

Accuracy of smartphone applications in the field measurements of tree height

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ABSTRACT

As tree height is one of the important variables measured in forestry, much effort is made to provide its fast, easy and accurate determination. We analysed precision of two widely available smartphone applications (Smart Measure and Measure Height) during the field measurements of tree height. The data was collected in three Scots pine stands in central Poland. We found negative systematic error of both tested applications regardless the distance of the measurement (15 or 20 m). RMSE values of the height estimates varied from 1.01 to 2.46 m depending on the application used and the distance of the measurement. Value of the calculated absolute and relative errors significantly ($p < 0.015$) positively depended on the actual height of the measured trees and was more diverse for higher trees. Smartphone applications seem to be promising measurement tool for tree height determination, however as for the time being they require improvement before wider introduction into the forest practice.

KEY WORDS

accuracy, tree height, smartphone, hypsometer, mobile applications

INTRODUCTION

Tree height is one of the most often determined variables in the forest inventory and in the quantitative assessment of forest biomass, carbon stocks, growth, and site productivity. Therefore much effort has been made to provide fast, easy and accurate height measurements. In general, recent studies have focused on the accuracy of various devices and calculation methods (Bragg et al. 2011; Larjavaara and Muller-Landau 2013), application of the novel techniques of the data acquisition (Andersen et al. 2006; Stereńczak and Zasada 2011) or the speed of the measurements (Bozic et al. 2005).

Rapid development of the mobile techniques has introduced smartphones also into the forestry. Many applications that enable various types of measurements or calculations have appeared on the market (Hemery 2011, 2012). There are also some applications created for tree height determination exclusively. Such measurement is based on the data provided either by the 3D accelerometer, which indicates the inclination of the device with regard to three orthogonal axes that intersect in its centre (Lee and Cho 2011), or by the post-processing of the images taken with a smartphone camera (Han 2012).

The accuracy of the tree height measurements with smartphones has not been analysed widely so far. Itoh et al. (2010) compared the heights obtained with iPhone

with those from TruPulse 200 laser telemeter. Villasante and Fernandez (2014) investigated errors of the measurements obtained with HTC Desire or Samsung Galaxy Note compared to those from Blume Leiss and Vertex IV clinometers. As there is a substantial gap in the knowledge about the precision of the mobile telephones used as the measuring tools in the forestry, the objective of the presented research was to analyse the accuracy of the tree height measurements performed with two free and widely accessible smartphone applications.

MATERIAL AND METHODS

Field measurements were carried out in the Las Poćwiarski forest complex (51°52'39.36" N, 19°43'23.52" E; central Poland) in three pure Scots pine (*Pinus sylvestris* L.) stands (25, 52 and 110 years old). In each stand we randomly chose and measured 30 trees. In total we investigated 90 individuals, which was sufficient for further statistical analyses. Selected trees were located at least 30 m away one from another to avoid considering specimens from the same bio-group.

We measured the tree height with popular forest hypsometer (Suunto PM-5/1520) as well as with two applications mounted on Motorola XT1068 smartphone that runs under Android 4.4.4. KitKat OS. The built-in camera has 8Mpx matrix with 3264x2448 px resolution. Height measurements with the smartphone were made using the 3D accelerometer, which detects changes in linear acceleration along three axes and enables to determine the inclination of the terminal (Lee and Cho 2011; Villasante and Fernandez 2014). Further on, calculation of the tree height was based on the trigonometric principles (Larsen et al. 1987; Bragg et al. 2011). All measurements were performed from the distance of 15 and 20 m by the same, well-qualified person.

We analysed two smartphone applications: Smart Measure 2.3 (Smart Tools 2014) and Measure Height (Deskis OU 2014). The previous is a part of the Smart Tools software, while the latter is a product dedicated to the forestry. During the measurements, the smartphone was kept at the height of 1.7 m above the ground (observer's eye height). As the measurement took place from the pre-defined distance, adequate value (15 or 20 m) was provided into the application options to al-

low the calculations. Moreover, +5% calibration of the measurement distance was set in the Smart Measure software accordingly to the app manual to reduce lack of the terrain flatness.

We considered the Suunto derived heights as the true ones being aware that this clinometer itself gives biased estimates of the actual tree height, but according to our experience this bias is at the acceptable level. Moreover, this hypsometer is the most often used device in Polish forestry and that is why we wanted to compare the smartphone results with Suunto derived values.

For each individual tree height measurement we calculated absolute and relative errors as well as root mean square error (RMSE) (eqs. 1–3 respectively):

$$\text{Absolute error} = h_{app} - h_{suunto} \quad (1)$$

$$\text{Relative error} = \frac{h_{app} - h_{suunto}}{h_{suunto}} \cdot 100\% \quad (2)$$

$$RMSE = \sqrt{\frac{1}{n} \sum (h_{app} - h_{suunto})^2} \quad (3)$$

where:

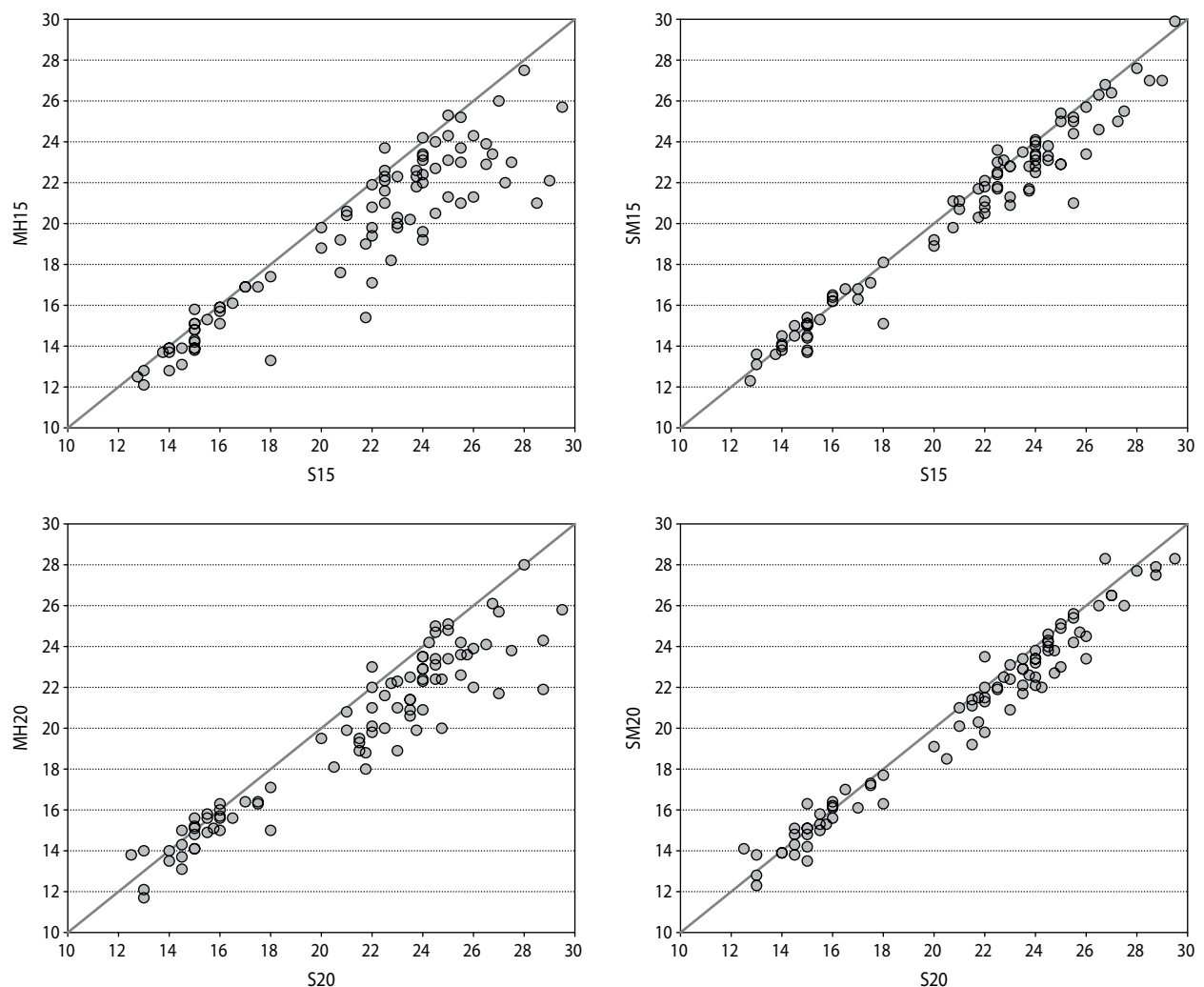
- h_{app} – tree height obtained with the smartphone application,
- h_{suunto} – tree height determined with Suunto PM-5/1520 hypsometer,
- n – number of measurements.

Basic statistics were calculated to describe these errors in each combination of the application and the measurement distance (4 experiment variants in total). For almost all investigated variants, the hypothesis about the normal distribution of the errors should be rejected (Shapiro-Wilk test, $p(\text{normal})$ values in Tab. 1), suggesting skewed distribution of the analysed errors. That is why we used Wilcoxon test to check the significance of the difference of the error median from zero (systematic error) and Mann-Whitney test to analyse the differences between the applications and the measurement distances (experiment variants). Further on we studied relation of the tree height determination error with the actual tree height (Spearman rank correlation). All calculations were performed in PAST 3.05 software (Hammer et al. 2001).

Table 1. Accuracy of the tree height measurements in analysed variants (MH – Measure Height, SM – Smart Measure; 15, 20 – measurement distance: 15 m and 20 m)

Measure	absolute error [m]				relative error [%]			
	MH15	MH20	SM15	SM20	MH15	MH20	SM15	SM20
Minimum	−7.50	−6.85	−4.50	−2.60	−29.2	−23.8	−17.6	−10.7
Maximum	+1.20	+1.30	+1.10	+1.60	+5.3	+10.4	+4.9	+12.8
Mean	−1.67	−1.39	−0.59	−0.55	−7.2	−6.0	−2.5	−2.3
Median	−1.05	−1.10	−0.30	−0.50	−5.6	−5.5	−1.4	−2.1
Standard error	0.19	0.16	0.10	0.09	0.8	0.7	0.4	0.4
p(normal)*	<0.001	0.001	<0.001	0.023	<0.001	0.830	<0.001	0.004

* p-value in Shapiro-Wilk normality test.

**Figure 1.** Actual and smartphone derived tree height [m] for analysed variants

S – reference data measured with Suunto hypsometer; MH – height acquired with Measure Height application; SM – height acquired with Smart Measure application; 15, 20 – measurement distance: 15 m and 20 m).

RESULTS

Absolute error of the tree height determination for all investigated variants ranged from -7.5 to $+1.6$ m, while the values of the relative error changed from -29 to $+13\%$ (Tab. 1). For the SM application the Root Mean Square Error (RMSE) equalled to 1.11 and 1.01 m (15 and 20 m of measurement distance respectively), while for MH software was higher and amounted to 2.46 and 2.04 m respectively.

We found the systematic error of the height estimates as both tested applications significantly underestimated the tree height regardless the distance of the measurement ($p < 0.001$ for all variants). On average Measure Height produced higher errors than Smart Measure ($p < 0.001$ for both measurement distances). Measurements from the farther distance resulted in smaller error, which should be expected especially for older and hence taller trees.

Values of the absolute errors significantly depended on the actual height of the measured trees ($p < 0.015$ for all variants). Correlation coefficient for Measure Height equalled to 0.555 and 0.516 (measurement distance 15 and 20 m respectively), while for Smart Measure they were lower (0.383 and 0.263). In case of relative error, its values also significantly depended on the true tree height ($p < 0.05$), except for SH software and measurement from the distance of 20 m ($p = 0.979$).

As shown on Figure 1, both applications estimated the height of the smaller (12–18 m) trees quite precisely. However they significantly underestimated this parameter for higher individuals (>20 m). The height estimates acquired with MH application were more diverse than those produced with SM software, especially for taller trees.

DISCUSSION

The studies on the accuracy of tree height measurements using a smartphone as a forest hypsometer have been very limited so far. Itoh et al. (2010) reported RMSE of 0.7 m for iPhone measurements of 10 m in height from a distance of 20 m. Villasante and Fernandez (2014) obtained for the same parameter RMSE equal to 0.63 and 0.86 m for HTC Desire and Samsung Galaxy smartphones respectively. In our study RMSE varied from

1.01 to 2.46 m depending on the application used (Measure Height gave higher RMSE). The acquired values are significantly higher than in aforementioned studies. In case of iPhone, the obtained accuracy may result from the fact that this device utilizes the dedicated software and there might be a difference in the built-in accelerometer among tested smartphones. Villasante and Fernandez (2014) took measurements for points of pre-defined height (6–12 m, which is far lower than trees analysed in this study), so they eliminated the problem of tree-top identification and localization. We analysed trees that were much higher (12–29 m) and the observations were carried out in the forest where it is more difficult to locate the tree top precisely. That could be the reason for significant absolute errors obtained especially for high trees (e.g. -7.5 m for the 29 m high tree).

The measurement process realised in the investigated applications itself bases on the inclination of the smartphone and the calculations use tangent method of the tree height determination. Even small deviation from the vertical may result in a significant error. This is consistent with findings of Larsen et al. 1987 who reported increase in error with increasing tree height for the tangent method.

Villasante and Fernandez (2014) found that a prior calibration of the smartphone is required in order to transform the data from the accelerometer into height measurements correctly. However they report that calibration method included in the applications tested by them was insufficient. Our observation confirm that findings. Smart Measure application produced higher errors prior than after the calibration. Measure Height gives the opportunity to correct the inclination angle only. However this operation is time-consuming if carried out for single measurements individually, which is especially unfavourable during multiple measurements.

CONCLUSIONS

Fast development of the mobile technologies will cause wider introduction of smartphones and their applications into the forestry practice. However, so far studies indicate that results of the utilization of this hardware and software gives significant errors and both smartphones and the applications need substantial improvement. More effort is required in the software design (e.g. easi-

er and more effective calibration and self-corrections of such routines) for its full and satisfactory application in the forestry.

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