Accuracy of Unmanned Aerial System (Drone) Height Measurements

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Abstract
Vertical height estimates of earth surface features using an Unmanned Aerial System (UAS) are important in natural resource management quantitative assessments. An important research question concerns both the accuracy and precision of vertical height estimates acquired with a UAS and to determine if it is necessary to land a UAS between individual height measurements or if GPS derived height versus barometric pressure derived height while using a DJI Phantom 3 would affect height accuracy and precision. To examine this question, height along a telescopic height pole on the campus of Stephen F. Austin State University (SFASU) were estimated at 2, 5, 10 and 15 meters above ground using a DJI Phantom 3 UAS. The DJI Phantom 3 UAS (i.e., drone) was flown up and down the telescopic height pole to estimate height at the 2, 5, 10 and 15 meter locations using four different user controlled flight modes with a total of 30 observations per flight mode. Flight mode configurations consisted of having GPS estimate height while landing the drone between flights, non-GPS mode to estimate height via barometric pressure while landing the drone between flights, flying continuously up and down the height pole while estimating height with GPS on, and flying continuously up and down the height pole in non-GPS mode to estimate height via barometric pressure. A total of 480 height measurements were recorded (30 measurements per height interval per all four flight mode combinations). Standard deviation results indicated that height measurements taken with the drone were less precise when landing was not reset between measurements. Root mean square error (RMSE) analysis indicated that having the landing reset without GPS on achieved the highest accuracy of all measurements taken. An ANOVA conducted on the absolute errors reconfirmed that having the landing reset before each height measurement using the drone achieved higher accuracy compared to flying the drone continuously. This indicates the practical application of height measurement of the DJI Phantom 3 UAS and the importance of resetting the UAS before each height measurement.

Keywords
UAS, drone, height, accuracy, GPS

1 INTRODUCTION

Estimating the height of vertical features (trees, buildings, light poles) on the earth's surface is a critical component of *in situ* assessments and remote sensing applications. The traditional method of estimating height *in situ* for a vertical feature 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). *In situ* height can also be estimated with a laser range finder with estimated tree height using a laser ranging from 0.9250 to 0.9293 (Williams et al. 1994).

The general field of remote sensing, including aerial photography and LiDAR (Light Detection and Ranging), has also been used to estimate height. Aerial photography has been used to estimate height since the dawn of aerial photography using image displacement within overlapping areas of a stereoscopic pair of aerial photos (Avery 1977) while LiDAR data uses laser-scanning of the earth's surface to convert reflected energy into a height estimate (Anderson et al. 2006; Gatziolis et al. 2010; Kulhavy et al. 2015; Maltamo et al. 2006).

Pictometry® data, which are a relatively new form of digital imagery acquired via an airplane based platform, mimic data obtained from commercial grade satellites like IKONOS, QuickBird and GeoEye (Sawaya et al. 2003). Pictometry® data are acquired along a predetermined flight path similar to traditional aerial photography but include imagery obtained from multiple perspectives including nadir and oblique angles up to 40 degrees that are used to create a composite image that a user can use to accurately measure earth surface feature height using the Pictometry® patented web based interface (Kulhavy et al. 2015; Unger et al. 2014; Unger et al. 2016a; Wang et al. 2008).

Unmanned aerial systems (UASs), also known as drones, can also be used to estimate height of earth's surface features. By flying a drone up and down the vertical profile of an earth's surface feature a drone can estimate height interactively along the vertical profile based on its GPS trilateration or via an internal barometer which is user controlled (Khanna et al. 2015; Themistocleous 2014; Unger et al. 2016b). With the advent of this new technology it is important to determine if drone height estimates will be equal to or better than the traditional methods of estimating height with a clinometer, laser range finder, aerial photographs, LiDAR or Pictometry® data.

An important research question addressed by this study concerns the accuracy and precision of vertical height measurements acquired with a UAS (drone). In particular, this study determined if it is necessary to land a UAS between individual height measurements or if GPS derived height versus barometric pressure derived height while using a DJI Phantom 3 drone would affect drone estimated height accuracy and precision. Little research has addressed the concern of assessing height accuracy between drone flight mode options for a specific drone with the DJI Phantom 3 chosen for this study based on its ease of use, popularity, affordability and continued use in the spatial science community. This study gives an insight on the optimum setting for accuracy when one is using a commercially available drone to measure height on a few objects and attain the height value immediately without any further data processing.

2 METHODOLOGY

This study evaluated the use of a drone to estimate height along a telescopic height pole on the campus of Stephen F. Austin State University (SFASU) in Nacogdoches, Texas. The objective was to compare the actual height at four intervals of 2, 5, 10 and 15 meters above ground along the vertical profile of a telescopic height pole with their estimated height derived via a DJI Phantom 3 drone. To determine if drone flight mode (GPS on or off and flying continuously or landing and resetting the drone between flights) affects height accuracy the DJI Phantom 3 was used to estimate height 30 times at each height interval of 2, 5, 10 and 15 meters by altering the DJI Phantom 3 drone flight modes of flying continuously with GPS on, flying continuously with GPS off, landing and resetting the drone with GPS on, and landing and resetting the drone with GPS off for all 30 height estimations per four height locations.

A telescopic height pole was setup vertically on the SFASU campus away from student walkways and trees to provide a clear vertical flying path for the DJI Phantom 3 (Figure 1). To facilitate drone vertical height measurements remotely, a telescopic height pole with clear markings was used to aid the identification of each height interval at 2, 5, 10, and 15 meters along the pole (Figure 2). For each vertical height identified (2, 5, 10, and 15 meters) the drone, when the GPS was turned on, was flown continuously up and down the telescopic height pole 30 times without landing while recording height at each of the four height intervals resulting in 120 observations (Figure 3). While in flight, the estimated height of the drone, when observed on-screen to be at each identified vertical location, was recorded (Figure 4). This process was repeated 3 more times while using only the internal barometer to calculate height without the GPS when flown continuously up and down the telescopic height pole 30 times without landing per height interval (120 observations); with the GPS on when flown up and down the telescopic height pole 30 times per height interval while landing the UAS each time (120 observations); and using only the internal barometer without the GPS to calculate height when flown up and down the telescopic height pole 30 times per height interval while landing the UAS each time (120 observations).

To assess the accuracy between DJI Phantom 3 estimated height and actual height per height interval stratified by user-controlled drone flight mode and height estimation, the average, standard deviation, and RMSE (Equation 1) of drone estimated height per combination was calculated for each set of 30 observations.

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

Figure 1. Location of telescopic height pole on the campus of Stephen F. Austin State University.

Figure 2. Measurement unit increments on the telescopic height pole on the campus of Stephen F. Austin State University.

Figure 3. Flying a drone up and down the telescopic height pole to visually record height.

Figure 4. Height of drone recorded on-screen during a flight.

In order to test for accuracy differences between DJI Phantom 3 estimated height and actual height per height interval stratified by user controlled drone flight mode, a series of two-factor (landing and GPS) analysis of variance (ANOVA) was conducted on the absolute errors (replication n = 30) for each set of 30 observations.

3 RESULTS AND DISCUSSION

A total of 480 height measurements were recorded using a DJI Phantom 3 drone. At each of the four height locations (2, 5, 10, and 15 m) along the telescopic height pole, the height was recorded with the drone 30 times. This process was repeated at each telescopic height pole point four times, with the four combinations of GPS On/Off and landing Reset/Continuous. The average of drone estimated height (n = 30) of each combination at different height points can be found in Table 1 while Figure 5 shows the visual height comparison. It is obvious that the drone estimated heights are closer to the actual height when the drone landing was reset for each measurement, while the continuous mode without landing tended to overestimate the actual height at all measured height intervals. When comparing between having GPS on and off, GPS on consistently measured the height greater than with GPS off. However, this difference is not as obvious as that of the landing setting.

In order to see the variation of data observed, the standard deviation of the drone measured height values of each setting is displayed in Figure 6. Height measurement taken with the drone was less precise when landing was not reset for each measurement. This higher variation of drone measured height without landing reset held the same trend across all of the four measured height intervals. When comparing data precision between having GPS on and off, it appeared that the GPS was introducing noise in height measurement that resulted in higher data variation, although its effect is not as obvious as that of landing setting.

The RMSE was calculated for assessing the accuracy of height measurement by using the drone. Figure 7 echoed what was observed in average height (Table 1 and Figure 5), where having the landing reset with GPS off achieved the highest accuracy (RMSE = 0.17 m), while having no landing reset with GPS on was the least accurate (RMSE = 2.48 m).

Table 1. Average of drone estimated height values at different height intervals by landing and GPS settings. (n = 30)

GPS Mode	**Average Measured Height per Height Interval (m)**			
	2-meter	**5-meter**	**10-meter**	**15-meter**
Continuous-GPS	4.05	6.98	11.88	16.81
Continuous-No GPS	3.73	6.71	11.61	16.50
Landing-GPS	2.26	5.20	10.28	15.39
Landing-No GPS	1.91	4.88	9.99	14.96

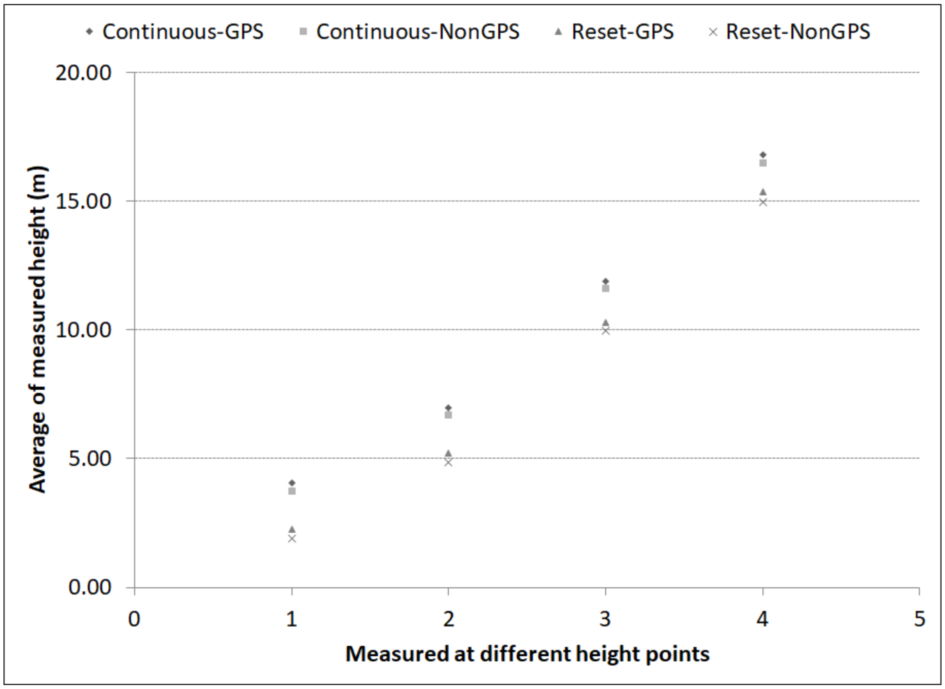
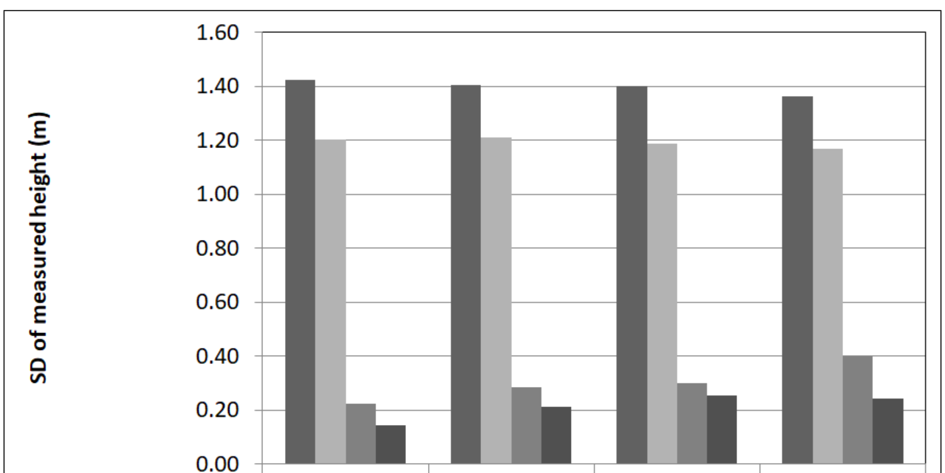


Figure 5. Average of drone estimated height values at different height intervals by landing and GPS settings. (n = 30, 1: 2m, 2: 5m, 3: 10m, and 4: 15m above the ground)



	2-meter	5-meter	10-meter	15-meter
Continuous-GPS	1.42	1.40	1.40	1.36
Continuous-NonGPS	1.20	1.21	1.19	1.17
Reset-GPS	0.22	0.28	0.30	0.40
Reset-NonGPS	0.14	0.21	0.25	0.24

Figure 6. Standard deviation of drone estimated height values at different height intervals by landing and GPS settings. (n = 30)

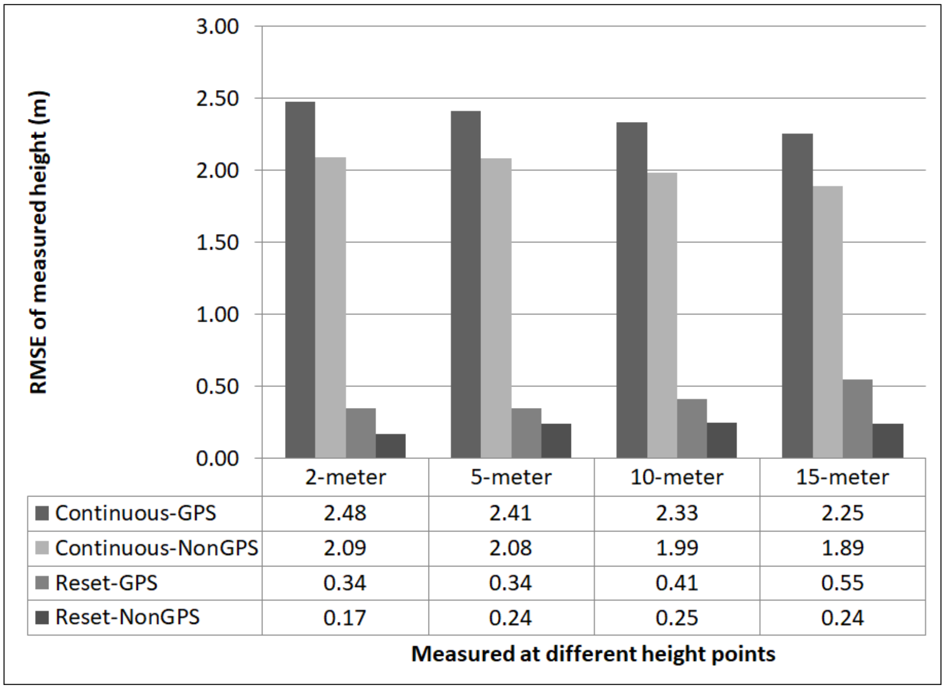


Figure 7. Root mean square error (RMSE) of drone estimated height values at different height intervals by landing and GPS settings. (n = 30)

While having no landing reset was much less accurate than having reset, it seems the accuracy increased while measuring at higher measuring intervals. The opposite trend was found for the groups of having the landing reset, where higher errors were found at higher measuring intervals. The same pattern was also found when plotting average again standard deviation of height measurements. Figure 8 shows that the precision of the continuous methods increased when measuring higher point intervals, while the precision of the reset methods decreased.

In order to test if accuracy between the different drone settings on estimated height was statistically significant, a series of two-factor (landing and GPS) ANOVA was conducted on the absolute errors (replication n = 30), each on a measured height interval. Table 2 summarizes the mean absolute error of each combination, with lower values representing higher accuracy. It was reconfirmed that having the landing reset before each height measurement using the drone achieved higher accuracy compared to having no reset.

Table 2. Mean absolute error of drone estimated height values at different height intervals by landing and GPS settings. (n = 30)

GPS Mode	Mean Absolute Error per Height Interval (m)			
	2-meter	5-meter	10-meter	15-meter
Continuous-GPS	2.05	1.99	1.90	1.82
Continuous-No GPS	1.73	1.71	1.62	1.52
Landing-GPS	0.26	0.24	0.31	0.45
Landing-No GPS	0.15	0.18	0.21	0.19

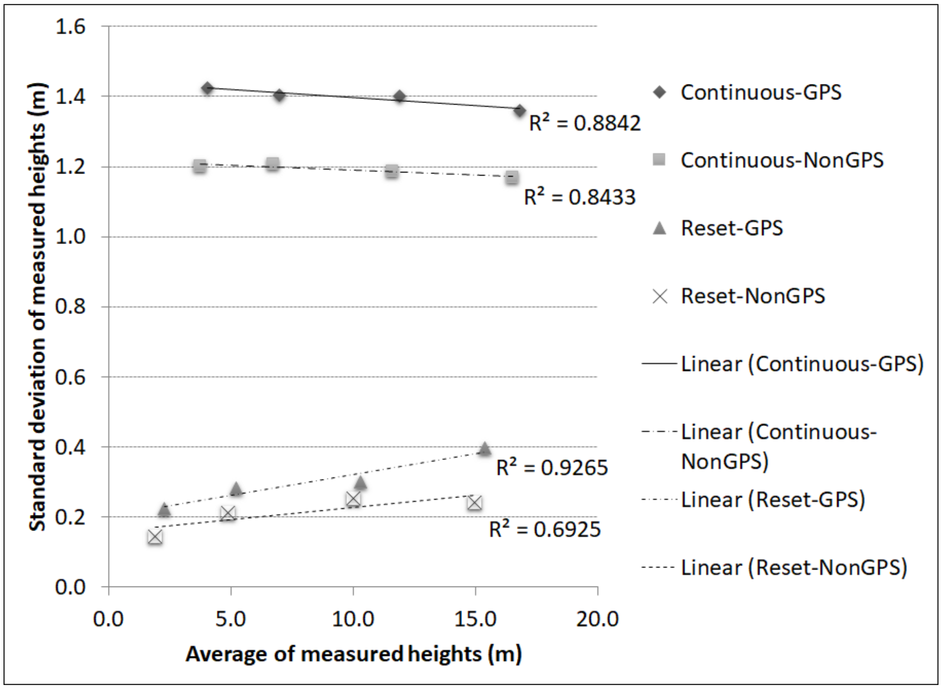


Figure 8. Average vs. standard deviation of estimated height values of at different height intervals by landing and GPS settings. (n = 30)

The interaction between the two factors, landing and GPS, was observed graphically in Figures 9-12. It was found that there was no interaction between the two factors at all of the four measured height intervals. Having landing reset always resulted in higher accuracy regardless the GPS setting. This is confirmed statistically in the ANOVA (Tables 3-6) where none of the interaction is significant (p-values range from 0.5209 to 0.9163). Also found not significant is the factor of GPS at all measured height intervals (*p*-values range from 0.2020 to 0.2501), except the 15-m measured height interval (*p*-value = 0.0887). Having the GPS on did not make a difference when estimating height with the drone, except that having GPS on reduced the accuracy significantly when measuring at the height interval of 15 m.

What made a significant difference in height estimated with the drone is the landing setting. Compared to flying the drone to different height points continuously, landing the drone on the ground before taking each height measurement resulted in much higher accuracy at all measured height intervals (mean absolute errors range from 0.15 to 0.21 m) where all of the *p*-values are less than 0.0001.

For the drone tested in this study, the main device used for measuring height is the on-board barometer chip. It sets the ground level as zero and measures height above ground after takeoff by detecting the atmospheric pressure change. The barometer height accuracy degrades overtime due to the local change of air temperature and wind speed which explains why resetting the drone for each height measurement achieved the highest accuracy. When the GPS was turned on, it introduced uncertainty in height measurement due to the low precision for GPS measuring elevation, which was also found in this study.

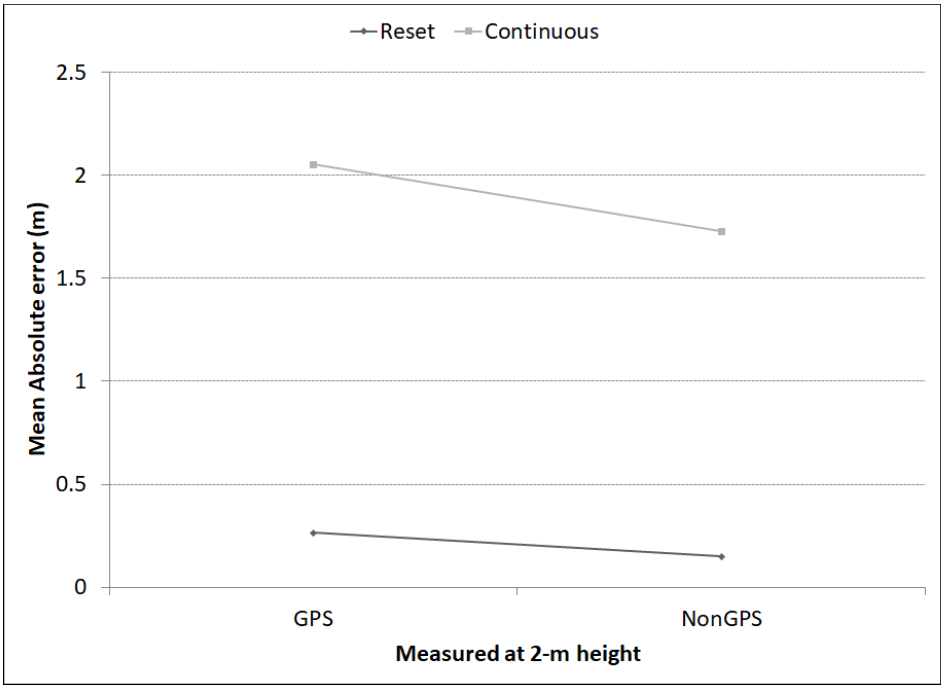


Figure 9. Mean absolute error of drone estimated height values at 2-m height interval by landing and GPS settings. (n = 30)

Figure 10. Mean absolute error of drone estimated height values at 5-m height interval by landing and GPS settings. (n = 30)

Figure 11. Mean absolute error of drone estimated height values at 10-m height interval by landing and GPS settings. (n = 30)

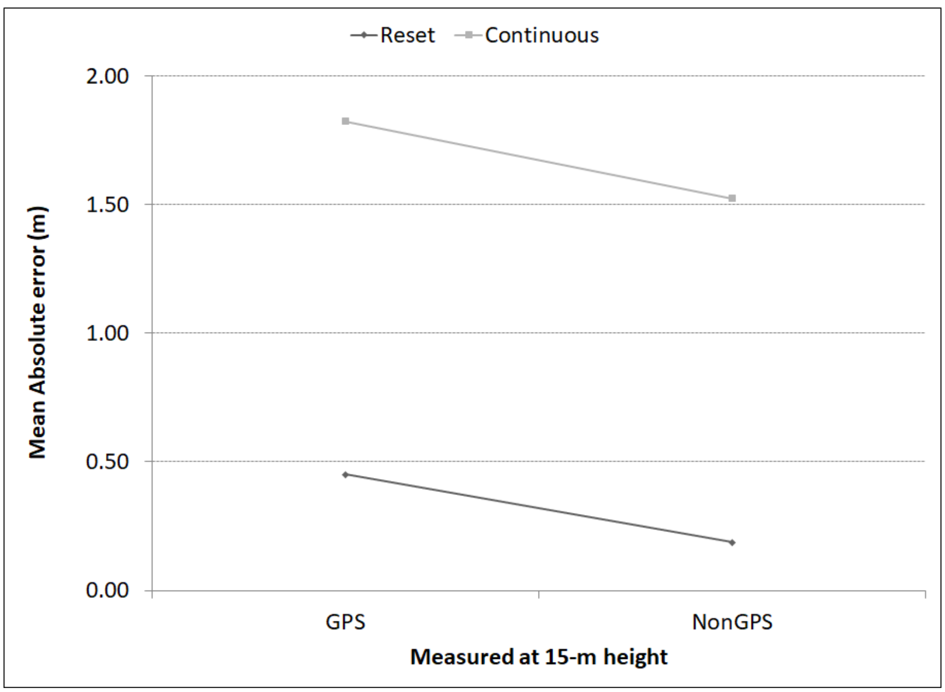


Figure 12. Mean absolute error of drone estimated height values at 15-m height interval by landing and GPS settings. (n = 30)

Table 3. ANOVA on absolute error of drone estimated height values at 2-m height by landing and GPS settings. (n = 30)

2-m ANOVA

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Landing	84.9833	1	84.9833	97.2244	5.02E-17	3.92288
GPS	1.4392	1	1.4392	1.6465	0.2020	3.92288
Interaction	0.3346	1	0.3346	0.3828	0.5373	3.92288
Within	101.3949	116	0.8741			
Total	188.1521	119				

Table 4. ANOVA on absolute error of drone estimated height values at 5-m height by landing and GPS settings. (n = 30)

5-m ANOVA

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Landing	80.6405	1	80.6405	93.1916	1.54E-16	3.9228
GPS	0.858	1	0.858	0.9916	0.3214	3.9228
Interaction	0.3587	1	0.3587	0.4146	0.5209	3.9228
Within	100.377	116	0.8653			
Total	182.2343	119				

Table 5. ANOVA on absolute error of drone estimated height values at 10-m height by landing and GPS settings. (n = 30)

10-m ANOVA

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Landing	67.9299	1	67.9299	81.2547	4.82E-15	3.9229
GPS	1.1169	1	1.1169	1.336	0.2501	3.9229
Interaction	0.2467	1	0.2467	0.2951	0.5880	3.9229
Within	96.9774	116	0.836			
Total	166.2709	119				

Table 6. ANOVA on absolute error of drone estimated height values at 15-m height by landing and GPS settings. (n = 30)

15-m ANOVA

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Landing	55.1068	1	55.1068	68.1297	2.75E-13	3.9229
GPS	2.3845	1	2.3845	2.948	0.0887	3.9229
Interaction	0.009	1	0.009	0.0111	0.9163	3.9229
Within	93.8267	116	0.8089			
Total	151.327	119				

4 CONCLUSION

Remote sensing via drone technology with its ability to collect data systematically, and in inaccessible areas, has the potential to aid field-based height estimation. The integration of drone technology was effective at estimating height and proved to be as accurate as traditional height estimates using a clinometer, laser range finder and LiDAR data. Airborne LiDAR has been used for measuring object height in large area, particularly in forestry. In forest management, tree height is an indicator of site productivity and is hard to measure from the ground. Kaartinen et al. (2012) conducted a comprehensive research applying algorithms developed by international researchers for individual tree detection and extraction using airborne laser scanning. They found that the best models achieved a RMSE of 0.60-0.80 m in accuracy for tree height, which is no better than our highest accuracy (RMSE = 0.17 m) when having the landing reset with GPS off on the drone. While LiDAR usually covers a much larger area, it comes with a higher price point with more preparation and post processing. If the task is to have a quick height measurement on a few objects, a consumer grade drone is a good option.

Repeated height measurements at four different intervals along a telescopic height pole indicate the utility of using a drone to estimate height in the field. However, the study showed that to achieve the highest level of accuracy possible that the drone should land and be turned off before each flight to reset the height measurement algorithm before each flight.

The results from our study indicate the practical application of height measurements when using the DJI Phantom 3 UAS. A drone operator, after being introduced to basic drone operation procedures lasting an hour or less, can effectively use a drone to quantify height after mastering basic flight controls. If height is the only field measurement required this study demonstrated that estimating height can be obtained fast and efficiently with a drone as opposed to the more timely process of creating 3D representations of the landscape with drone acquired imagery which must be acquired remotely then processed in a computer environment using software similar to Drone2Map.

In particular, the results emphasis that it is imperative to reset the UAS before each height measurement to obtain the most accurate results rather than fly the UAS and continuously record measurements. However, it must be pointed out that our results represent height estimates using the DJI Phantom 3 drone which may not transfer to other drones and further research should be undertaken to validate the robustness of our research. In conclusion, a UAS when flown properly with the correct settings could be used to supplement or replace time consuming field-based height estimation and has the potential to revolutionize remotely sensed height measurements.

5 REFERENCES

Anderson, H-E., Reutebuch, S.E. and McGaughey, R.J. (2006) A rigorous assessment of tree height measurements obtained using airborne LiDAR and conventional field methods. *Canadian Journal of Remote Sensing*, 32, 355-366.

Avery, T.E. (1977) *Interpretation of Aerial Photographs*. Minneapolis, Minnesota: Burgess Publishing Company.

Gatziolis, D., Fried, J.S. and Monleon, V.S. (2010) Challenges to estimating tree height via LiDAR in closed-canopy forests: A parable from western Oregon. *Forest Science*, 56, 139-155.

Kaartinen, H., Hyyppä, J., Yu, X., Vastaranta, M., Hyyppä, H., Kukko, A., Holopainen, M., Heipke, C., Hirschmugl, M., Morsdorf, F., Næsset, E., Pitkänen, J., Popescu, S., Solberg, S., Wolf, B.M. and Wu J. (2012) An international comparison of individual tree detection and extraction using airborne laser scanning. *Remote Sensing*, 4, 950-974.

Khanna, R., Moller, M., Pfeifer, J., Liebisch, F., Walter, A. and Siegwart, R. (2015) Beyond point clouds—3D mapping and field parameter measurements using UAVs. *Proceedings of Emerging Technologies and Factory Automation 2015 IEEE 20th Conference*. Luxembourg City, Luxembourg, September.

Kovats, M. (1997) A large-scale aerial photographic technique for measuring tree heights on long-term forest installations. *Photogrammetric Engineering & Remote Sensing*, 63, 741-747.

Kulhavy, D.L., Unger, D.R., Hung, I. and Douglass, D. (2015) Integrating hands-on undergraduate research in an applied spatial science senior level capstone course. *International Journal of Higher Education*, 4, 52-60.

Maltamo, M., Hyyppa, J. and Malinen, J. (2006) A comparative study of the use of laser scanner data and field measurements in the prediction of crown height in boreal forests. *Scandinavian Journal of Forest Research*, 21, 231-238.

Sawaya, K., Olmanson, L.G., Heinert, N.J., Brezonik, P.L. and Bauer, M.E. (2003) Extending satellite remote sensing to local scales: land and water resource monitoring using high-resolution imagery. *Remote Sensing of Environment*, 88, 144-156.

Themistocleous, K. (2014) The use of UAV platforms for remote sensing applications: Case studies on Cyprus. *Proceedings of Second International Conference of Remote Sensing and Geoinformation of the Environment*. Paphos, Cyprus, August.

Unger, D.R., Hung, I., and Kulhavy, D.L. (2014) Comparing remotely sensed Pictometry® web-based height estimates with in situ clinometer and laser range finder height estimates. *Journal of Applied Remote Sensing*, 8. doi:10.1117/1.JRS.8.083590).

Unger, D., Kulhavy, D., Hung, I. and Zhang, Y. (2016a) Accuracy assessment of Pictometry height measurements stratified by cardinal direction and image classification. *International Journal of Geospatial and Environmental Research*, 3(1), Article 4.

Unger, D.R., Kulhavy, D.L., Busch-Petersen, K. and Hung, I. (2016b) Integrating faculty led service learning training to quantify height of natural resources from a spatial science perspective. *International Journal of Higher Education* 5, 104-116.

Wang, Y., Schultz, S. and Giuffrida, F. (2008) Pictometry's proprietary airborne digital imaging system and its application in 3d city modelling. *International Archives of Photogrammetry and Remote Sensing*, 37, 1065-1069.

Williams, M.S., Bechtold, W.A. and LaBau, V.J. (1994) Five instruments for measuring tree height: An evaluation. *Southern Journal of Applied Forestry*, 18, 76-82.