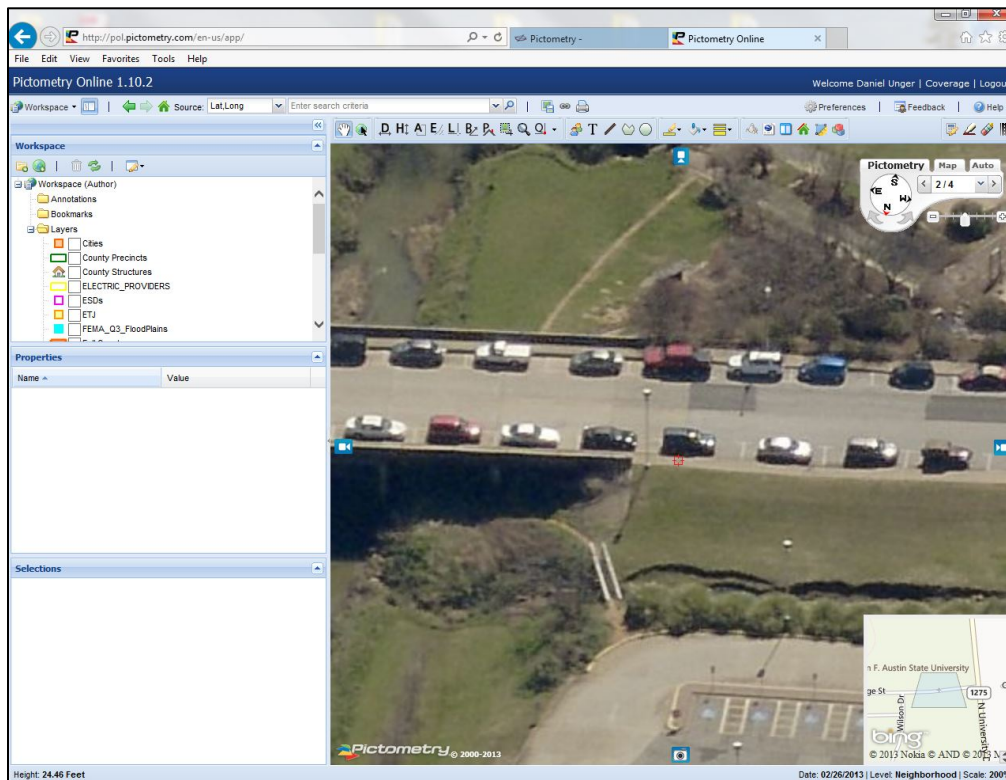


Figure 2. Viewing the light pole within the Pictometry<sup>®</sup> web-based interface from a North perspective at 200% magnification.



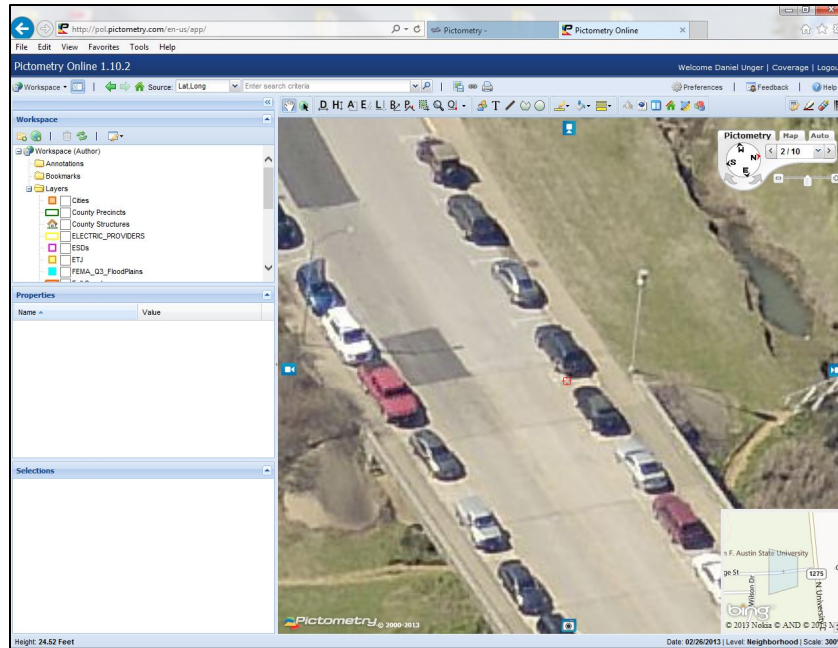


Figure 3. Viewing the light pole within the Pictometry® web-based interface from an East perspective at 300% magnification.



Figure 4. Measuring the height of the light pole within the Pictometry® web-based interface from an East perspective at 300% magnification.



The difference, also known as error, is calculated by subtracting an actual height value measured with the height pole with a Pictometry<sup>®</sup> estimated height value of the same light pole. The output is either a positive or negative value. When the arithmetic mean of the 32 difference values is calculated, the average difference value is attained for each estimate technique. Since the positive or negative values of difference cancel out the magnitude of error when the average is calculated, the absolute value of difference is used to assess the disagreement of an estimated height value to the actual height value. This is done by taking the absolute difference of each measurement divided by the actual height of the light pole (7.47 meters) and displayed as percentage. Having a lower disagreement percentage represents a higher accuracy.

RMSE between light pole height and Pictometry<sup>®</sup> estimated light pole height was also calculated for each cardinal direction and all cardinal directions combined per five image magnification scales using Equation 1.

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (x_{i,actual} - x_{i,estimated})^2} \quad (1)$$

In order to test for normality, a Shapiro-Wilk test was run on each of the 20 groups (four cardinal directions by five magnification scales) of absolute errors. It was found that none of them was normally distributed (max  $p = 0.02$ ) and an ANOVA test would be inappropriate as it violates the assumption that the data are normally distributed. Therefore, a nonparametric Kruskal-Wallis test was conducted to test the null hypothesis that the means of the absolute errors from different groups are equal. In other words, there is no difference in accuracy among the four cardinal directions or among the five magnification scales in measuring height using the Pictometry<sup>®</sup> web-based interface. A Kruskal-Wallis test was run on absolute errors with cardinal direction as the factor, followed by the magnification scale.

### 3. RESULTS AND DISCUSSION

There was minimal difference between measured light pole height of 7.47 meters and Pictometry<sup>®</sup> estimated light pole height (Table 1). Pictometry<sup>®</sup> estimated mean light pole height ranged from 7.41 meters for the West perspective at an image magnification factor of 100% to 7.70 meters for the West perspective at an image magnification factor of 150% and 300%. Seventeen of the 20 Pictometry<sup>®</sup> estimated mean light pole heights stratified by cardinal direction and five image magnification factors overestimated the light pole height, indicating an overestimation bias.

Pictometry<sup>®</sup> estimated mean light pole height measured at different image magnification factors is listed as height difference in Tables 2a-e stratified by cardinal direction. Pictometry<sup>®</sup> measured light pole height at an image magnification factor of 100%, 125%, 150%, 200% and 300% overestimated light pole height 23 out of 32 times, 29 out of 32 times, 28 out of 32 times, 24 out of 32 times, and 22 out of 32 times respectively. Pictometry<sup>®</sup> estimated mean light pole height, when summarized over all four cardinal directions, overestimated light pole height by 0.08 meters, 0.13 meters, 0.13

Table 1. Light pole height and Pictometry® measured light pole height for all four cardinal directions and five image scales at 100%, 125%, 150%, 200%, and 300% magnification.

Oblique View	Pole Height (meters)	Height per Magnification Scale				
		100% (meters)	125% (meters)	150% (meters)	200% (meters)	300% (meters)
North	7.47	7.61	7.46	7.61	7.58	7.46
	7.47	7.46	7.61	7.61	7.46	7.46
	7.47	7.61	7.76	7.61	7.46	7.46
	7.47	7.46	7.61	7.46	7.46	7.46
	7.47	7.46	7.61	7.61	7.46	7.46
	7.47	7.61	7.61	7.61	7.46	7.46
	7.47	7.61	7.61	7.61	7.46	7.46
	7.47	7.61	7.61	7.61	7.46	7.46
South	7.47	7.59	7.87	7.58	7.73	7.59
	7.47	7.73	7.73	7.59	7.59	7.58
	7.47	7.73	7.59	7.59	7.58	7.58
	7.47	7.73	7.59	7.59	7.59	7.59
	7.47	7.59	7.73	7.72	7.59	7.59
	7.47	7.58	7.73	7.58	7.73	7.59
	7.47	7.72	7.59	7.58	7.58	7.58
	7.47	7.73	7.59	7.58	7.73	7.58
East	7.47	7.62	7.63	7.46	7.48	7.46
	7.47	7.62	7.49	7.48	7.46	7.46
	7.47	7.49	7.49	7.61	7.65	7.48
	7.47	7.61	7.63	7.46	7.48	7.48
	7.47	7.62	7.49	7.48	7.49	7.49
	7.47	7.49	7.49	7.46	7.48	7.80
	7.47	7.48	7.51	7.62	7.49	7.48
	7.47	7.48	7.62	7.61	7.48	7.48
West	7.47	7.45	7.41	7.85	7.69	7.71
	7.47	7.55	7.41	7.71	7.69	7.69
	7.47	7.29	7.57	7.71	7.69	7.71
	7.47	7.27	7.69	7.69	7.57	7.71
	7.47	7.27	7.57	7.57	7.71	7.69
	7.47	7.55	7.69	7.71	7.71	7.71
	7.47	7.45	7.71	7.69	7.55	7.71
	7.47	7.43	7.59	7.69	7.71	7.69
North	Mean	7.55	7.61	7.59	7.47	7.46
South	Mean	7.67	7.68	7.60	7.64	7.58
East	Mean	7.55	7.54	7.52	7.50	7.51
West	Mean	7.41	7.58	7.70	7.67	7.70
Combined	Mean	7.55	7.60	7.60	7.57	7.56

Table 2a. Percent disagreement and average percent disagreement of the absolute value difference between light pole height and Pictometry® estimated light pole height for each cardinal direction and all cardinal directions combined at 100% magnification.

Oblique View	Pole Height (meters)	100% Magnification		Absolute Difference (meters)	Disagreement (percent)
		Height (meters)	Height Difference (meters)		
North	7.47	7.61	0.14	0.14	1.88
	7.47	7.46	-0.01	0.01	0.16
	7.47	7.61	0.14	0.14	1.88
	7.47	7.46	-0.01	0.01	0.16
	7.47	7.46	-0.01	0.01	0.16
	7.47	7.61	0.14	0.14	1.88
	7.47	7.61	0.14	0.14	1.88
	7.47	7.61	0.14	0.14	1.88
South	7.47	7.59	0.12	0.12	1.59
	7.47	7.73	0.26	0.26	3.47
	7.47	7.73	0.26	0.26	3.47
	7.47	7.73	0.27	0.27	3.55
	7.47	7.59	0.12	0.12	1.59
	7.47	7.58	0.11	0.11	1.47
	7.47	7.72	0.25	0.25	3.35
	7.47	7.73	0.26	0.26	3.47
East	7.47	7.62	0.15	0.15	2.04
	7.47	7.62	0.15	0.15	2.04
	7.47	7.49	0.02	0.02	0.29
	7.47	7.61	0.14	0.14	1.84
	7.47	7.62	0.15	0.15	2.04
	7.47	7.49	0.02	0.02	0.29
	7.47	7.48	0.01	0.01	0.08
	7.47	7.48	0.01	0.01	0.08
West	7.47	7.45	-0.02	0.02	0.29
	7.47	7.55	0.08	0.08	1.10
	7.47	7.29	-0.18	0.18	2.41
	7.47	7.27	-0.20	0.20	2.65
	7.47	7.27	-0.20	0.20	2.65
	7.47	7.55	0.08	0.08	1.10
	7.47	7.45	-0.02	0.02	0.29
	7.47	7.43	-0.04	0.04	0.53
North	Mean	7.55	0.08	0.09	1.23
South	Mean	7.67	0.21	0.21	2.74
East	Mean	7.55	0.08	0.08	1.09
West	Mean	7.41	-0.06	0.10	1.38
Combined	Mean	7.55	0.08	0.12	1.61

Table 2b. Percent disagreement and average percent disagreement of the absolute value difference between light pole height and Pictometry® estimated light pole height for each cardinal direction and all cardinal directions combined at 125% magnification.

Oblique View	Pole Height (meters)	125% Magnification		Absolute Difference (meters)	Disagreement (percent)
		Height (meters)	Height Difference (meters)		
North	7.47	7.46	-0.01	0.01	0.16
	7.47	7.61	0.14	0.14	1.88
	7.47	7.76	0.29	0.29	3.88
	7.47	7.61	0.14	0.14	1.88
	7.47	7.61	0.14	0.14	1.88
	7.47	7.61	0.14	0.14	1.88
	7.47	7.61	0.14	0.14	1.88
	7.47	7.61	0.14	0.14	1.88
South	7.47	7.87	0.40	0.40	5.31
	7.47	7.73	0.26	0.26	3.47
	7.47	7.59	0.13	0.13	1.67
	7.47	7.59	0.12	0.12	1.59
	7.47	7.73	0.26	0.26	3.47
	7.47	7.73	0.27	0.27	3.55
	7.47	7.59	0.12	0.12	1.59
	7.47	7.59	0.13	0.13	1.67
East	7.47	7.63	0.16	0.16	2.20
	7.47	7.49	0.02	0.02	0.29
	7.47	7.49	0.02	0.02	0.29
	7.47	7.63	0.16	0.16	2.20
	7.47	7.49	0.02	0.02	0.29
	7.47	7.49	0.02	0.02	0.29
	7.47	7.51	0.04	0.04	0.49
	7.47	7.62	0.15	0.15	2.04
West	7.47	7.41	-0.06	0.06	0.78
	7.47	7.41	-0.06	0.06	0.78
	7.47	7.57	0.10	0.10	1.35
	7.47	7.69	0.22	0.22	2.98
	7.47	7.57	0.10	0.10	1.35
	7.47	7.69	0.22	0.22	2.98
	7.47	7.71	0.24	0.24	3.22
	7.47	7.59	0.12	0.12	1.59
North	Mean	7.61	0.14	0.14	1.91
South	Mean	7.68	0.21	0.21	2.79
East	Mean	7.54	0.08	0.08	1.01
West	Mean	7.58	0.11	0.14	1.88
Combined	Mean	7.60	0.13	0.14	1.90

Table 2c. Percent disagreement and average percent disagreement of the absolute value difference between light pole height and Pictometry® estimated light pole height for each cardinal direction and all cardinal directions combined at 150% magnification.

Oblique View	Pole Height (meters)	150% Magnification	Height Difference (meters)	Absolute Difference (meters)	Disagreement (percent)
		Height (meters)			
North	7.47	7.61	0.14	0.14	1.88
	7.47	7.61	0.14	0.14	1.84
	7.47	7.61	0.14	0.14	1.88
	7.47	7.46	-0.01	0.01	0.16
	7.47	7.61	0.14	0.14	1.88
	7.47	7.61	0.14	0.14	1.88
	7.47	7.61	0.14	0.14	1.88
	7.47	7.61	0.14	0.14	1.88
South	7.47	7.58	0.11	0.11	1.47
	7.47	7.59	0.12	0.12	1.59
	7.47	7.59	0.12	0.12	1.59
	7.47	7.59	0.13	0.13	1.67
	7.47	7.72	0.25	0.25	3.35
	7.47	7.58	0.11	0.11	1.47
	7.47	7.58	0.11	0.11	1.47
	7.47	7.58	0.11	0.11	1.47
East	7.47	7.46	-0.01	0.01	0.08
	7.47	7.48	0.01	0.01	0.08
	7.47	7.61	0.14	0.14	1.84
	7.47	7.46	-0.01	0.01	0.08
	7.47	7.48	0.01	0.01	0.08
	7.47	7.46	-0.01	0.01	0.08
	7.47	7.62	0.15	0.15	2.04
	7.47	7.61	0.14	0.14	1.84
West	7.47	7.85	0.38	0.38	5.10
	7.47	7.71	0.24	0.24	3.22
	7.47	7.71	0.24	0.24	3.22
	7.47	7.69	0.22	0.22	2.98
	7.47	7.57	0.10	0.10	1.35
	7.47	7.71	0.24	0.24	3.22
	7.47	7.69	0.22	0.22	2.98
	7.47	7.69	0.22	0.22	2.98
North	Mean	7.59	0.12	0.12	1.66
South	Mean	7.60	0.13	0.13	1.76
East	Mean	7.52	0.05	0.06	0.77
West	Mean	7.70	0.23	0.23	3.13
Combined	Mean	7.60	0.13	0.14	1.83

Table 2d. Percent disagreement and average percent disagreement of the absolute value difference between light pole height and Pictometry® estimated light pole height for each cardinal direction and all cardinal directions combined at 200% magnification.

Oblique View	Pole Height (meters)	200% Magnification	Height Difference (meters)	Absolute Difference (meters)	Disagreement (percent)
		Height (meters)			
North	7.47	7.58	0.11	0.11	1.47
	7.47	7.46	-0.01	0.01	0.16
	7.47	7.46	-0.01	0.01	0.16
	7.47	7.46	-0.01	0.01	0.16
	7.47	7.46	-0.01	0.01	0.16
	7.47	7.46	-0.01	0.01	0.16
	7.47	7.46	-0.01	0.01	0.16
	7.47	7.46	-0.01	0.01	0.16
South	7.47	7.73	0.26	0.26	3.47
	7.47	7.59	0.12	0.12	1.59
	7.47	7.58	0.11	0.11	1.47
	7.47	7.59	0.12	0.12	1.59
	7.47	7.59	0.12	0.12	1.59
	7.47	7.73	0.26	0.26	3.47
	7.47	7.58	0.11	0.11	1.47
	7.47	7.73	0.26	0.26	3.47
East	7.47	7.48	0.01	0.01	0.08
	7.47	7.46	-0.01	0.01	0.08
	7.47	7.65	0.18	0.18	2.41
	7.47	7.48	0.01	0.01	0.08
	7.47	7.49	0.02	0.02	0.29
	7.47	7.48	0.01	0.01	0.08
	7.47	7.49	0.02	0.02	0.29
	7.47	7.48	0.01	0.01	0.08
West	7.47	7.69	0.22	0.22	2.98
	7.47	7.69	0.22	0.22	2.98
	7.47	7.69	0.22	0.22	2.98
	7.47	7.57	0.10	0.10	1.35
	7.47	7.71	0.24	0.24	3.22
	7.47	7.71	0.24	0.24	3.22
	7.47	7.55	0.08	0.08	1.10
	7.47	7.71	0.24	0.24	3.22
North	Mean	7.47	0.00	0.02	0.33
South	Mean	7.64	0.17	0.17	2.27
East	Mean	7.50	0.03	0.03	0.42
West	Mean	7.67	0.20	0.20	2.63
Combined	Mean	7.57	0.10	0.11	1.41

Table 2e. Percent disagreement and average percent disagreement of the absolute value difference between light pole height and Pictometry® estimated light pole height for each cardinal direction and all cardinal directions combined at 300% magnification.

Oblique View	Pole Height (meters)	300% Magnification		Absolute Difference (meters)	Disagreement (percent)
		Height (meters)	Height Difference (meters)		
North	7.47	7.46	-0.01	0.01	0.16
	7.47	7.46	-0.01	0.01	0.16
	7.47	7.46	-0.01	0.01	0.16
	7.47	7.46	-0.01	0.01	0.16
	7.47	7.46	-0.01	0.01	0.16
	7.47	7.46	-0.01	0.01	0.16
	7.47	7.46	-0.01	0.01	0.16
	7.47	7.46	-0.01	0.01	0.16
South	7.47	7.59	0.12	0.12	1.59
	7.47	7.58	0.11	0.11	1.47
	7.47	7.58	0.11	0.11	1.47
	7.47	7.59	0.12	0.12	1.59
	7.47	7.59	0.12	0.12	1.59
	7.47	7.59	0.12	0.12	1.59
	7.47	7.58	0.11	0.11	1.47
	7.47	7.58	0.11	0.11	1.47
East	7.47	7.46	-0.01	0.01	0.08
	7.47	7.46	-0.01	0.01	0.08
	7.47	7.48	0.01	0.01	0.08
	7.47	7.48	0.01	0.01	0.08
	7.47	7.49	0.02	0.02	0.29
	7.47	7.80	0.33	0.33	4.37
	7.47	7.48	0.01	0.01	0.08
	7.47	7.48	0.01	0.01	0.08
West	7.47	7.71	0.24	0.24	3.22
	7.47	7.69	0.22	0.22	2.98
	7.47	7.71	0.24	0.24	3.22
	7.47	7.71	0.24	0.24	3.22
	7.47	7.69	0.22	0.22	2.98
	7.47	7.71	0.24	0.24	3.22
	7.47	7.71	0.24	0.24	3.22
	7.47	7.69	0.22	0.22	2.98
North	Mean	7.46	-0.01	0.01	0.16
South	Mean	7.58	0.11	0.11	1.53
East	Mean	7.51	0.04	0.05	0.64
West	Mean	7.70	0.23	0.23	3.13
Combined	Mean	7.56	0.10	0.10	1.37



meters, 0.10 meters and 0.10 meters at an image magnification factor of 100%, 125%, 150%, 200% and 300% respectively. The mean absolute errors of Pictometry® estimated mean light pole height were 0.08 meters, 0.17 meters, 0.06 meters, and 0.18 meters for the North, South, East, and West cardinal directions respectively. The mean of absolute errors of Pictometry® estimated mean light pole height were 0.12 meters, 0.12 meters, 0.14 meters, 0.11 meters, and 0.10 meters for the image magnifications of 100%, 125%, 150%, 200%, and 300% respectively.

Average percent disagreement of the absolute value difference between light pole height and Pictometry® estimated light pole height for each cardinal direction per image magnification factor is summarized in Table 3. Average percent disagreement between light pole height and Pictometry® estimated light pole height ranged from 0.16% for the North cardinal direction at an image magnification factor of 300% to 3.13% for the West at an image magnification factor of 150% and 300% respectively. Average percent disagreement between light pole height and Pictometry® estimated light pole height stratified by cardinal direction and image magnification factor was less than or equal to 1.00% for 5 out of 20 times, between 1.00% and 2.00% for 9 out of 20 times, between 2.00% and 3.00% for 4 out of 20 times, and greater than 3.00% for 2 out of 20 times. All average percent disagreements between light pole height and Pictometry® estimated light pole height summarized by image magnification factor were within 98% of light pole height with percent disagreement ranging from 1.37% to 1.90%.

RMSE between light pole height and Pictometry® estimated light pole height for each cardinal direction per image magnification factor is summarized in Table 4. The RMSE ranged from 0.01 meters at an image magnification factor of 300% for the North to 0.24 meters at an image magnification factor of 150% for the West respectively. RMSE stratified by cardinal direction and image magnification factor was less than 0.10 meters for 5 out of 20 times, between 0.10 meters and 0.20 meters for 10 out of 20 times, and between 0.20 meters and 0.30 meters for 5 out of 20 times. RMSE summarized by image magnification factor ranged from 0.14 meters (1.87% disagreement) to 0.17 meters (2.28% disagreement), whereas on the four cardinal directions it ranged from 0.08 meter (1.07% disagreement) to 0.14 meters (1.87% disagreement). The overall RMSE was calculated at 0.11 meters (1.47% disagreement).

Table 3. Average percent disagreement of the absolute value difference between light pole height and Pictometry® estimated light pole height for each cardinal direction and all cardinal directions combined per Pictometry® magnification scale. Unit: %.

Oblique View	Disagreement per Magnification Scale				
	100%	125%	150%	200%	300%
North	1.23	1.91	1.66	0.33	0.16
South	2.74	2.79	1.76	2.27	1.53
East	1.09	1.01	0.77	0.42	0.64
West	1.38	1.88	3.13	2.63	3.13
Combined	1.61	1.90	1.83	1.41	1.37

Table 4. Root Mean Square Error (RMSE) between light pole height and Pictometry® estimated light pole height for each cardinal direction and all cardinal directions combined per Pictometry® magnification scale (Values in parentheses show the percentage disagreement of RMSE to the true height). Unit: meters.

Oblique View	RMSE per Magnification Scale					
	100%	125%	150%	200%	300%	Combined
North	0.11 (1.47%)	0.03 (0.40%)	0.13 (1.74%)	0.04 (0.54%)	0.01 (0.13%)	0.11 (1.47%)
South	0.22 (2.95%)	0.23 (3.08%)	0.14 (1.87%)	0.18 (2.41%)	0.11 (1.47%)	0.08 (1.07%)
East	0.11 (1.47%)	0.10 (1.34%)	0.09 (1.20%)	0.06 (0.80%)	0.12 (1.61%)	0.11 (1.47%)
West	0.13 (1.74%)	0.16 (2.14%)	0.24 (3.21%)	0.21 (2.81%)	0.23 (3.08%)	0.14 (1.87%)
Combined	0.15 (2.01%)	0.17 (2.28%)	0.16 (2.14%)	0.14 (1.87%)	0.14 (1.87%)	0.11 (1.47%)

The results of Kruskal-Wallis test on the absolute errors of Pictometry® height estimate found that there was significant difference among the direction groups ( $p < 0.0001$ ,  $df = 3$ ), but not the image magnification factors. Table 5 shows the Wilcoxon scores by different cardinal direction, where East (57.53750) and North (57.33750) together had lower mean scores than those of West (107.28750) and South (99.83750). This difference reconfirmed what was found in the mean absolute errors by cardinal direction (Tables 2a-e), where lower error was found for the East (0.06 meters) and North (0.08 meters) directions than South (0.17 meters) and West (0.18 meters) directions. The result is statistically significant at the 0.05 level revealing that measuring height from East and North was more accurate than from South and West. As to the magnification scale, the Kruskal-Wallis test resulted in  $p = 0.0901$  ( $df = 4$ ) indicating that magnification scale did not make a difference in height measurement accuracy.

Actual height of a light pole measured *in situ* was compared to Pictometry® estimated light pole height using hyperspatial 4-inch (10.2 centimeters) multispectral oblique imagery onscreen via a web-based interface. There was minimal difference between the actual light pole height and Pictometry® estimated light pole height. Average percent disagreement between light pole height and Pictometry® estimated light pole height summarized by Pictometry® image magnification factors at 100%, 125%, 150%, 200%, and 300% magnification were within 98% of light pole height with percent disagreement ranging from 1.37% to 1.90%. RMSE between light pole height and Pictometry® estimated light pole height summarized by Pictometry® image magnification factors at 100%, 125%, 150%, 200%, and 300% magnification factor ranged from 0.14 meters (1.87%) to 0.17 meters (2.28%) with an overall RMSE of 0.11 meters (1.47%). At different cardinal directions the mean absolute errors were 0.08 meters, 0.17 meters, 0.06 meters, and 0.18 meters for North, South, East, and West directions respectively.

Table 5. Comparison of absolute differences between light pole height and Pictometry® estimated light pole height by cardinal direction through Wilcoxon scores in Kruskal-Wallis test.

Oblique View	N	Sum of Scores	Expected Under $H_0$	Std Dev Under $H_0$	Mean Score
East	40	2301.50	3220.0	252.526106	57.53750
North	40	2293.50	3220.0	252.526106	57.33750
West	40	4291.50	3220.0	252.526106	107.28750
South	40	3993.50	3220.0	252.526106	99.83750

Results of Kruskal-Wallis tests indicated that Pictometry® estimated light pole heights measured at the cardinal directions of North and East were more accurate than the directions of South and West, while increasing the magnification scale did not increase light pole height accuracy significantly. The higher accuracy of estimating height using Pictometry® data at the North and East cardinal directions is related to the geographic location of the study area and the time of year of image acquisition date. When the sun came from the South and West, shadows within the images were cast toward the North and East which make finding the base of an object more difficult in estimating height when facing South or West.

Although this study only addressed the height of a light pole of 7.47 meters on the campus of SFASU, further research should be undertaken to determine if Pictometry® data can accurately measure the height of vertical features with higher or lower heights and if the data are robust at other geographic locations. Studies related to this topic are supported by Unger et al. (2014) when estimating light pole height; Unger et al. (2015) when estimating tree height; and Kulhavy et al. (2015) when measuring building heights comparing Pictometry®, LiDAR and a laser against measured heights. Estimating height of vertical features in a landscape using Pictometry® hyperspatial 4-inch (10.2 centimeters) multispectral oblique imagery onscreen via a web-based interface proved to be accurate regardless of image magnification scale.

#### 4. CONCLUSION

Remote sensing with its ability to collect data systematically over large geographic areas has the potential to aid field-based height estimation. The integration of hyperspatial resolution multispectral data into a web-based interface was effective at estimating height and proved more accurate than traditional height estimates using a clinometer, laser range finder and LiDAR data.

Repeated height measurements of a light pole at the four cardinal directions and different magnification scales indicated both the versatility of Pictometry® as a web-based tool for measurements and its accuracy and precision. The results indicated that Pictometry® estimated light pole heights measured at the cardinal directions of north and east were more accurate than others, while increasing the magnification scale did not make a difference. The overall RMSE was calculated at 0.11 meters that is only 1.47% in disagreement with the actual height of the tested light pole. Pictometry® data, and its

patented web-based interface, could be used to supplement or replace time consuming field-based height estimation and has the potential to revolutionize remotely sensed height measurements.

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