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Comparing Remotely Sensed Pictometry® Web Based Slope Distance Estimates with In Situ Total Station and Tape Slope Distance Estimates

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Abstract

Slope distance was measured between the top of 30 light poles and their respective ground level coordinate identified within a central parking lot on the campus of Stephen F. Austin State University, Nacogdoches, Texas. Slope distance measured using Pictometry® hyperspatial 4-inch (10.2 centimeters) multispectral imagery within a web based interface was compared to *in situ* total station and tape measured slope distance. The range for mean slope distance for Pictometry®, total station, and tape measured slope distance was 0.05 meters. Mean slope distance was 15.36 meters, 15.37 meters, and 15.41 meters for Pictometry®, total station, and tape measured slope distance respectively. An analysis of variance (ANOVA) between Pictometry®, total station, and tape measured slope distance resulting in a p-value of 0.9996 indicated there was not a significant difference between Pictometry®, total station, and tape measured slope distance. A two-tail t-test between the absolute difference between Pictometry® and tape measured slope distance and the absolute difference between Pictometry® and total station measured slope distance with a p-value of 0.6680 indicated there was not a significant difference between the two measurement errors. Results indicate that slope distance measured remotely with Pictometry® hyperspatial 4-inch (10.2 centimeters) multispectral imagery within a web based interfaced can be used in lieu of *in situ* total station and tape measured slope distance.

Keywords

Pictometry®, hyperspatial, slope distance, accuracy, web

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1. INTRODUCTION

Measuring slope distance in a landscape has been a component of *in situ* assessments for decades. Slope distance has historically been measured *in situ* with a tape. Slope distance has also been derived via the Pythagorean Theorem by measuring the rise in elevation versus the horizontal distance or run from the beginning and end point of the slope distance via remotely sensed data (Paine 1981). Slope distance can also be estimated with a laser range finder allowing the operator to stand at the beginning or end of a distance in question and shoot the slope distance as long as there is a clear view from the beginning to the end of the required slope distance line (Williams et al. 1994).

Remote sensing with its ability to collect data systematically over large geographic areas, combined with the increased ease of integrating high spatial resolution multispectral data into a web based interface, has potential to aid field-based slope distance measurements (Abd-Elrahman et al. 2010). Pictometry® high spatial resolution data, which represents remotely sensed image data collected from up to 12 oblique perspectives, depicts the front and sides of vertical features (Jurisch and Mountain 2008). The ability to measure the size and position of objects on the earth's surface with Pictometry® data has the potential to revolutionize slope distance measurement.

This study evaluated the use of Pictometry® hyperspatial 4-inch (10.2 centimeters) multispectral imagery to measure slope distance between the top of 30 light poles and their respective ground level coordinate identified within a central parking lot on the residential campus of Stephen F. Austin State University, Nacogdoches, Texas. Slope distance measured between the top of 30 light poles and their respective ground level coordinate were compared to *in situ* total station and tape measured slope distance. An analysis of variance (ANOVA) between Pictometry®, total station, and tape measured slope distance was calculated. A two-tail t-test between the absolute difference between Pictometry® and tape measured slope distance and the absolute difference between Pictometry® and total station measured slope distance was calculated. Overall objective was to ascertain if Pictometry® measured slope distance could be used in lieu of *in situ* total station and tape measured slope distance.

Measuring slope distance in a landscape has been a component of *in situ* assessments for decades. Slope distance has historically been measured *in situ* with a tape or topographic chain (Bonner and Bonner 1916; Buell 1940). A revolutionary advancement of distance measurement was the development of EDM (Electronic Distance Measuring) instruments about 70 years ago. There are two main principles or methods for an EDM instrument to measure accurate distance, one is phase shift methodology and the other is time of flight methodology.

A very good example of a EDM instrument is a laser range finder that allows an operator to stand at the beginning or end of a distance in question and shoot the slope distance as long as there is a clear view to the beginning or end of the required slope distance line (Williams et al. 1994; Wing et al. 2004). The most accurate distance measurement method is using a total station with a prism, as in this way, the starting point and ending point of the distance can be accurately located while taking into account the slope of the linear measurement.

The use of aerial photography to estimate height of landscape features has been used for decades (Avery 1977). Slope distance has been derived via the Pythagorean Theorem by measuring the rise in elevation versus the horizontal distance or run from the beginning and end point of the slope distance via remotely sensed data (Paine 1981). 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. A stereoscopic pair of aerial photographs has proven successful in estimating height by converting parallax displacement measured along a flight path into a height estimate (Paine 1981). Although estimating height of a landscape feature with aerial photos provides a large geographic coverage not available with field-based estimations, it can be time consuming when dealing with a large amount of aerial photos.

In 2013 the Arthur Temple College of Forestry and Agriculture (ATCOFA) purchased 2013 Pictometry® multispectral imagery from Pictometry International Corporation, 100 Town Centre Drive, Suite A, Rochester, NY 24623 (Unites States Patent Application 2013). The word Pictometry® is the name of Pictometry International Corporations patented aerial image capture process that acquires digital imagery of the earth's surface within a proprietary image capture process. Pictometry® is contracted through Pictometry International Corporation and is available throughout most of the United States, 1500 cities in Europe, Canada, Australia, South/Central America, South America, the Middle East, Israel, Korea and Japan. The purchase included 4-inch (10.2 centimeters) spatial resolution multispectral imagery for the City of Nacogdoches (69.96 km^2). The Pictometry® imagery was acquired in late February and early March of 2013 to minimize the temporal difference of surface features within the City of Nacogdoches between two different image acquisition dates.

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. Pictometry® data are similar to data available with commercial grade satellites IKONOS, QuickBird and GeoEye in application but Pictometry® data are acquired at a finer spatial resolution than commercial grade satellite sensors allowing for an improved visual assessment of surface features with a Pictometry® image (Dennison et al. 2010; Dial et al. 2003; Sawaya et al. 2003).

Pictometry® data are acquired along a predetermined flight path, within an oval circular pattern above the area of interest, to obtain imagery from multiple perspectives by low flying aircraft including nadir and oblique angles up to 40 degrees. Pictometry® image data depict the fronts and sides of vertical ground features in a web based interface. Images acquired contain up to 12 oblique perspectives and are stitched together to create a composite image that a user can use to measure surface object size and position using the Pictometry® patented web based interface (Wang et al. 2008).

Alexander et al. (2013) concluded the combination of oblique mapping from Pictometry® data, combined with Lidar and aerial photography significantly improved the mapping of Karst topography and reduced field mapping. Pictometry® data allowed for oblique views to identify and measure depressions in karst features and to compare change over time. Xiao et al. (2010) used multi-view oblique imagery to detect and distinguish rectangular flat roofs. In The Netherlands, Pictometry® data allowed users to view and accurately measure surface features within both orthogonal and oblique images within a cadastral context (Lemmens et al. 2007). Höhle (2008) concluded Pictometry® data shows oblique images clearly and measurement of distance, spatial coordinates, terrain elevations and heights are measured accurately within its patented web based interface.

The high spatial accuracy of Pictometry® imagery, combined with the integration of elevation information embedded within each pixels spatial location, 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). The Pictometry® online interface also allows the user to measure height, distance, and area of surface features accurately from both an orthogonal and multiple oblique angles; thereby decreasing the amount of time and cost required to record field measurements (Gerke and Kerle 2011).

2. METHODOLOGY

This study evaluated the use of Pictometry® hyperspatial 4-inch (10.2 centimeters) multispectral imagery to measure slope distance between the top of 30 light poles and their respective ground level coordinate identified within a central parking lot on the residential campus of Stephen F. Austin State University (SFASU), Nacogdoches, Texas. We had four specific objectives: (1) use Pictometry® hyperspatial 4-inch (10.2 centimeters) multispectral imagery to measure the slope distance between the top of 30 light poles and their respective ground level coordinate; (2) measure the slope distance *in situ* between the top of 30 light poles and their respective ground level coordinate with a total station and tape; (3) use an ANOVA to test for statistical significance between Pictometry®, total station, and tape measured slope distance; and, (4) use a two-tail t-test to test for statistical significance between the absolute difference between Pictometry® and tape measured slope distance and the absolute difference between Pictometry® and total station measured slope distance

All 30 light poles were located within a central parking lot on the residential campus of SFASU (Figure 1). Light poles within a small town urban environment were chosen to provide an unobstructed view of a vertical feature and to ensure no change in height between *in situ* measurements and Pictometry® oblique image acquisition during February and March, 2013 (Figure 2).

Pictometry® hyperspatial 4-inch (10.2 centimeters) multispectral imagery was used to measure the slope distance between the top of 30 light poles and their respective ground level coordinate within the Pictometry® web based interface (Figure 3). Ground level coordinate locations chosen represented the beginning and end of parking space lines that could easily be located on the ground and visually identified within the Pictometry® web based interface. The Pictometry® web based interface does not require a right triangle to calculate slope distance as the Pictometry® slope measurement compensates for any angle of a given triangle. The slope distance between the top of 30 light poles and their respective ground level coordinate were measured *in situ* with a total station and a tape stretched between the top of a light pole and its corresponding ground coordinate location (Figures 4 & 5). Onscreen Pictometry® slope distance measurements were recorded after

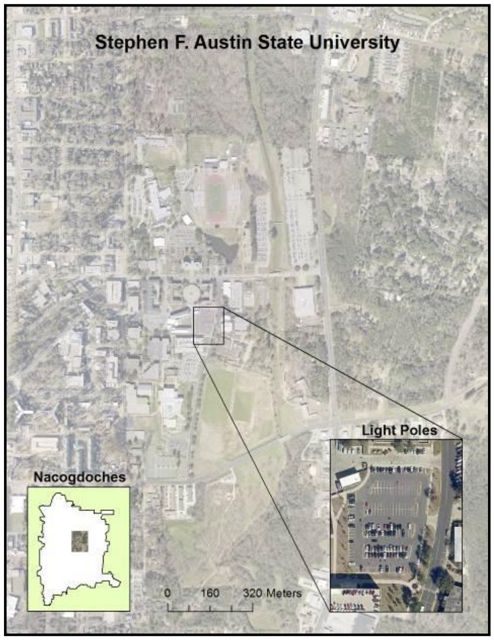

Figure 1. Locations of light poles were within a central parking lot on the residential campus of Stephen F. Austin State University, Nacogdoches, Texas.

Figure 2. Representative light pole within a central parking lot on the residential campus of Stephen F. Austin State University, Nacogdoches, Texas.

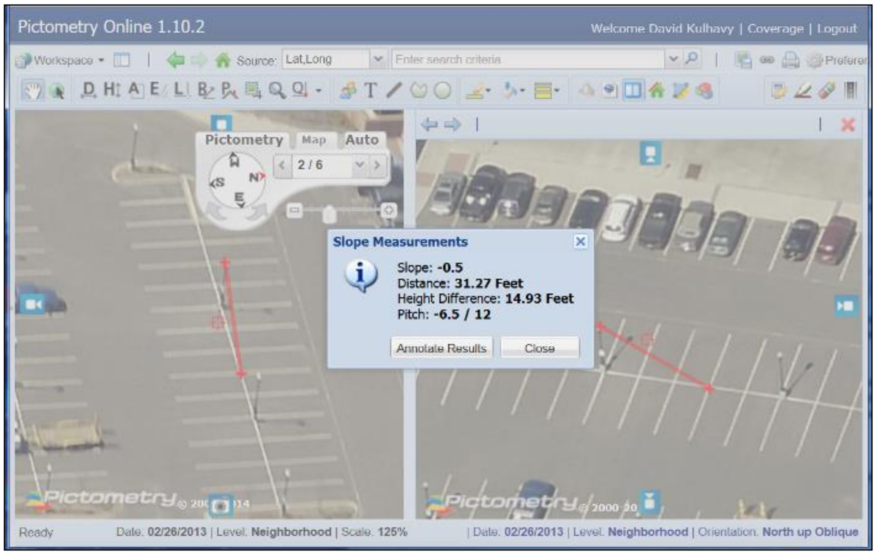

Figure 3. Measuring slope distance within the Pictometry® web based interface between the top of a light pole and a ground level coordinate identified within a central parking lot on the residential campus of Stephen F. Austin State University, Nacogdoches, Texas.

Figure 4. Measuring slope distance with a total station between the top of a light pole and a ground level coordinate identified within a central parking lot on the residential campus of Stephen F. Austin State University, Nacogdoches, Texas.

Figure 5. Measuring slope distance with a tape between the top of a light pole and a ground level coordinate identified within a central parking lot on the residential campus of Stephen F. Austin State University, Nacogdoches, Texas.

measuring total station and tape slope distance *in situ*, and by two separate individuals, to eliminate slope distance measurement bias between *in situ* and remotely measured slope distance. All slope distance measurements resulted in a triangle representing ground distance, slope distance and degree angle between a light pole and its corresponding ground level coordinate (Figure 6).

An ANOVA between Pictometry®, total station, and tape measured slope distance was calculated to test for statistical difference between the three slope distance methods. A two-tail t-test between the absolute difference between Pictometry® and tape measured slope distance and the absolute difference between Pictometry® and total station measured slope distance was calculated to test for statistical difference between the two measurement errors between Pictometry® and total station and tape slope distances respectively.

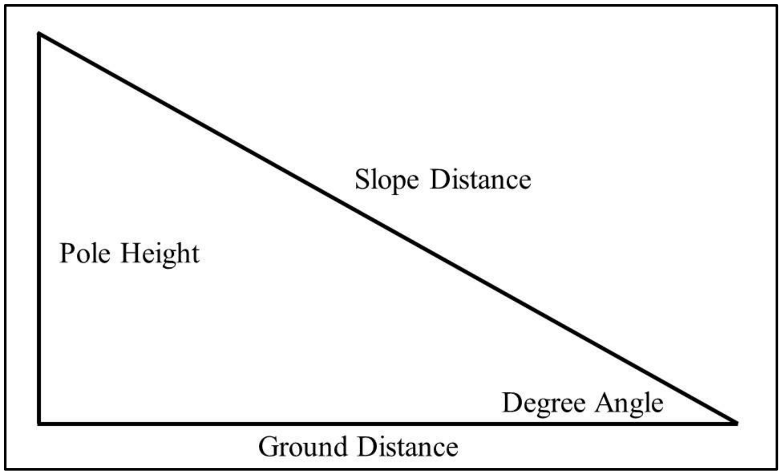

Figure 6. Schematic diagram showing ground distance, slope distance and degree angle between a light pole and its corresponding ground level coordinate identified within a central parking lot on the residential campus of Stephen F. Austin State University, Nacogdoches, Texas.

3. RESULTS

The range for mean slope distance for Pictometry®, total station, and tape measured slope distance was 0.05 meters with a mean slope distance of 15.36 meters, 15.37 meters, and 15.41 meters for Pictometry®, total station, and tape measured slope distance respectively (Table 1). The mean ground distance (horizontal distance) between the base of 30 light poles and their respective ground level coordinate measured by a tape was 14.30 meters and ranged from 2.31 meters to 29.30 meters. The mean slope angle from the ground level coordinate to the top of its respective light pole measured with a total station was 24.19 degrees and ranged from 8.58 degrees to 62.14 degrees (Table 2). Figure 7 shows a scatterplot of Pictometry® measured slope distance versus in situ measured total station and tape slope distance. Both total station and tape measured slope distance revealed a very high agreement with Pictometry® measured slope distance with a coefficient of determination (R^2) greater than 0.99 and a regression coefficient (slope) close to 1.0.

An ANOVA between Pictometry®, total station, and tape measured slope distance resulting in a p-value of 0.9996 indicated there wasn't a significant difference between Pictometry®, total station, and tape measured slope distance (Table 3). A two-tail t-test between the absolute difference between Pictometry® and tape measured slope distance and the absolute difference between Pictometry® and total station measured slope distance with a p-value of 0.6680 indicated there was not a significant difference between the two measurement errors (Table 4). The wide range in ground distance and slope angle between the base of 30 light poles and their respective ground level coordinate confirms the ANOVA and t-test results that there was not a significant difference between Pictometry®, total station, and tape measured slope distance across a wide range of linear ground distance.

Table 1. Pictometry®, total station and tape measured slope distance between the top of 30 light poles and their respective ground level coordinate identified within a central parking lot on the residential campus of Stephen F. Austin State University, Nacogdoches, Texas.

Light Pole (lamp ID)	**Pictometry Distance (meters)**	**Total Station Distance (meters)**	**Taped Distance (meters)**
1	7.59	7.44	7.59
2	8.24	8.08	8.17
3	5.38	5.37	5.49
4	9.19	9.25	9.24
5	7.22	7.06	7.27
6	9.27	9.25	9.39
7	6.30	6.22	6.27
8	8.42	8.55	8.51
9	9.98	9.99	9.97
10	8.16	8.19	8.11
11	11.92	11.89	12.01
12	15.48	15.60	15.55
13	11.09	11.28	11.31
14	14.57	14.59	14.57
15	17.19	17.18	17.13
16	13.35	13.44	13.41
17	11.12	11.12	11.19
18	14.04	14.10	14.15
19	14.21	14.35	14.18
20	14.98	15.07	15.00
21	25.14	25.37	25.18
22	26.34	26.39	26.31
23	29.02	28.96	29.09
24	25.46	25.40	25.24
25	29.55	29.69	29.85
26	9.40	9.21	9.42
27	29.17	29.25	29.39
28	25.12	25.27	25.40
29	18.17	17.93	18.14
30	25.78	25.64	25.91
Mean	**15.36**	**15.37**	**15.41**
Maximum	**29.55**	**29.69**	**29.85**
Minimum	**5.38**	**5.37**	**5.49**
Range	**24.18**	**24.32**	**24.36**

Table 2. Tape measured ground distance between the base of 30 light poles and their respective ground level coordinate, and degree angle between the top of 30 light poles and their respective ground level coordinate, identified within a central parking lot on the residential campus of Stephen F. Austin State University, Nacogdoches, Texas.

Slope (point)	**Measured Distance (meters)**	**Slope Angle (degrees)**
1	5.76	39.24
2	6.57	35.31
3	2.31	62.14
4	7.93	30.26
5	5.07	43.03
6	7.80	29.54
7	3.92	53.47
8	7.13	34.67
9	8.84	28.07
10	6.66	34.67
11	10.83	23.83
12	14.78	18.00
13	10.18	24.62
14	13.73	19.71
15	16.50	15.38
16	12.59	19.71
17	9.97	25.80
18	13.20	19.71
19	13.56	19.29
20	14.32	18.00
21	25.00	9.93
22	25.97	9.93
23	28.57	9.00
24	24.84	11.77
25	29.30	8.58
26	7.79	30.61
27	28.75	10.39
28	24.69	12.68
29	17.36	16.70
30	25.13	11.77
Mean	**14.30**	**24.19**
Maximum	**29.30**	**62.14**
Minimum	**2.31**	**8.58**
Range	**26.99**	**53.56**

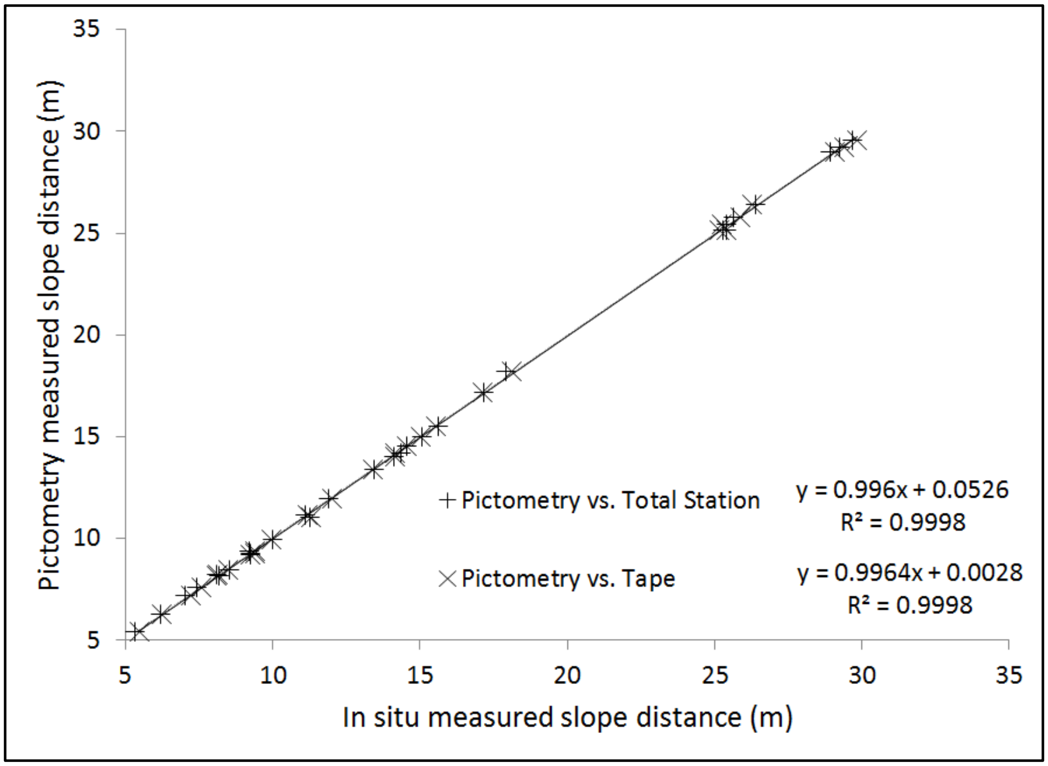

Figure 7. Scatterplot of Pictometry® measured slope distance versus *in situ* measured total station and tape slope distance.

Table 3. Analysis of variance (ANOVA) results between Pictometry®, total station and tape measured slope distance between the top of 30 light poles and their respective ground level coordinate identified within a central parking lot on the residential campus of Stephen F. Austin State University, Nacogdoches, Texas.

SUMMARY

Groups	Count	Sum	Average	Variance
Pictometry	30	460.9	15.4	60.9
Total Station	30	461.1	15.4	61.4
Tape	30	462.4	15.4	61.3

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.05	2	0.0240	0.0004	0.9996	3.1013
Within Groups	5326.075	87	61.2193			
Total	5326.123	89				

Table 4. T-test results between the absolute difference between Pictometry® and tape measured slope distance and the absolute difference between Pictometry® and total station measured slope distance between the top of 30 light poles and their respective ground level coordinate identified within a central parking lot on the residential campus of Stephen F. Austin State University, Nacogdoches, Texas.

	Total Station	**Tape**
Mean	0.3151	0.2877
Variance	0.052894783	0.068666782
Observations	30	30
Pooled Variance	0.060780782	
Hypothesized Mean Difference	0	
df	58	
t Stat	0.430964074	
P(T<=t) one-tail	0.334045990	
t Critical one-tail	1.671552762	
P(T<=t) two-tail	0.668091980	
t Critical two-tail	2.001717484	

4. DISCUSSION

The integration of hyperspatial resolution multispectral data into a web based interface was effective at measuring slope distance and proved statistically equivalent to in situ slope distance measurements when using a total station or tape. An ANOVA between Pictometry®, total station, and tape measured slope distance with a p-value of 0.9996 indicated there was not a significant difference between Pictometry®, total station, and tape measured slope distance. A two-tail t-test between the absolute difference between Pictometry® and tape measured slope distance and the absolute difference between Pictometry® and total station measured slope distance with a p-value of 0.6680 indicated there was not a significant difference between the two measurement errors implying all methods were equally accurate and in high agreement with each other. In addition, total station and tape measured slope distance revealed a very high agreement with Pictometry® measured slope distance with a coefficient of determination greater than 0.99 and a regression coefficient (slope) close to 1.0. The results indicate that slope distance measured with Pictometry® hyperspatial 4-inch (10.2 centimeters) multispectral imagery within a web based interfaced can be used in lieu of in situ total station and tape measured slope distance. The close agreement seen visually within a scatterplot (Figure 7) from both the total station and the tape measure distance indicates all three methods give accurate (close agreement) measurements of slope and slope distance.

The measurement of slope is important in use of area measurements for calculation of losses from damage as each point in Pictometry® is georeferenced and both slopes and areas of building roofs and be reconstructed form existing imagery (Gerke and Kerle 2011). Pictometry slope analysis increases the efficiency of calculating area for solar panels on sloped roofs (Hoberg 2012). The accuracy of Pictometry® for slope measurement will increase speed and measurements of forest trees as slope is one of the main variables used in determining the height of a tree from a distance (Figure 6). Traditionally foresters go out to a fixed distance and estimate a tree with a clinometer or similar measuring device that measures from the base to the top of the tree for height. Onscreen digitizing of trees was as accurate as height measured with a pole using Pictometry® (Unger et al. 2015); and for building heights (Kulhavy et al. 2015). As Pictometry coverage expands, the use of the imagery will increase, especially in municipal areas. The resolution of the 10 cm Pictometry® imagery is increasing in use in urban planning, forestry and damage assessment.

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