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Analysing log length measurement accuracy of harvester and processor heads

Analyse der Längenmessgenauigkeit von Harvester- und Prozessorköpfen

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Kurzfassung

Harvester und Prozessoren ermöglichen eine Mechanisierung der Holzernte am Steilhang und verbessern gleichzeitig die Produktivität und Arbeitssicherheit. Die Unsicherheit über die Genauigkeit der Längenmessung und die übliche Praxis aus Gründen einer Qualitätsabwertung mehr Überlänge zuzuschlagen, sind limitierende Faktoren für die Einführung und Anwendung dieser Systeme. Ungenaue Längenausformung kann Wertverluste und Probleme entlang der gesamten Wertschöpfungskette Holz verursachen.

Ziel dieser Studie war es, die Fehler bei der Längenmessgenauigkeit von Harvestern und Prozessoren besser zu verstehen und die Einflussfaktoren auf diese Fehler zu bestimmen sowie die ökonomischen Effekte eines zu langen Übermaßes zu evaluieren. Zwei diesbezügliche Studien werden im vorliegenden Beitrag vorgestellt. Die erste analysiert 69.133 in einem Sä-

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gewerk gemessene Bloche, getrennt nach Erntesaison und Ausformungskopf. Im zweiten Teil werden die vom Harvester und Prozessor ermittelten Längenmaße mit einem manuell ermittelten Referenzmaß verglichen. Vergleichsmessungen vor und nach einer professionellen Kalibrierung wurden für die Harvesterköpfe Komatsu 350.1 und Ponsse H7 sowie den Prozessorkopf Woody H60 durchgeführt.

Das in Österreich meist verbreitete Längensortiment hat 4 m und muss auf Grund der geltenden Usancen mit einer Länge von mindestens 406 cm ausgeformt werden. Die Analyse der Sägewerksdaten hat gezeigt, dass 73.7 % der Bloche eine Länge von mehr als 412 cm hatten. Die im Winter ausgeformten Bloche waren durchschnittlich 1.8 cm länger als jene des Sommers. Es gab keine Unterschiede zwischen den unterschiedlichen Köpfen für die Ausformung. Wenn man bedenkt, dass der Waldbesitzer sowie die Holzernte- und Transportunternehmer nach dem Volumsmaß eines 4 m Sortiments bezahlt werden, ergibt sich ein Verlust von 0.93 € bis 1.90 € pro m³. Professionelle Kalibrierung der Ausformungsköpfe resultierte in einer Reduktion der Variabilität und insgesamt einer Verbesserung der Genauigkeit der Längenmessung. Für die zwei Harvesterköpfe war es möglich, dass 58 % der Längenmessung in einem Fenster von plus/minus 0.5 cm waren, während 96 % der Messungen weniger als 2.5 cm Abweichung vom Referenzmaß ergaben.

Abstract

Harvesters or processors can help mechanise harvesting operations in mountainous regions and thereby improve both productivity and safety. Uncertainty about the accuracy and precision of log length measurements, and the common practice of always cutting logs long to avoid the risk of a log being downgraded, is limiting their application and implementation. Incorrect log lengths can cause losses and problems along the whole supply chain.

The objectives of this study were to improve our understanding of harvester and processor length measurement errors, to determine factors affecting these errors and to evaluate the economic effect of over-length logs. Two related studies are presented in this paper. The first analysed sawmill measurement data of 69,133 logs, separated by season and head type. The second part compared harvester and processor head accuracy and precision of target length (as shown on the on-board computer) versus actual length (physical measurement). Measurements were taken both pre- and post- professional calibration for three heads; the Komatsu 350.1 and Ponsse H7 harvesting heads, and a Woody H60 processing head.

The most common Austrian log length is referenced as a 4 m log, but the requires 6 cm of over-length, so the specification is a minimum log length of 406 cm. The analyses of the sawmill data showed that 73.7 % of the logs were longer than 412 cm. The harvesting season affected the results with logs being on average 1.8 cm longer in winter. There was no difference between head type. When considering that the forest owner, and harvesting and trucking contractors are paid for the volume of a 4 m length, the effect of the additional over length is a loss of between 0.93 € and 1.90 € per sold m³. Professional calibration of the heads resulted in an improvement in precision (reduced variability), as well as improving the accuracy of the measurement system. For the two harvester heads it was possible to achieve a log length measurement precision where 58 % or more were within 0.5 cm, and 96 % were within 2.5 cm.

1. Introduction

Mechanisation of forest harvesting operations can improve both productivity and safety. In flat to moderate terrain fully mechanized systems, such as the harvester and forwarder combination, can fell trees, process them into logs, extract them to roadside and load them onto trucks without any human physical intervention. Harvesters and forwarders with integrated winches (also called cable-assist) are increasing the operating slope range for ground-based equipment. However, felling with chainsaw, cable yarder extraction and processing with processor heads at roadside is considered the most common level of mechanisation in steep terrain. To avoid the need of using a chainsaw to buck stems to log lengths, harvester and or processor heads are an integral part of a mechanized harvesting system. The distinction between the two head types is that the harvester head can also fell a standing tree; both can delimb and buck the tree into log lengths (called processing). The effectiveness of the heads, as well as their computer control systems, has continued to improve, but length measurement and diameter-sensing are still a weaknesses (Sondell et al. 2002).

In Austria, final measurement and quality classification of logs is mostly done at the sawmill. Logs are graded based on parameters such as length, diameter and quality in accordance with the Austrian Timber-Trade Usages (ATTU) 2006. It specifies a ‘4 metre’ log to have nominal length of 400 cm with at least 6 cm of over-length, so an overall minimum length of 406 cm. Logs that do not meet the minimum specification are downgraded to the next log sort. As a worst case scenario, a 405 cm log that otherwise meets all other sawlog requirements is downgraded to a 3 m pulp and paper log, leading to considerable financial losses. Given that no processor head length measuring system is consistently accurate or precise, most operators intentionally set a larger target length to avoid the risk of logs being downgraded. Some harvester and processor head control systems also use a “bucking window” to help automate the control function. If the “bucking window” is set over a larger range then the processor is faster but less accurate.

In addition to log value loss to the forest owner, the harvesting and transport companies are typically paid based on the log volume established by the sawmill, as per the nominal grade specification. Therefore, the log volume is calculated based on a 400 cm length, despite the fact that they need to be at least 406 cm long. Any additional over-length reduces the profit margin for each participant in this wood supply chain. For example, if each log was on average 412 cm, then a truckload would be carrying approximately 0.6 m^3 more payload than it gets paid for, or an opportunity cost of 5 € per truck and trailer and round trip at a distance of 50 km (Johannes Loschek, MM-Forsttechnik GmbH. pers. comm. in 2011).

The most common length-measurement method on a harvester or processor head uses a toothed wheel equipped with an encoder. During feeding and delimbing, the wheel is pressed against the log and the encoder generates a fixed number of impulses per rotation. The on-board computer starts the length measurement by using either the barsaw (to cut the end flush) or by photocells that sense the end of the stem being processed. While the wheels circumference and the number of rotations, as measured by the impulse counter, can give an estimate of log length, all systems have an additional calibration procedure to improve the level of accuracy. This can compensate for penetration depth of the measuring wheel or the effect of other influencing factors such as bark roughness, swellings at branch whorls, stem damage or even wet logs. Maintenance is also critical as fouling or blockages of the measuring wheel or photoelectric sensors due to resin or bark lead to measurements errors (Makkonen 2001). When a photoelectric sensor is used to set the start point, strands of fibre pulled during felling and protruding from the end of the log, or a recessed felling scarf, are examples that may trigger the photoelectric sensor and mark a false start point (Karl Klöbl, Konrad Forsttechnik GmbH, pers. comm. in 2011).

Branches can also influence precision as the more frequent and bigger they are, the more inexact the measurement process will be (Andersson and Dyson 2001). Nieuwenhuis and Dooley (2006) found that the lengths of sawlogs are more accurate than those of pulp logs, caused by the either fewer, or smaller, branches. Möller and Arlinger (2006) found less accuracy for butt logs, which is linked to a larger diameter and possibly the effect overall weight.

The operators can have a significant impact on length measurement as they are responsible for maintenance and calibration of the measurement system. With production pressure, or the lack of emphasis on log length accuracy, frequent recalibration of the system might be neglected. In some cases there is insufficient training of the operator. While most suppliers of new machines offer trainings with delivery of the machine, when operators change or the machine is resold training seldom occurs.

Möller and Arlinger (2006) investigated several harvester heads and compared length measurement as noted by the on-board computer and compared it with measurement using a logger's tape. They observed that 83 % of measurements were within ±2 cm; whereas five years earlier this had been just 71 %. This showed that accuracy improvement through technical development had occurred, and this was also confirmed in other publications such as Grußdorf (1999) and Sondell et al. (2002). Grußdorf (1997, 1999) observed that only 26 % of logs were within the intended length range, and similar results can be seen in the study of Marence et al. (2009) where the median processed log length exceeded the sawmill's requirement. Studies that have included a calculation on economic losses caused by inaccuracy of length and diameter range from 4.4 % to 8 % (Conradie et al. 2003; Marshall et al. 2006; Marence et al. 2009).

Most studies of length measurement accuracy for mechanized processing have been carried out in flat terrain. Operating a processor in mountainous conditions can be more difficult, complicated by landing constraints and the operator being required to manipulate and process the trees on steep terrain. There is also a lack of knowledge within the wood supply chain about the opportunity cost caused by over-length logs. Furthermore, there remains discussion about the origin of length measurement errors as to whether they are primarily caused by the measurement system of the head or by the operator.

The objectives of this study were to improve our understanding of the harvester or processor length measurement accuracy and the potential effect it has on the supply chain. It includes establishing which factors affect length errors, calculating the value loss of excessive over-length logs as well as a professional intervention to show the influence of calibration and maintenance on precision and accuracy. Finally, a benchmark for evaluating operator performance is discussed.

2. Materials and Methods

2.1 Analyses of sawmill measurement data

This part of the study evaluated the logs supplied to a sawmill by two different operators with different machines, namely a Komatsu 350.1 harvester head as operated on a Komatsu 901 TX harvester, and a Woody H60 processing head as operated on a Syncrofalke tower yarder. The data was supplied by Hasslacher Norica Timber where the logs were measured with the Microtech DiShape HAS laser scanning system. In total 69,133 log records (21,971 m³ of roundwood under bark with a value of € 1,824,924) were provided that included species, nominal length (as per grade specification), actual length, diameter class, quality and price for each grade. Although the sawmill measures the log diameter using a laser scanner, the diameter data provided was in 5 cm Diameter Classes and is annotated by a number representing deca-centimeters, and either an 'a' for 0 to 4.9 cm, or a 'b' for 5 to 9.9 cm range. For example, a '2a' log has a mid-diameter between 20 and 24.9 cm, whereas a '4b' a diameter between 45 and 49.9 cm. The data were separated according to the head used as well as the season in which it was delivered to the mill. The data was managed, and calculations complete, in a standard office package (Microsoft Excel 2010), and PASW 18 was used for statistical analyses. Differences are reported as significant if $p < 0.05$. As the data did not have a normal distribution, non-parametric tests (Mann-Whitney U-Test and the Kruskal-Wallis Test) were applied.

Two scenarios were calculated for evaluating the economic effect of over-length. In the first scenario 406 cm was set as the required length. All log volume above this threshold was seen as loss. Using the length difference (delivered length minus 406 cm) and the diameter, the over-length volume could be calculated and multiplied by the price. A second scenario was also evaluated whereby the acceptable log length limit was extended to 412 cm. That is, only logs longer than 412 cm were considered over-length and that volume evaluated. This is expected to reflect a more realistic scenario where forest owners accept the additional over-length to avoid the risk of under-cutting the log. The economic effect was calculated from the view of the forest owners and based solely on the excess log volume at the value of that particular log grade. By-product value, such as chipping the excess volume for either heating or on-selling clean chips to a pulp and paper mill, was not considered. Also not considered was a potential shift in grade, or the possible opportunity cost of cutting an extra log from a stem where prior logs were cut with over-length.

2.2 Professional calibration

For the professional calibration part of study three heads were tested; the Woody H60 processor head mounted on a Syncrofalke tower yarder; the Komatsu 350.1 harvesting head on a Komatsu 901 TX; and a Ponsse H7 harvesting head mounted on a Ponsse Ergo 8w. Two sets of length measurements were taken. The first is labelled 'as is' and based simply on what the machine was set at when the researchers arrived on site. The second set was captured after professional calibration, defined as a certified engineer from each respective harvester/processor head manufacturer providing system maintenance, full calibration as well as feedback to the operator on improving accuracy. This data set was designated as 'calibrated'.

The procedure at the yarder mounted Woody H60 was to produce five logs and then measure the actual length with a Leica distance meter (reference method, accuracy ±1.5 mm). The intended length as per processor head could be seen in a history frame on the machine's computer display and the operator transmitted this information by walkie-talkie. The procedure for both the Komatsu 350.1 and Ponsse H7 harvester heads was that ten trees were felled, processed and numbered and measured with Leica distance meter. The harvesting head data was printed out from the on-board computer and provided by the operator.

Normally harvesters are positioned so that the felled trees can be processed parallel the contour of the slope. However, processors mounted on a tower yarder have to manipulate the stems in the slope line. This requires the feed rollers to apply extra force as it not only pulls the stem through the head, but also has to overcome the gravitational pull on the stem as it pulls it uphill. To see if slope had an effect on accuracy an additional 30 trees were felled and provided on the forest road for the Woody H60 processor to have an improved position to process the trees. This test was only carried out during the capture of the 'calibrated' data set.

The operations were carried out in Carinthia and Styria (Austria) in Norway spruce stands with experienced and well-trained operators between July 2011 and May 2012. Data collection was not influenced through precipitation.

3. Results

3.1 Analyses of sawmill measurement data

Two thirds of the logs were produced by the Komatsu harvester and one third by the Woody H60 processor. 0.4 % were shorter than the required 406 cm. 25.9 % were between 406 and 412 cm, meaning that 73.7 % were in excess of 412 cm in length (Figure 1). The Mann-Whitney U Test indicated no significant difference between head types (p-value 0.05).

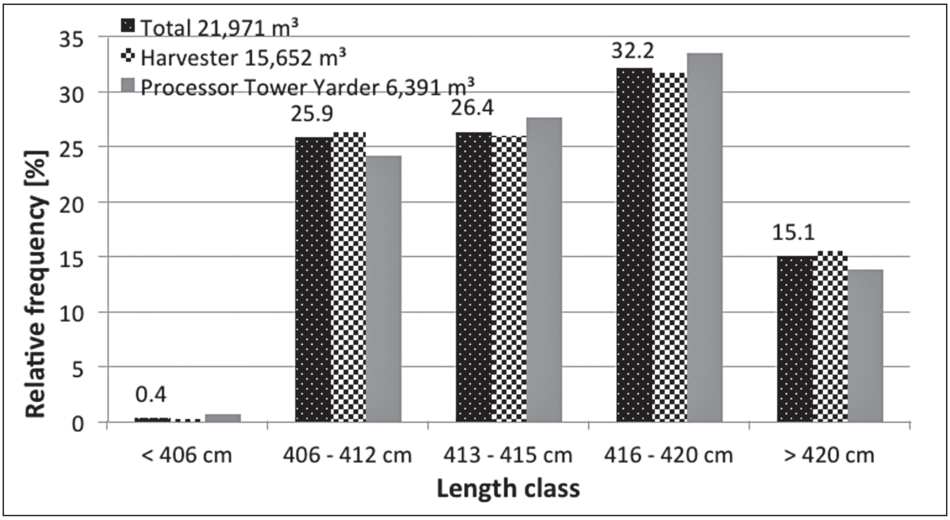

Figure 1: Distribution of laser scanned log lengths (at sawmill) separated by head type.

A significant difference was observed with harvesting season. On average, logs produced by a harvester head were 1.75 cm longer during winter. A similar result was obtained for the yarder mounted processor, where the length was 1.95 cm longer (Table 1).

Table 1: Descriptive statistics of the 69,133 log lengths separated by head type and season.

	Harvester head		Processor head tower yarder	
Length [cm]	Summer	Winter	Summer	Winter
Mean	415.4	417.1	415.4	417.3
Standard Deviation	6.97	6.91	6.01	5.79
5th percentile	408	410	407	410
95th percentile	427	427	425	426

Figure 2 shows that larger the diameter class, the longer the logs were. From class 6a upwards (logs greater than 60 cm) a major step change can be seen in the results. These log are bucked very accurately at the 412 cm target length as bucking was done motor-manually. With the exception of 'Winter Harvest' there also appears to be a jump in log over-length between the 1a and 2a diameter classes. The Kruskal-Wallis Test identified a significant difference between the diameter classes (p-value < 0.05).

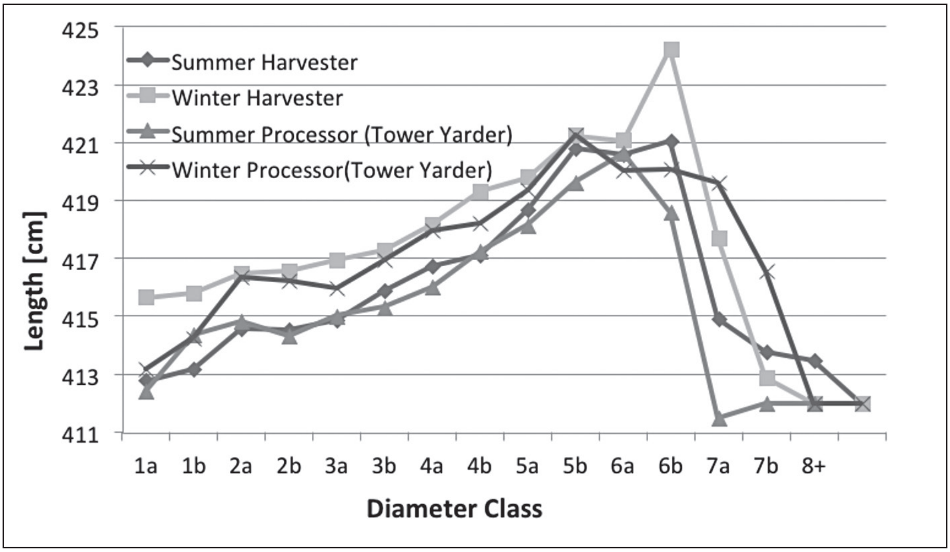

Figure 2: Log length depending on Diameter Class separated by head type and season.

The log grades defined in the Austrian-Timber Trade Usage (2006) allows larger diameter branches for the lower quality logs. As branch size was not surveyed, grade was taken as an indicator as categorized by Quality Class. Grades are separated into four Quality Classes: High (A or B), Medium (C), Low (CX) and Poor (Y). The Kruskal-Wallis Test results indicated a significant difference within the Quality Classes (p-value 0.05). From high quality to poor quality, the average length increased by 1.49 cm (Table 2).

Table 2: Descriptive statistics of log length measurement separated by quality.

	Quality			
Length [cm]	AB	C	CX	Y
Mean	415.6	416.3	416.8	417.1
Standard Deviation	6.33	6.86	7.44	6.33
5th percentile	409	409	409	409
95th percentile	425	427	428	428

The frequency of log lengths over 420 cm increased from 11.9 % to 20.4 % when comparing the highest (A&B) to lowest (Y). Conversely, log lengths between 406 and 412 cm decreased from 28.9 % to 19.2 % (Figure 3).

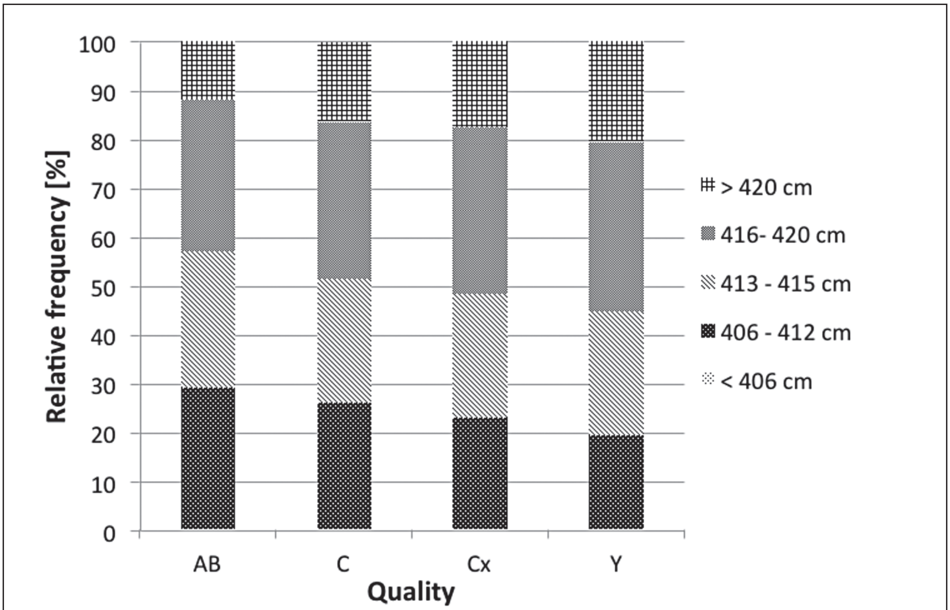

Figure 3: Frequency of length measurements within length classes separated by Quality Classes.

The result of the economic evaluation of value loss due to over-length was a loss of € 1.90 per m³ (under bark) for scenario 1. This was the loss associated with the log volume over the minimum required 406 cm. In scenario 2 only the volume for length over 412 cm was considered, and the value of that loss was equated to be € 0.93 per m³ (Table 3).

Table 3: Economic effect of granting too much over-length.

	Scenario 1	Scenario 2
Total volume [m³ u.b.]	21,972	21, 972
Volume over-length [m³ u.b.]	506	248
Value over-length [€]	41,920	20,475
Total value [€]	1,824,924	1,824,924
Loss [%]	2.3	1.12
Loss [€/m³ u.b.]	1.90	0.93

3.2 Calibration Experiment

In the state ‘as is’, 749 logs were measured with the Leica and compared with the machines’ measurement (Table 4). As the Ponsse H7 data collection was conducted during growing season, the operator had intentionally increased the target length to 414 cm to accommodate the expected higher level of variability. For the other two machines the target length is set as 212 cm.

Table 4: Mean ‘as is’ log length values, comparing the actual reference values from physical measurement versus the length values as shown on the computer in the machine.

Machine	Samples [n]	Reference method [cm]	Machine’s measurement [cm]	Difference [cm]
Woody H60	396	413.72	412.63	1.09
Komatsu 350.1	189	411.32	410.61	0.76
Ponsse H7	164	414.92	416.86	- 1.88

Figure 4 shows the absolute length difference when subtracting the reference value from the machine value. It indicates the performance of the heads in this trial with regard to frequency and the range between minimum and maximum differences. The range was from -12 to +36.3 cm at the Woody H60, -4 to +4 cm at the Komatsu 350.1 and from -5 to +2 cm at the Ponsse H7.

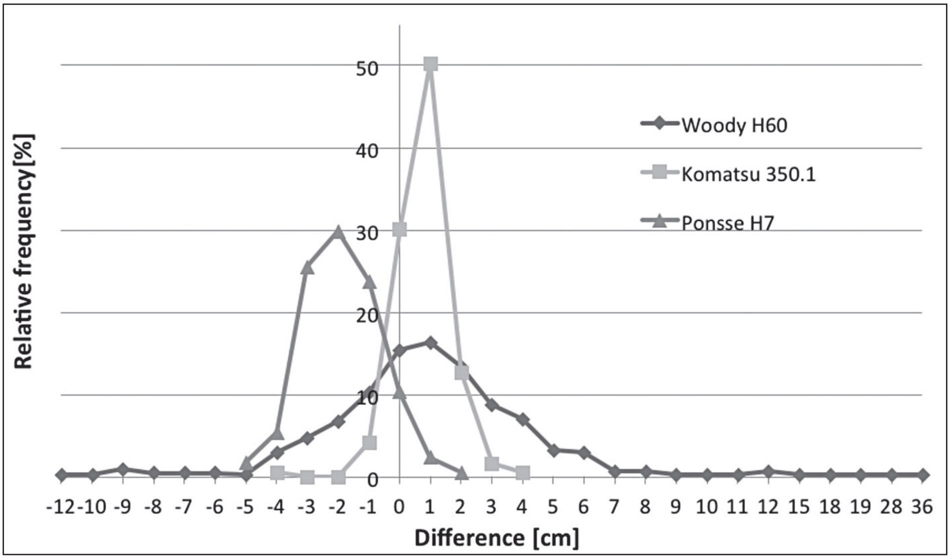

Figure 4: Log length differences of surveyed heads between reference method and machine's measurement in the state 'as is'.

After calibration and maintenance, as well as advice from the professional to the operator, comparative measurement was repeated (Table 5). The Mann-Whitney U-Test indicated a significant difference between measurements in the state 'as is' and 'calibrated' (p-value 0.05). However, it showed no difference between the Woody H60 when operating normally, and when it was processing the trees that had been laid out along the road ('harvester simulation').

Table 5: Mean values of length in the state “calibrated”.

Machine	Samples [n]	Reference method [cm]	Machine’s measurement [cm]	Difference [cm]
Woody H60	302	412.80	412.14	0.66
Woody H60 harvester simulation	98	411.80	411.07	0.78
Komatsu 350.1	238	410.99	410.84	0.21
Ponsse H7	159	413.71	413.75	- 0.01

The result of the professional calibration experiment shows that frequency distributions of differences between the reference method and the machines’ measurement are spread around 0 cm (Figure 5). It was possible with harvester heads to get 58 and 70 % (Komatsu 350.1 and Ponsse H7 respectively) of sensing values within 0.5 cm difference from the target length. The processor mounted on a tower yarder only achieved 30 % with less than 0.5 cm difference.

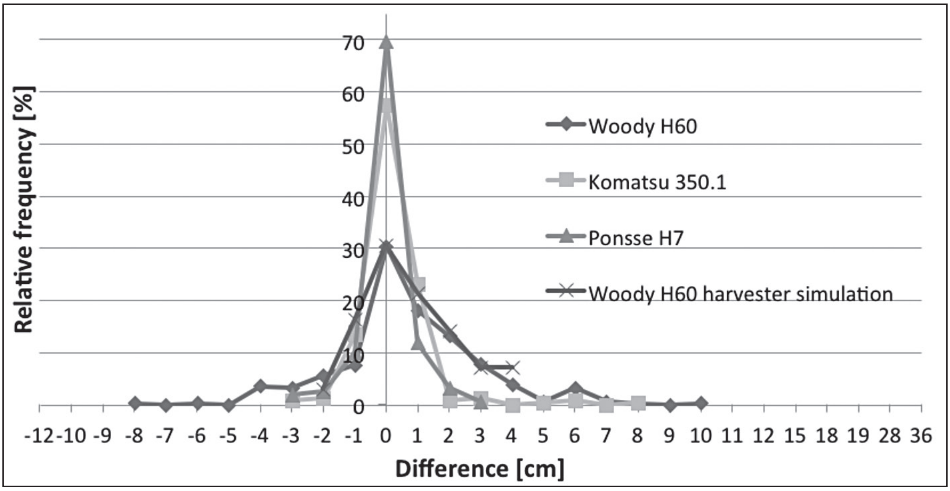

Figure 5: Differences of surveyed heads between reference method and machine’s measurement in the state ‘calibrated’ and harvester simulation.

The professional calibration experiment showed the potential to improve log length measurement through calibration, maintenance and professional advice (Figure 6). For example, when considering an acceptable accuracy range of ±2 cm, the Woody H60 calibration improved by 12.8 % and the Ponsse H7 30.4 %. The Komatsu 350.1 head did not improve as it already had a very high percentage of accuracy in the 'as-is' state, and anecdotally it was noted that the operator regularly calibrated and maintained this harvester head.

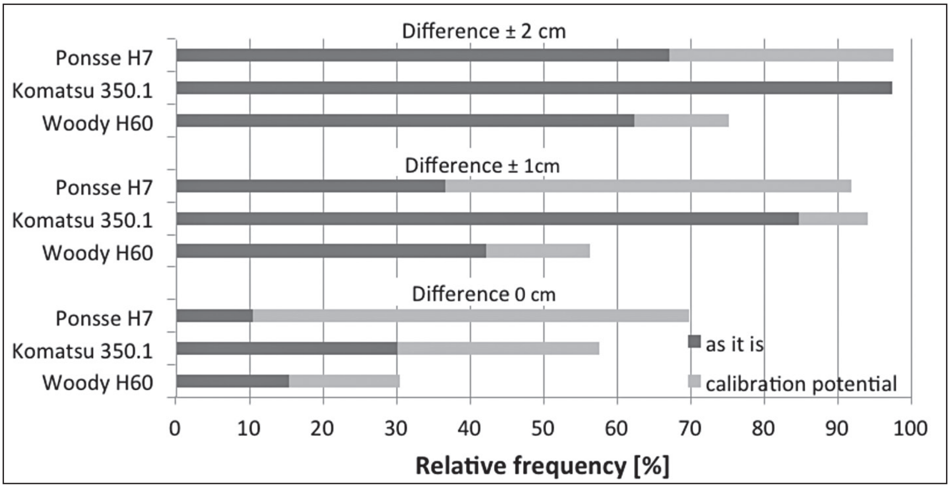

Figure 6: Professional calibration potential of the surveyed heads, swing the improvement through maintenance, calibration and professional advice.

4. Discussion

Analyses of sawmill measurement data showed that 73.9 % of logs have at least 6 cm over-length compared to the minimum requirement of 406 cm. A comparable German study indicated 74 % over 415 cm (Grußdorf 1999), with the author noting that it was conducted in the summer season with significant rainfall possibly affecting the outcome. In this study 47 % of logs were over 415 cm. Analysis indicated no difference in the average processed log length between harvester heads and processor head mounted on a tower yarder. Andersson and Dyson (2001) presented a similar result where there was no significant difference between processing in the stand or at landing sites. Aligned with the results from this study Grußdorf (1997), Makkonen (2001) and FERIC (2004) also showed that harvesting season has an influence on the measurement process. Grußdorf (1997) indicated that log length would be overestimated in the summer, but that is contradictory to what was found in this study where logs were around 2 cm shorter during summer. Operator comments suggested the reasons for the seasonal difference is loose bark (caused by feed rollers and delimbing knives) and different penetration depths of the measuring wheel in the bark and wood (Makkonen 2001; FERIC 2004). Contrary to this Andersson and Dyson (2001) found no strong indication that the accuracy of the length-sensing process was related to the season.

Analysis of sawmill measurement data indicated that the log diameter was also a factor affecting length measurement. The greater the diameter of the log the longer the logs were cut. Similar results were stated by Möller and Arlinger (2006), who observed a decreasing accuracy for butt logs in comparison to the following smaller diameter logs cut from the stem. Plamondon (1999) found larger errors in length at lower volume. The size and number of branches has also been shown to have an impact on log length measurement (Andersson and Dyson 2001; Nieuwenhuis and Dooley 2006). As the size of branches on the logs were available in our data, log quality was taken as a substitute indicator instead. The Austrian Timber-Trade Usages allows larger branches for lower quality logs. This study proved that logs were bucked longer at a lower quality (for example low quality logs on average are 1.25 cm longer than high quality logs). The economic loss of 2.3 % and 1.90 € per m³ (defined as the value of material over the limit of 406 cm) is much lower than that calculated by Marshall et al. (2006). However, in their study, changes in log grades caused by diameter measurement errors are included. Accepting that an additional 6 cm might be required to accommodate the head accuracy in an operational setting (that is, only logs longer than 412 cm are considered over-length) allowance there is still a loss of 0.93 € per m³, which is a clear opportunity for improvement.

The expert calibration experiment showed that the harvester and processor heads are able to measure accurately and the result can be improved through calibration and maintenance, as also noted by Nieuwenhuis and Dooley (2006). However, the Woody H60 processing head had a considerably larger standard deviation when comparing the intended and actual log length.

Möller and Arlinger (2006) presented results that on average 83 % of logs are within ±2 cm difference. As such, the Komatsu 350.1 with 95 % and Ponsse H7 with 97.5 % in this study reached an excellent result. For the Woody

H60, it achieved 86 % in the 'harvester simulation' setting (i.e. processing at roadside), but only 75 % when the processor was required to process on the slope below or beside the yarder.

These results indicate that it is necessary to work more precisely with processors mounted on a tower yarder and to increase the interval for calibration. That might also be important for cable based harvesting systems where delimbing and bucking is done by a separately mounted processor, for example on an excavator. This system was not surveyed but possibly has the same problems of having to process while manipulating the stems on the slope. Additionally, the manufacturer of the Woody H60 could try to implement a simplified calibration system comparable to those of the Komatsu and Ponsse heads, where an electronic caliper with a communication interface to the computer was used.

The roller based technology used for length measurement might be at the limit of its accuracy so a switch to non-contact methods for log measurements might be necessary (Möller and Arlinger 2006). There are some approaches from Holzer et al. (2001) based on Doppler Effect which have the needed toughness and speed for forest usage. Miettinen et al. (2009) conducted a study about non-contact measurement devices but concluded further research has to be done to make such systems operational.

Given the results of this study, where the harvester heads were able to process 57 – 69.8 % of logs within 1 cm accuracy, it should be possible to set a benchmark for logs delivered to a sawmill. At a nominal 4 m length and a required over-length of 6 cm: (i) no logs under 406 cm; (ii) maximum 35 % over 412 cm. This would result in a minimum of 65 % of the logs being delivered between 406 and 412 cm. Given that the harvester and processor heads produced at least 86 % of logs within ±3 cm difference it should be very possible to exceed this sawmill target.

A benchmark for the harvester/processor measurement system could be that at a minimum 90 % of the values must be within ±2 cm difference at the time of calibration. This would allow some level of inaccuracy to occur due to operational affect, but still allow the harvesting company to meet the above benchmark for logs delivered to the sawmill.

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