1-2015

Urban Tree Height Assessment Using Pictometry Hyperspatial 4-Inch Multispectral Imagery

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BRIEF COMMUNICATION

J. For. 113(1):7–11
http://dx.doi.org/10.5849/jof.14-020

geospatial technologies

Urban Tree Height Assessment Using Pictometry Hyperspatial 4-Inch Multispectral Imagery

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Tree height is a critical variable of forest inventory assessments, and estimating the height of trees has been a component of forest inventory assessments for decades. The actual tree height of 60 open-grown baldcypress (*Taxodium distichum*) trees measured with a telescopic height pole were compared to Pictometry hyperspatial 4-in. multispectral imagery estimated tree height on the campus of Stephen F. Austin State University, Nacogdoches, Texas. Linear correlation coefficients (*r*) between actual tree height and Pictometry-estimated tree height for all 60 trees and the shortest 30 and tallest 30 trees were $>$0.997 for all *r* values. Pictometry-estimated tree height was within, on average, 1.77, 2.15, and 1.40% of actual tree height for all 60 trees, the shortest 30 trees, and the tallest 30 trees, respectively. All three paired *t*-tests, for all 60 trees, the shortest 30 trees, and the tallest 30 trees, resulted in a *P* value $\geq$0.08, indicating that there was no statistical significance between actual and estimated tree height at a 95% confidence level. Pictometry-estimated tree height can be used in lieu of field-based tree height estimation for open-grown urban forests.

Keywords: Pictometry, hyperspatial, accuracy, tree height, baldcypress

Tree height is a critical component of any forest inventory assessment. Estimating the height of trees has been a mainstay in forest inventory assessments for decades (Chapman and Demeritt 1936, Forbes 1955, Avery and Burkhart 1994). When a forest stand assessment is performed, the height of an individual tree or average height of a stand of trees can be used to assess nominal tree age (Monserud 1984), estimate volume (Tewari and Gadow 1999), evaluate site index (Waring et al. 2006), and estimate tree growth rates (Carmean 1972). Numerous methods to estimate tree height have been developed and proven successful and fall into three general categories: traditional field methods, remote sensing, and remote sensing within a web-based interface.

Traditional Field Measurements

Tree height for an open-grown individual tree or average height of a stand of trees has been estimated with a clinometer (Kovats 1997). Standing on a horizontal plane 100 ft from the base of a tree, the percent slope read to the bottom of the tree (negative percent slope) is added to the percent slope read to the top of the tree (positive percent slope) if the horizontal plane from one's eye to the tree bole intersects the tree bole above the groundline. The addition of the absolute value of the negative percent slope to the bottom of the tree plus the positive percent slope to the top of the tree results in total tree height (Avery 1975). In one study, coefficients of determination between actual tree height and estimated tree height using a clinometer ranged from 0.9462 to 0.9501 (Williams et al. 1994). Rennie (1979) determined loblolly pine (*Pinus taeda*) heights to within 3 ft of actual height using a clinometer.

Tree height has also been estimated with a laser rangefinder, allowing the operator to stand at any distance from the tree with the clearest view of the top and bottom to increase the accuracy of height estimates (Asner et al. 2002). The operator uses the laser rangefinder to visually record the bottom and top of a tree with the laser rangefinder, providing the resulting height without a need for mathematical calculations. Linear correlation coefficients between actual tree height and estimated tree height using a laser rangefinder have ranged from 0.9250 to 0.9293 (Williams et al.

Received February 13, 2014; accepted August 11, 2014; published online September 18, 2014.

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Acknowledgements: *This project was funded in part by the McIntire-Stennis Cooperative Forestry Research Program.*

1994). Although use of a clinometer or laser rangefinder is relatively straightforward and easy, estimating tree height for a large volume of trees with either of these instruments over a large geographic area can be time-consuming and expensive.

Remote Sensing

Aerial photography to estimate tree height has also been used in forest inventory assessments for decades (Avery 1977). A stereoscopic pair of aerial photographs has proven successful for estimating tree heights by converting parallax displacement measured along a flight path into a height estimate (Titus and Morgan 1985). The straight displacement of an object within an aerial photograph, along with flying height, can also be used to estimate tree height as can an object's shadow (Paine 1981). Although estimation of tree height with aerial photos provides large geographic coverage not available with field-based estimations, it can be time consuming when one is dealing with a large number of aerial photographs and not applicable within a dense closed-canopy condition.

Light detection and ranging (LiDAR) data are a relatively new form of remotely sensed data compared with traditional digital imagery obtained from satellites or an aerial platform (Means 1999). LiDAR uses laser scanning to estimate the height and elevation of the landscape's physical attributes (Maltamo et al. 2006). LiDAR uses either full-waveform or discrete return laser light that strikes objects or bare ground on the earth's surface and determines the return location by measuring the time it takes for the light to return to the sensor. The return time for each pulse is used to calculate distance from the sensor, which can be used to derive a forest canopy height or digital terrain model. The difference in elevation between a canopy height and digital terrain model is the height of the forest canopy. Height estimates obtained from narrow-beam LiDAR data were within 1.41 ft of actual tree height and within 1.84 ft of actual tree height using wide-beam LiDAR data (Anderson et al. 2006). In western Oregon, the LiDAR data error exceeded 10% of tree height for 60% of trees at leaf-on and 55% of trees at leaf-off (Gatziolis et al. 2010). Popescu and Wynne (2004) and Popescu et al. (2002) found that LiDAR and multispectral data fusion was satisfactory for estimating forest plot-level tree height, accounting for 97% of the variance of the mean tree height of dominant pines.

Figure 1. Measuring urban tree height onscreen using Pictometry multispectral imagery.

Web-Based Interface

Pictometry is the name of an aerial image capture process patented by Pictometry International Corporation (Rochester, NY) and is classified as hyperspatial resolution remotely sensed data. Pictometry data are similar to the data available with the commercial grade satellites IKONOS (Dial et al. 2003), QuickBird (Sawaya et al. 2003), and GeoEye (Dennison et al. 2010) in application, but Pictometry data are acquired at a finer spatial resolution than those for commercial-grade satellite sensors.

Pictometry data are acquired via low-flying aircraft along a predetermined flight path and altitude above mean sea level within the coverage area. Flight paths are both parallel and perpendicular to and equidistant from each other to obtain imagery from multiple perspectives. The digital images captured by low-flying aircraft include a vertical perspective and oblique angles up to 40° that depict the fronts and sides of ground features in a web-based interface. Images acquired depict up to 12 oblique perspectives and are stitched together to create a composite image that a can be used to estimate surface object size and position. The estimates can be accomplished in seconds within the Pictometry web-based interface (Figure 1) as opposed to the time-consuming estimates obtained using a clinometer, laser rangefinder, aerial photograph, or LiDAR data (Wang et al. 2008).

Tree height for citrus trees were estimated with 89% height accuracy using Pictometry data (Ayyalssomayajula et al. 2009). Hohle (2008) had an average error of 0.66 ft when using Pictometry data to estimate the height of houses and towers, whereas Dailey (2008) found the root mean square error for Pictometry derived heights was 2.69 ft when measuring the height of buildings.

Remote sensing, with its ability to col-

Management and Policy Implications

Estimating tree height accurately, which is a critical component of any forest inventory, can be time-consuming and expensive. Tree height estimated remotely using the Pictometry web-based interface with high spatial resolution digital imagery was shown to be highly accurate. Estimation of tree height by remotely sensed imagery can be used in lieu of field-based tree height estimation for open-grown forests.

lect data systematically over large geographic areas, combined with the increased ease of integrating high spatial resolution multispectral data into a web-based interface, has the potential to revolutionize tree height estimation (Jurisch and Mountain 2008, Abd-Elrahman et al. 2010).

Methods

In this study, we evaluated the use of Pictometry hyperspatial 4-in. multispectral imagery to estimate the height of baldcypress (*Taxodium distichum*) trees along the banks of Lanana Creek on the campus of Stephen F. Austin State University, Nacogdoches, Texas. The goal was to assess the accuracy of Pictometry-estimated baldcypress tree height obtained from a web-based interface by comparing estimated height with the actual height measured in the field with a height pole.

In 2013, the Arthur Temple College of Forestry and Agriculture partnered with a consortium of users composed of the County of Nacogdoches 911 District, the City of Nacogdoches, and the Nacogdoches County Appraisal District to purchase 2013 Pictometry multispectral imagery. The purchase included 9-in. spatial resolution multispectral imagery for the entire county of Nacogdoches and 4-in. spatial resolution multispectral imagery for the City of Nacogdoches. The Pictometry imagery was acquired in late February and early March of 2013 to provide leaf-off images to maximize the temporal difference of forest coverage within the county.

The heights of 60 baldcypress trees were measured during April and May 2013. Tree height was measured in situ with a telescopic height pole in 1-in. increments, with one person holding the height pole vertical next to each tree and another person standing at least one chain distance away to visually assess when the height pole and the top of each tree were equal. The heights of all 60 baldcypress trees were estimated on-screen to 0.1 ft using Pictometry oblique hyperspatial 4-in. multispectral imagery via a web-based "black box" proprietary interface during summer 2013, and the image itself was acquired during February and March 2013. On-screen estimates and field-measured tree heights, recorded by three separate individuals to eliminate tree height bias estimation, represented in situ conditions before the start of the spring 2013 growing season.

Linear correlation coefficients between actual tree height and Pictometry-estimated height for all 60 trees and the shortest 30 and tallest 30 trees were calculated. A paired *t*-test was also conducted for each of the three groups to test for statistical significance between actual and estimated tree height.

Table 1. Tree height measurements of actual height and Pictometry-estimated height, differences between the two, and percent disagreement.

Tree identification	Actual height (ft)	Pictometry height (ft)	Height difference (ft)	Absolute difference (ft)	Disagreement (%)
3526	6.07	6.10	0.03	0.03	0.54
3527	6.20	6.56	0.36	0.36	5.82
3755	6.27	6.56	0.30	0.30	4.71
3528	6.43	6.53	0.10	0.10	1.53
3521	6.50	6.50	0.00	0.00	0.00
3525	7.51	7.45	−0.07	0.07	0.87
3732	8.01	7.51	−0.49	0.49	6.15
3520	8.60	7.91	−0.69	0.69	8.02
3533	8.66	8.83	0.16	0.16	1.89
3731	9.25	9.35	0.10	0.10	1.06
3524	10.01	9.78	−0.23	0.23	2.30
3730	10.01	10.30	0.30	0.30	2.95
3497	13.39	13.55	0.16	0.16	1.23
3881	13.58	14.83	1.25	1.25	9.18
3523	15.68	15.78	0.10	0.10	0.63
3501	16.37	16.47	0.10	0.10	0.60
3498	17.32	17.29	−0.03	0.03	0.19
3510	17.68	18.18	0.49	0.49	2.78
3499	18.24	18.21	−0.03	0.03	0.18
3509	18.50	18.77	0.26	0.26	1.42
3511	19.52	19.65	0.13	0.13	0.67
3514	19.69	19.65	−0.03	0.03	0.17
3515	19.69	19.55	−0.13	0.13	0.67
3530	19.91	20.01	0.10	0.10	0.49
3500	20.01	20.05	0.03	0.03	0.16
3506	20.01	20.11	0.10	0.10	0.49
3503	20.51	20.57	0.07	0.07	0.32
3512	21.69	22.41	0.72	0.72	3.33
3513	21.85	21.49	−0.36	0.36	1.65
3518	21.85	22.83	0.98	0.98	4.50
3516	22.01	21.98	−0.03	0.03	0.15
3508	22.51	22.90	0.39	0.39	1.75
3502	23.10	23.13	0.03	0.03	0.14
3519	23.75	23.82	0.07	0.07	0.28
3507	24.02	25.30	1.28	1.28	5.33
3517	24.02	24.77	0.75	0.75	3.14
3505	24.34	24.28	−0.07	0.07	0.27
3892	24.51	23.62	−0.89	0.89	3.61
3890	25.33	26.05	0.72	0.72	2.85
3532	25.43	24.67	−0.75	0.75	2.97
3504	25.75	25.79	0.03	0.03	0.13
3529	26.67	26.44	−0.23	0.23	0.86
3891	28.12	27.89	−0.23	0.23	0.82
3879	29.49	29.53	0.03	0.03	0.11
3880	31.00	31.89	0.89	0.89	2.86
3882	31.43	31.63	0.20	0.20	0.63
3889	34.68	34.22	−0.46	0.46	1.32
3883	36.02	36.19	0.16	0.16	0.46
3896	37.01	37.50	0.49	0.49	1.33
3899	37.01	36.75	−0.26	0.26	0.71
3884	37.43	37.99	0.56	0.56	1.49
3887	39.01	38.39	−0.62	0.62	1.60
3897	39.01	38.88	−0.13	0.13	0.34
3885	40.52	41.17	0.66	0.66	1.62
3886	40.52	40.72	0.20	0.20	0.49
3888	40.52	40.22	−0.30	0.30	0.73
3900	41.99	40.72	−1.28	1.28	3.05
3902	41.99	42.13	0.13	0.13	0.31
3898	43.01	42.39	−0.62	0.62	1.45
3901	43.01	43.50	0.49	0.49	1.14
Mean all 60	23.20	23.29	0.08	0.35	1.77
Mean shortest 30	14.30	14.43	0.13	0.26	2.15
Mean tallest 30	32.11	32.15	0.04	0.43	1.40

Results

There were minimal differences between actual tree heights and estimated tree heights (Table 1). The mean actual tree height for all 60 trees was 23.20 ft. The mean estimated tree height for all 60 trees was 23.29 ft. The shortest 30 trees had mean tree heights of 14.30 and 14.43 ft for actual tree height and estimated tree height, respectively. The tallest 30 trees had mean tree heights of 32.11 and 32.15 ft for actual tree height and estimated tree height, respectively. The estimated tree height was within, on average, 1.77% of actual height for all 60 trees. The estimated tree height was within, on average, 2.15 and 1.40% of actual height for the shortest 30 trees and the tallest 30 trees, respectively.

A scattergraph of estimated tree height versus actual tree height indicated a strong relationship between in situ and remotely sensed tree height (Table 2; Figure 2). A linear correlation coefficient between actual tree height and estimated height for all 60 trees was 0.999. Linear correlation coefficients between actual tree height and estimated tree height were 0.998 and 0.997 for the shortest 30 trees and the tallest 30 trees, respectively.

Before the paired *t*-test was conducted, a Shapiro-Wilk test was performed that resulted in a W value of 0.9732 ($P = 0.2078$), indicating the differences between actual tree height and estimated tree height are normally distributed. Then, a paired *t*-test between actual tree height and estimated tree height with a 95% confidence interval indicated no statistical difference between in situ and estimated height (Table 2). The calculated P value between actual tree height and estimated height for all 60 trees was 0.18. The calculated P values between actual tree height and estimated tree height were 0.08 and 0.70 for the shortest 30 trees and the tallest 30 trees, respectively.

Although Pictometry consistently overestimated the height of our open-grown baldcypress, we attribute this bias to the difficulty in identifying the top of the crown on these trees in leaf-off conditions and expect a better estimate when the trees are leafed-out. Even though the estimated and actual usbheights did not turn out to be statistically different from each other, a user of the Pictometry web-based interface needs to be aware of the tendency to overestimate actual tree height and could adjust the measurement accordingly, depending on leaf condition.

Table 2. Comparison and correlation between actual tree height and Pictometry-estimated height for all 60 trees, the shortest 30 trees, and the tallest 30 trees.

Sample	Actual mean (SD) height (ft)	Pictometry mean (SD) height (ft)	*t*-statistic	*P*	Linear correlation (*r*)
All 60 trees	23.20 (11.17)	23.29 (11.13)	−1.34	0.18	0.999
Shortest 30 trees	14.30 (5.82)	14.43 (5.91)	−1.80	0.08	0.998
Tallest 30 trees	32.11 (7.47)	32.15 (7.39)	−0.39	0.70	0.997

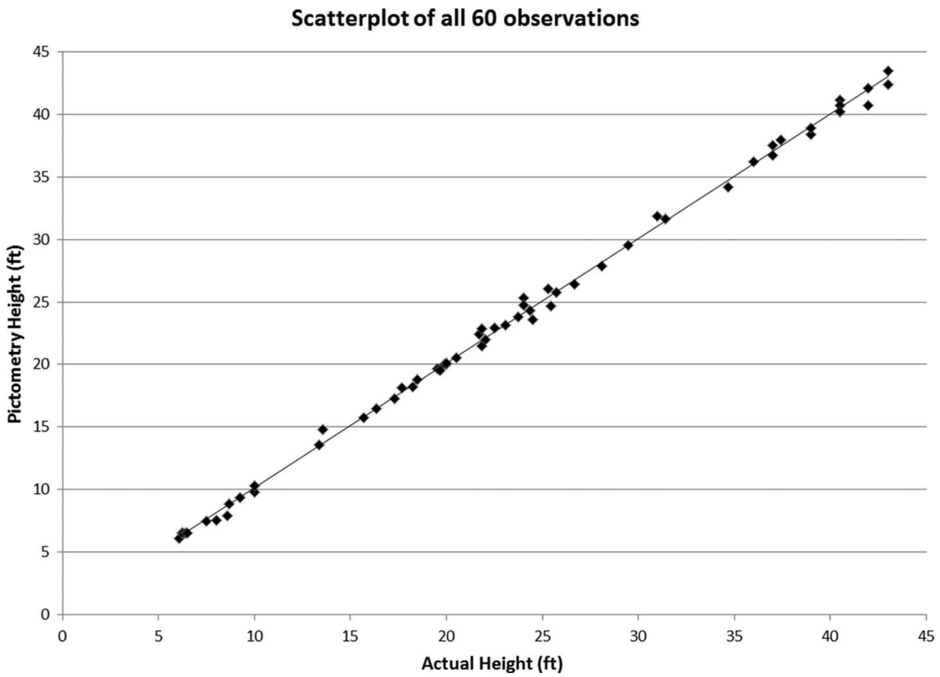

Figure 2. Scattergraph of Pictometry-estimated tree height versus actual tree height.

Conclusions

Estimating tree height has been a critical component of forest inventory assessments for decades. Although estimating tree height in situ is relatively straightforward, the ability to estimate tree height for multiple individual trees or stands of trees over remote and expansive areas can be time-consuming and expensive.

Remote sensing with its ability to collect data systematically over large geographic areas has the potential to aid field-based tree height estimation within an urban setting. The integration of hyperspatial resolution multispectral data into a web-based interface was effective for estimating tree height within seconds. In addition, crown shape, which can add difficulty in assessing tree height in situ, is not an issue in the Pictometry web-based interface, which allows a visual assessment of the top of a tree crown within an open grown urban setting. Estimation of the height of open-grown urban trees using the Pictometry web-based interface could be used to supplement or replace time-consuming field-based tree height estimation.

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