Accuracy and Efficiency of the Laser-camera

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Abstract

A new measuring device – the Laser-camera - was tested under typical forest conditions. With the device, constructed of a Canon EOS 400D digital reflex camera with an integrated Mitsubishi ML101J27 laser line generator, diameters of trees can be measured from the centre of a sample plot without having to visit the trees. The Laser-camera's principle is based on the reflection of a laser line and a point on a tree stem and the processing of digital images. The study material was gathered during the period in 2007-2008 from 13 circular sample plots and included a total of 728 diameter measurements from 265 trees. The standard error of the diameter observations, using semiautomatic interpretation, was 6 mm (5.3%). The accuracy of the diameter observations (standard error) was maximum for spruce (5.0 mm, 4.4%, followed by birch (6.4 mm, 3.3%) and pine (7.6 mm, 7.6 %). The most common errors were caused by the laser point not hitting the tree stem, branches in front of the stem hampering visibility or incorrect definition of the direction and height of the measurement. Overall tree diameter measurements can be obtained with a Laser-camera rapidly (10 s/tree) and with good reliability and efficiency. The future goal will be to integrate laser technique with an altimeter, data collection unit and GPS receiver inside a weatherproof Laser-camera device. This will enable ready checking of the measurement results in the field from the screen of the digital camera and the measuring of the diameters at any height of a tree, the heights, locations, as well as quality variables of trees.

Keywords: forest mensuration, stem diameter, laser, image processing, digital camera

1. Introduction

Tree diameter is one of the most important stand variables used in forest resource inventory, forest planning and timber measuring. Diameter-at-breast height ($d_{1.3}$) is in most cases the independent variable in single-tree and stand-level models describing the growing stock. Decisions concerning forest management procedures (silvicultural treatments, thinnings and final cuttings) are often made either directly or indirectly from tree diameter measurements. Tree diameter has traditionally been measured using a various callipers or a tallmeter. The use of such devices has always required the observer to visit the tree.

The future of forest resource inventory and forest planning will be based to an increasing extent on remote-sensing, airborne laser scanning (ALS) and methods based on digital photogrammetry. Remote-sensing methods give results at least as accurate in measuring standwise total volume (e.q.Naesset 2004; Naesset *et al.* 2004; Holmgren 2003) and single-tree information (e.q. Hyyppä and Inkinen 1999; Korpela 2004; Korpela *et al.* 2007;Hyyppä *et al.* 2004-2007; Maltamo *et al.* 2004) as traditional field measurement methods that are used in operative forest planning.

Field measurements that are based on traditional methods are expensive, hence the need to develop more accurate, efficient and simple ways to measure growing stock variables. The objective is to develop a method that does not require actual visits to the tree, i.e. remote-sensing methods that are used from within the forest.

Terrestrial laser scanning (TLS) methods have brought new opportunities to the measurement of growing stock attributes, particularly those that measure tree quality (Jutila *et al.* 2007, Henning ja Radtke 2006, Watt ja Donoghue 2005, Hopkinson *et al*. 2004). Currently, however, postprocessing of TLS data is laborious and time-consuming due to the lack of available algorithms and software programs with which one can generate attributes that depict the desired sample plot growing stand attributes from 3D data clouds collected by the TLS (Watt and Donoghue 2005). TLS research in the field of forest applications has so far focused mainly on the estimation of single sample plots and individual tree attributes, not on the development of inventory methods applicable to large forest areas.

TLS has been used on the stand level in projects aiming at developing ways to combine two-dimensional laser observations with harvester measuring (Miettinen *et al.* 2007). The aim of these studies was to develop an automatic method for the mapping of tree locations (Forsman and Halme 2005) and to define the diameter distributions of a stand (Jutila *et al.* 2007). Based on the spatial information gathered and the diameter distribution, it is then possible to formulate a plan for the removal of trees.

Laser-based devices for the measurement of tree diameter have been developed and tested, e.g. in the United States (Carr 1992, 1996; Williams *et al.* 1999), but the devices have not been easy enough to use efficiently and their prices have not been competitive against traditional forest-planning measurement devices (Skovgaard *et al.* 1998; Parker and Matney 1999). Devices that are based on multisensor systems or laser technologies have likewise not been reliable enough in terms of diameter measurements; the measurement accuracy was in one case 19.6 - 24.6 mm (Clark *et al.* 2001).

Kalliovirta *et al.* (2005) developed a device - the Laser-relascope - that enables measurement of tree variables without having to visit the tree. The device includes a laser rangefinder, a variable-width slot with a fixed-length arm, an electronic altimeter, a data collection/processing unit, and a Global Positioning System (GPS) receiver and makes it possible to measure the diameter distribution of a sample plot and the heights and locations of the trees from the centre point of the sample plot. It uses distance and angle information to determine the diameter of a tree and functionally is a combination of a relascope and dendrometer. The standard error of the diameter measurements was 8.2 mm at best (Kalliovirta *et al.* 2005). The accuracy was dependent on the distance, measuring time of a tree, $d_{1.3}$, the observer and the individual´s familiarity with the laser-relascope (Kalliovirta *et al.* 2005, Laasasenaho *et al.* 2002). The standard error varied from 6.8 mm to 15.8 mm depending on the observer (Laasasenaho *et al.* 2002). Measuring precision of the height (S.D. 4.9 cm) and the location (32 cm) measurements were favourable and unbiased (Kalliovirta *et al.* 2005).

The goal of Ojanen (2005) was to develop a method to measure tree diameters with a ± 5 mm level of uncertainty and to eliminate error caused by the observer. The method tested in laboratory conditions is based on laser technology, digital camera technique and digital image processing. The optimal measurement distance varied between 1 - 15 meters. The Laser-camera is the first prototype in which the method was tested under forest conditions.

Varjo et al (2006) studied the accuracy of diameter measurements at different heights of the stem using a simple digital camera (Canon PowerShot). A method was developed in which a tapering model (Lappi 1986) was used in supervising the image interpretation (Juujärvi *et al.* 1998). The distance to the tree was defined by using laser distance-measuring device. The geometry of the image plane of the camera in relation to the tree measured was solved automatically using a reference marker stick in front of each tree and trigonometry.

The aim of this study was to determine the efficiency and accuracy as well as technical feasibility and adaptability of a laser- and digital photography-based device under forest conditions. The Laser-camera was developed at the Centre for Metrology and Accreditation with the objective to develop a device for the measurement of growing stock variables (diameter distribution, tree heights, locations and quality attributes) from the centre of a sample plot, without having to visit the trees. The focus of the study was on the improvement in diameter measurement accuracy elimination of error caused by the observer and integration of laser technology with a digital camera.

2. Method

2.1 Study material

The study material was gathered during the year-end period in 2007 - 2008 from two different locations in Espoo, Finland: Nuuksio (n = 10, r =7.98 m)) and Espoonlahti (n =3, r = 10.0 m), from a total of 13 circular sample plots. The sample plots were located so that the variation in their growth stock, development stage (advanced growth forest to mature forest) and site type (rich site to very poor site) was as wide as possible.

For testing of the device, the trees of the sample plot were numbered by attaching a number label on the side of each tree with the label's lower edge at breast height. The diameter measurement was taken below the number label. Tree species and $d_{1.3}$ (vertically against the centre of the sample plot) were determined for the trees with a steel caliper. The study material included a total of 728 diameter measurements from 265 trees (Table 1). The distribution of diameter observations by tree species is illustrated in Figure 1.

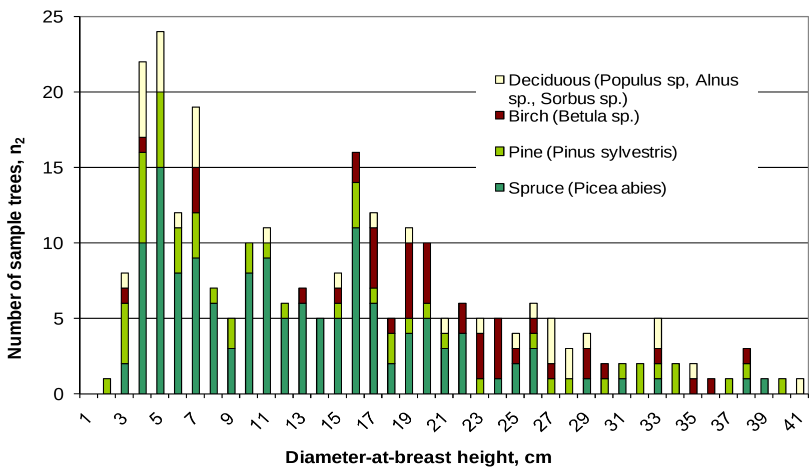


Figure 1. Diameter distributions of spruce, pine, birch and other deciduous sample trees.

Table 1. Description of the study material. Number of tree diameter measurements (n_1), number of sample trees (n_2) and the minimum/maximum values, average and standard deviation (S.D.) of the tree diameter measurements by tree species. The reference diameters were measured using a steel caliper.

	n_1	n_2	minimum	maximum	average	S.D.
Pine (Pinus sylvestris)	153	53	4.4	46.5	15.7	11.7
Spruce (Picea abies)	386	137	5.2	40.9	14.8	7.8
Birch (Betula sp.)	108	42	5.0	40.4	22.8	7.7
Deciduous[1]	81	33	4.7	47.8	20.9	11.7
All observations	**728**	**265**	**4.4**	**47.8**	**16.9**	**9.7**

1) aspen (n_1 = 51), rowan (n_1 = 17), alder (n_1 = 13)

The trees were photographed with a Laser-camera in the field from the centre of the sample plot. Afterwards the tree diameter measurements were interpreted from the photographs. If the tree was not visible from the centre of the plot, the observer moved several steps in order to enhance visibility. The majority of photos taken with the Laser-camera were interpreted afterwards with the help of an interpretation software program developed for this specific purpose. Repetition measurements were conducted, starting from the fourth sample plot in such a way that from the three following sample plots two diameter measurements were measured per tree and from the last sample plots (7) four measurements were done. The number of measurements was increased when new information concerning functioning of the devices was obtained.

The time spent conducting the sample plot measurements was defined to an accuracy of 1 min based on time stamps recorded on the image files. The sample plot measurements were conducted by measuring tree diameters with a Laser-camera. Two photographs were taken from each tree during each measurement occasion. The number of observations gathered from each tree varied from one to four observations.

2.2 Laser-camera

The Laser-camera under study consists of a Canon EOS 400D digital reflex camera with an integrated Mitsubishi ML101J27 laser line generator. The Laser-camera used Canon's EF 70 - 300 mm f/4.5 – 5.6 DO IS USM objective. The resolution of the camera is 10 megapixels. A software program for the visual interpretation of photographs and validation of measurement results was developed with a Canon Software Development Kit. With the program, one can check the measurement result by visual means as well as by adjusting the camera settings, if desired. If the border markers are incorrectly placed, they can be manually adjusted to their correct locations and thus help determine the true diameter. Interpretation of images was performed using the image-processing software either under real-time field conditions or afterwards.

The laser line generator is turned on automatically as the camera focuses. An electronic altimeter can be added to the device (Masser Ltd.), to enable the gathering of diameter observations from different stem heights. The weight of the Laser-camera is approximately 1.5 kg; the camera (0.51 kg) and the objective (0.72 kg) make up most of the weight. The price of the laser camera prototype is 2600 - 3000 €, while the field computer costs around 1000 € (Kivilähde 2008).

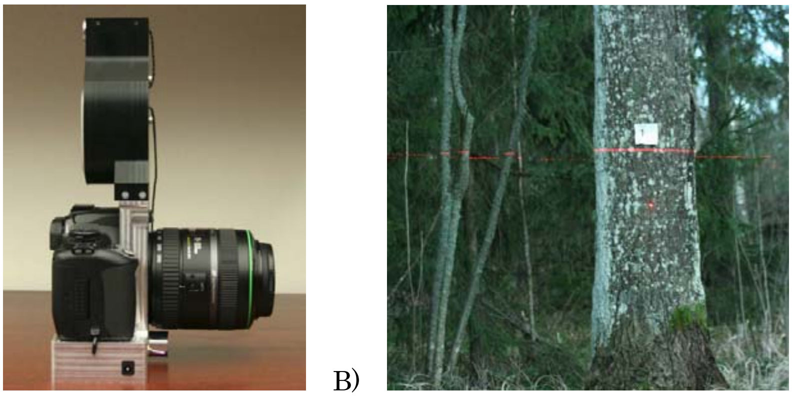
A)  B)

Figure 2. A) The Laser-camera consists of a Canon EOS 400D digital reflex camera with an integrated Mitsubishi ML101J27 laser line generator. An inclinator can also be added to the device. B) Principle of breast height diameter measuring. (Photographs© Jani Kivilähde & Mikko Vastaranta)

2.3 Principle of diameter measuring

The principle of measuring tree diameters with the new Laser-camera prototype is based on the reflection of a laser line and point on a tree stem (Figure 2). The laser line reflection breaks at the border lines of the tree stem so that the stem diameter can be measured, based on the length of the reflected laser line. The length of the laser line can be obtained from the photograph as the number of pixels and local image scale. The scale of the photograph can be derived from the invariable distance between the laser line and point. The interpretation software focuses on the stem and automatically recognizes the laser beam and laser point reflected on the tree stem calculating the tree diameter based on these. The measurement is obtained from the centre of the photograph.

The program functions either fully automatically so that the user has only to open the picture from the file (.jpeg) and the diameter measurement is found directly from the screen or semiautomatically. If the user notices errors in the photograph resulting from the automatic photo interpretation method, the diameter measurement can be derived from the photo manually, either during the field measurements or afterwards.

2.4 Accuracy of diameter measurements

Tree diameter measurements measured with a Laser-camera were compared with measurements conducted with a traditional method (a steel caliper). Bias, S.D. and standard error were calculated for all the study material and separately for Norway spruce, Scots pine, birch and other deciduous trees (aspen, alder, rowan).

The diameter measurement error was defined as

$$e\_d = d_{1.3laser} - d_{1.3ref} \quad (1)$$

where $d_{1.3ref}$ represents the reference diameter and $d_{1.3laser}$ the diameter measured with a Laser-camera.

The reliability of the measurements was examined using estimation of mean-square errors (MSE). Since the true values of diameter were assumed to be known, MSE can be divided into the variance and square of the bias (Cochran 1977). The estimate of bias was given by

$$b[e\_d] = e\_\bar{d} = \frac{1}{n}\sum_{i=1}^{n} e\_d_i \quad (2)$$

and the standard error was given by

$$s[e\_d] = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left[e\_d_i - e\_\bar{d}\right]^2}\ , \quad (3)$$

where n is the number of observations and d is the diameter.

When calculating standard errors for different methods and the measurement errors are independent, the standard error of reference method can be taken into account as follows:

$$s[e\_d]_{method} = \sqrt{s[e\_d]^2 - s[e\_d]^2_{ref}} \ , \qquad (4)$$

where $s[e\_d]_{ref}$ is the standard error for steel calipers.

Clear outliers were excluded from the material. The main reason for excluding the outliers was either that the laser point reflected by the Laser-camera did not hit the tree stem (the laser point was either reflected on the branches in front of the tree, or they did not hit the tree stem at all) or the measurement height of the diameter observation or direction did not correspond with the reference measurement. The number of clear outliers was significant (176 in total) as the measurement results were not immediately visible to the measurer in the screen of the camera having most of them been measured without the use of a field computer. Another reason for the high number of outliers was that the measurement height was constant and did not reflect, for instance, visibility that impacts the precision of measurement results.

If it was observed during postprocessing that the automatism of the diameter observation did not function correctly, the border markers that depicted the tree stem (semiautomatic interpretation) were moved to match the true border lines of the tree in the image. The goal was to make the measurement depict the situation under field conditions. The measurement can be verified in the field enabling the observer to exclude outliers and make a new diameter observation immediately.

2.5 Efficiency of measuring the diameter

The efficiency of the measuring device was determined by measuring sample plots in different stand types and comparing the results with reference measurements. The time spent measuring the sample plots was documented to an accuracy of 1 min.

3. Results

3.1 Accuracy of breast height diameter measurements

The standard error of diameter observations using semiautomatic interpretation was 6 mm (5.3%). The proportion of bias was 2.5 mm, i.e. the results obtained with the Laser-camera were slightly overestimated. The relative standard error was approximately 4% for trees with widths of above 7 cm, and approximately 10% for trees with widths below this. (Figure 3).

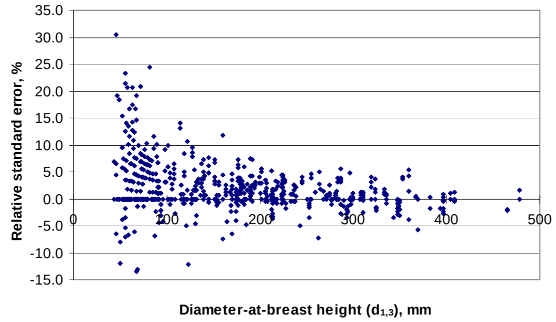


Figure 3. Relative differences in diameter observations obtained with a Laser-camera and reference diameter ($d_{1.3laser}$-$d_{1.3ref}$), as a function of diameter.

The accuracy of the diameter observations (standard error) was maximum for spruce 5.0 mm (4.4%), followed by birch 6.4 mm (3.3%) and pine 7.6 mm (7.6%). Other deciduous trees (aspen, rowan, alder) resulted in a standard error of 6.1 mm (6.0%). Bias for all tree species, excluding other deciduous trees, was positive. Pine resulted in a bias almost twice the magnitude of that for spruce and birch (see Table 2). The results were calculated, assuming that the reference measurements were the true values.

Table 2. Precision of breast height diameter observations using semiautomatic image processing.

	n	$d_{1.3}$	bias, mm	bias, %	S.D, mm	S.D., %	S.E., mm	S.E., %
Pine (*Pinus sylvestris*)	124	17.2	**4.6**	4.8	**6.0**	5.8	**7.6**	7.6
Spruce (*Picea abies*)	272	16.9	**2.2**	1.8	**4.5**	4.0	**5.0**	4.4
Birch (*Betula sp.*)	88	22.8	**2.5**	1.0	**5.9**	3.1	**6.4**	3.3
Deciduous[1]	68	21.9	**-0.6**	1.5	**6.1**	5.8	**6.1**	6.0
All observations	552	18.5	**2.5**	2.3	**5.5**	4.8	**6.0**	5.3

1) aspen (n_1 = 51), rowan (n_1 = 17), alder (n_1 = 13)

The success rate of the diameter observations, using semiautomatic image interpretation, was approximately 80% for all tree species except spruce, which had a success rate of 70%. The measurement of diameter was clearly more successful (by as much as 20%), when semiautomatic image interpretation was used instead of the fully automatic method. (Table 3.)

Table 3. Success rate of observations by tree species and for all study material.

	Automatic method	Semiautomatic method
Pine (Pinus sylvestris)	51.6	81.0
Spruce (Picea abies)	58.0	70.5
Birch (Betula sp.)	80.6	81.5
Deciduous[1]	60.5	84.0
All observations	**57.4**	**75.8**

A diameter result was obtained for approximately 60% of all observations, with a standard error of 12.7 mm, when the automatic method was used. This method, thus, required manual checking of the diameter results, to ensure that they were reliable enough.

The measuring distance had no impact on measuring accuracy. The trees were located not more than 10 m from the sample plot centre point. For the purpose of the project goals, the optimal operational distance was defined as 2 - 15 m.

3.2 Efficiency of tree diameter measurements

It required approximately 7.5 min to measure a sample plot of about 22 trees and 10 sec to measure the diameter of one tree stem. The measurement time included observation of the tree stem at breast height, focusing of the camera objective and taking of the image. The results did not include checking of the measurement result under field conditions, since they were checked afterwards.

4. Discussion

The results obtained with the Laser-Camera were very promising compared with the measurements taken with traditional measuring devices. The accuracy of a Laser-camera is at least as good as that of a steel caliper. In earlier studies, the standard error of a steel caliper varied between 2.7 mm and 6.9 mm (Hyppönen and Roiko-Jokela 1978; Päivinen *et al.* 1992). The results obtained with the Laser-camera were clearly better than those obtained with other laser technology-based devices. The Barr & Stroud and Criterion laser dendrometers (Williams et all 1999) showed standard errors of 8.8 mm and 14.3 mm for measuring upper diameters. According to a study by Varjo *et al.* (2006) the standard errors of diameters varied between 7.0

mm and 9.4 mm, depending on the measuring height (2.5-6.5 m) and the size of the tree. Compared with results obtained with the Laser-relascope, standard error was approximately 3 - 5 mm lower.

Traditionally, it has been assumed that diameter measurements obtained with a steel caliper, are true values. In reality, however, standard errors are also found in steel caliper measurements. If the standard error of reference measurements is taken into account, the accuracy of the Laser-camera (semi-automatic) is 7.1 mm for pine, 5.8 mm for birch and 4.2 mm for spruce. For all the study material, the standard error was 5.4 mm. It was assumed that the standard error of a steel caliper is 2.7 mm (Hyppönen and Roiko-Jokela 1978).

Tree diameter measurements can be obtained with a Laser-camera rapidly (10 s /tree), with good reliability and efficiency. Another advantage of the device is that the procedure for each measurement can be documented and be returned to if exceptions or errors are found within the results. Future diameter measurements will be obtained from various tree stem heights enabling, for instance, the usage of more than one tree diameter measurement result when calculating tree volume. This will enable the use of more accurate volume models (Laasasenaho 1982; Varjo *et al.*. 2006).

The future goal will be to integrate the laser technique with an altimeter, data collection unit and GPS receiver inside a weatherproof Laser-camera device. This will enable ready checking of the measurement results in the field from the screen of the digital camera, measuring of the diameters at any height of the tree and measuring the heights, locations, quality variables of the trees. To integrate this type of quality into the Laser-camera, more cooperation will be required with camera manufacturers.

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