A Field-Tested Log Traceability System

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Abstract

Today, an information gap exists between log measurements performed in the forest and at the sawmill. By applying a code in the forest during harvesting and then reading it at the sawmill, this information gap would vanish. A log applicator, which applies two-dimensional log codes through the saw bar, and a corresponding detection system based on vision technology have been developed. Key features of this technology are the very low cost of each mark and the zero-time-loss characteristic of both marking and detection.

A field test utilizing this equipment was performed on 210 logs in northern Sweden in December 2009. For logs harvested during real harvesting conditions and automatically detected at the log sorting station of a running sawmill, a detection rate of 40 percent was achieved. A comparison between parameters (length and diameter) measured in the forest and at the sawmill is presented, as are a number of suggested improvements to increase the detection rate substantially.

The comparison of forest and sawmill measurements is just one sought-after feature expressed by the forest industry, and is therefore used here to demonstrate a novel system. The present work originates from a 3.5-year research project called ''The Indisputable Key'' (I-Key; Uusijärvi et al. 2010), which was launched by the European Union in 2006 and ended in 2010. The I-Key project aimed to achieve traceability for the whole wood value chain, from the forest to the second manufacturer. By introducing such a system, several improvements and economic gains can be made concerning environmental impacts, logistics, yield usage, and production simulation models.

Sawn timber from softwood (*Pinus silvestris* and *Picea abies*) constitutes a major industrial sector worldwide. Various end products are made from softwood, such as construction material, furniture, and paper. With today's ever-increasing production rate, rejections and downgrades of refined wood are an unavoidable and costly reality. If one could select specific trees, based on their properties, for specific end products, then material loss could be greatly reduced and the end product quality improved. However, refining a log with particular wood properties, such as specific gravity, knots, and fiber direction, for a specific end product demands traceability (Uusijärvi 2000).

Introducing traceability tools would improve the wood value chain (Wilhelmsson et al. 2010), reducing the environmental impacts while increasing the financial gain. With reliable traceability data from the wood value chain, simulation software (Erlandsson et al. 2010) can be used to analyze such improvements. Implementing traceability in the wood value chain requires that several technologies be combined and integrated to function as a single system. Marking and/or reading operations need to be implemented at each refining stage in the production process, together with an information and communication technology (ICT) system that can handle the data correctly.

The work presented in this article focuses on a field test of log traceability (i.e., traceability in the first part of the wood value chain, between the forest and the sawmill). The developed prototype system was tested on a high-volume softwood production system common in Scandinavian countries. A schematic of the log supply chain is presented in Figure 1.

Within the process studied, the trees were felled in the forest using a harvester machine. In Europe, softwood is usually ''cut to length'' (CTL) when harvested, which means that the trees are felled and then cut into predefined log lengths in the forest. In softwood harvesting using the CTL technique, which is the focus of the present work, optimization of log length is handled by the computer in the harvester machine in combination with the knowledge and experience of the human operator. The optimization is based on parameters such as dimension, length, quality, and price.

The next step after harvesting is transporting the logs from the forest to the roadside. After cutting, the harvester operator roughly sorts the logs so that a forwarder can

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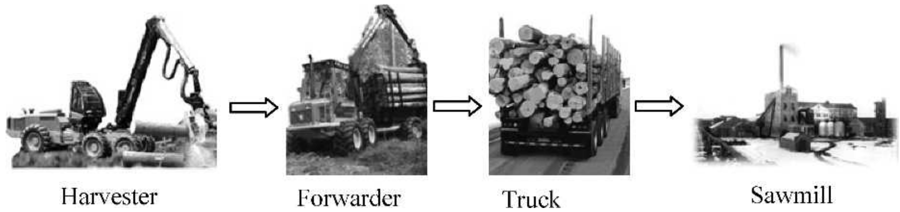

Figure 1.—Log supply chain studied (part of the wood value chain) from forest to sawmill. (Source: Rottne Industries AB, Rottne, Sweden.)

transport them to the roadside. This sorting is often based on the type of tree, its quality, and its dimensions. At the roadside, the logs are placed in piles according to their properties; these roughly sorted logs are then loaded onto trucks for transport to the appropriate sawmill. At the sawmill, the logs are measured, sorted based on dimensions and quality, and then further processed into final products.

Measurements and quality judgments are made both in the forest and at the sawmill, but no possibility currently exists to connect those measurements with each other on the level of individual items. To eliminate this information gap, in this article we present a novel log traceability system, including its field test.

The Log Traceability System

The log traceability system (Möller 2011) comprises an applicator, a detector, and a database structure (Fig. 2). Modern harvesters store data on relevant parameters, such as length and diameter, for each log. A standard for such data is present in several Nordic countries and is called StanForD (Arlinger et al. 2011). In Sweden, the standardized data are transmitted to a database administered by the forest industry IT company, SDC (www.sdc.se). Forest or sawmill owners can access these data if they subscribe to this ICT service provided by SDC.

Under the log traceability system, a printed code is applied to each log by the harvester. The code and log data are stored and transferred from the harvester to SDC continuously via general packet radio service (GPRS) communication, or daily using memory sticks, and further via the Internet. The logs are then transported from the forest to the sawmill. The first process at the sawmill is to sort the logs based on dimensions and quality. The log is measured (i.e., diameter and length) by a scanner or similar equipment and then transported on a conveyer through the detection equipment that reads the code as the log passes it. Via the ICT service, the detection equipment retrieves the harvester log production data. Information such as the scanned log data at the sorting station, the harvester log data, and the detected code are combined, and this information is then stored and made accessible via the sawmill computer system.

At the saw intake where the logs are sawn into boards, similar detection equipment (not implemented in the present study) reads the log code to facilitate further traceability inside the sawmill. After the logs are sawn into boards, the lifetime of the log code ends.

Log code applicator

The physical code marking of logs is done by the harvester operating in the forest. The applicator (Möller 2011) is mounted on the harvester head and is connected to the harvester control system via a Controller Area Network (CAN) communication interface (CAN 2011). The developed applicator is modular in design, which allows it to fit different harvester models. The marking equipment applies a code to the log end during cutting, as depicted in Figure 3. Nozzles and paint lines are integrated into the saw bar to enable the application of paint during the cutting motion.

The code sent from the harvester and received by the applicator is recalculated to sequentially activate 10 valves—one for each nozzle—located on the saw bar bracket (Fig. 3). As the saw bar cuts through the log, the saw bar angles are continuously read by the applicator. At a specific angle, the code printing starts and then proceeds continuously at incrementally increasing angles. This marking procedure is awaiting patent. The main components of the applicator are depicted in Figure 4.

The code applicator is designed to produce standard data matrix codes (International Organization for Standardization 2006), which apart from being a standard allows a sufficient

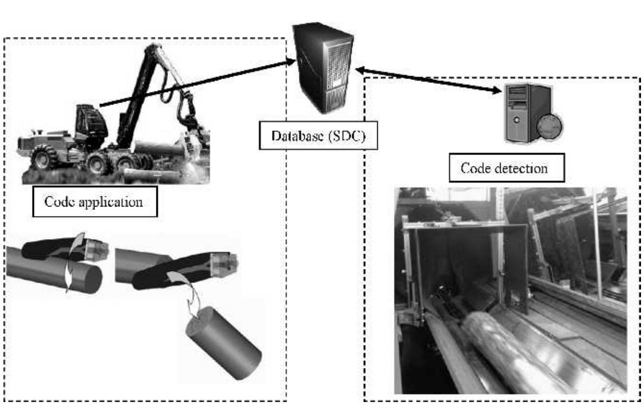

Figure 2.—Log traceability from forest to sawmill based on log marking, code detection, and database communication.

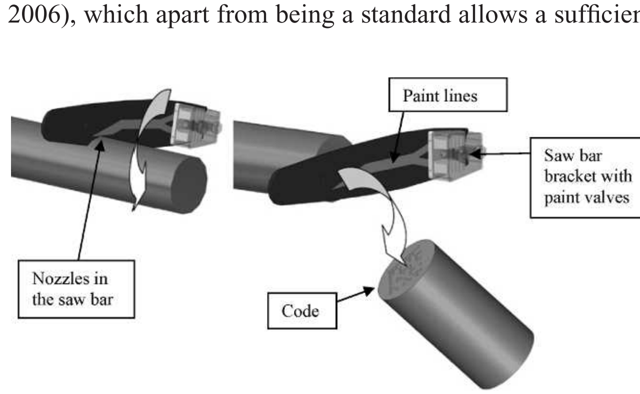

Figure 3.—Saw bar–integrated log code printer. Paint dots/lines are applied to the falling log end during the cutting motion.

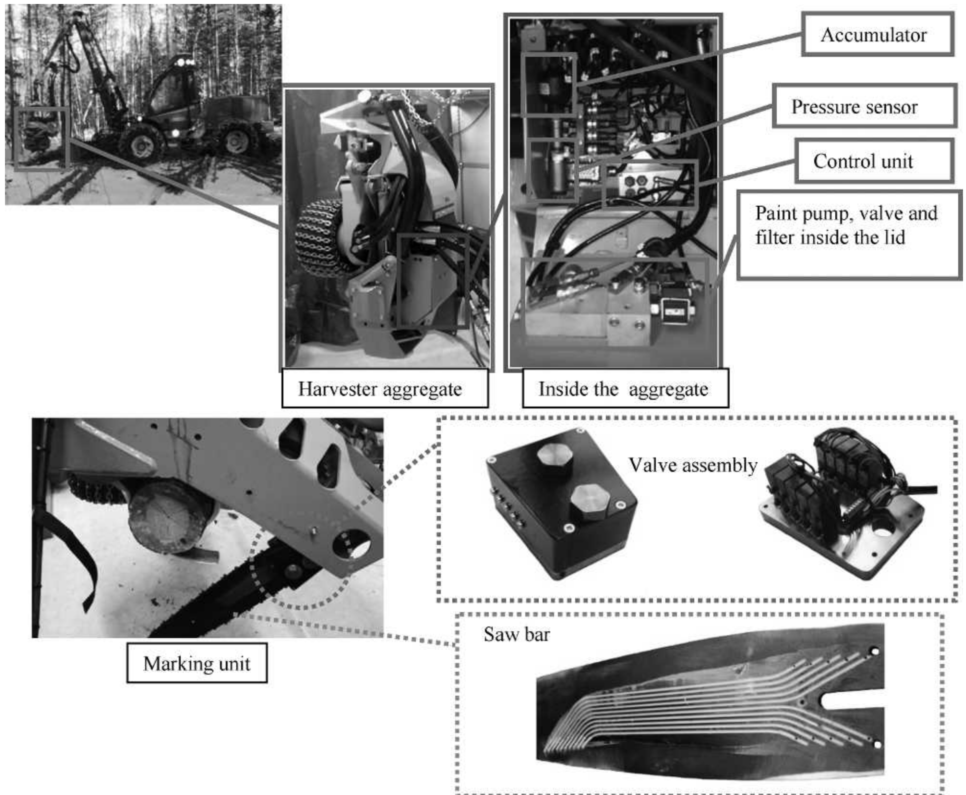

Figure 4.—Location of the applicator subcomponents on the harvester head.

number of unique identities and has a certain degree of redundancy in the code itself. However, for the field test, which required only a limited number of identities, a custom-designed barcode was used, in part to demonstrate the versatility of the system. The custom barcode was designed to use 8 of the 10 nozzles and can support 4,095 identities using a binary base (Fig. 5).

Log code detection equipment

Detecting two-dimensional codes printed on a moving surface is preferably done using a vision system (i.e.,

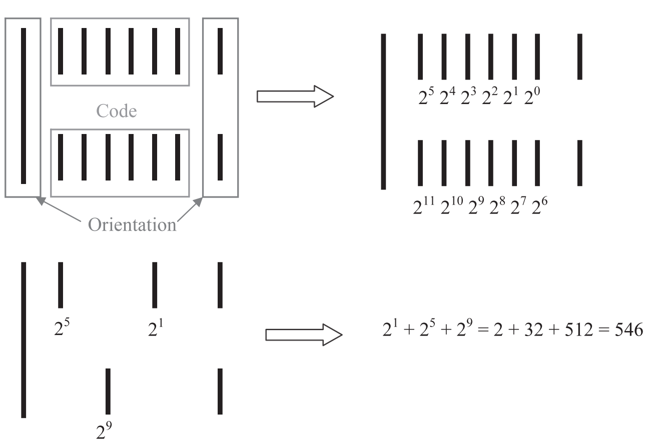

Figure 5.—Custom-designed barcode that supports 4,095 possible codes using a binary base. Two nozzles are used for code orientation (during detection) and six nozzles (divided in two rows) for the code number. Two nozzles are left unused to facilitate distinguishing the code from the orientation bars.

software-processed digital images). In the developed system (Möller 2011), the top end surface of the log is imaged by a camera that produces a digital image of the log surface. Figure 6 shows the positioning of the camera in relation to a log end, to the left in the laboratory setup and to the right in the log sorting station during the field test.

The overall detection sequence is as follows. An image of the log end surface is acquired as the camera and lighting are triggered by a photoelectric sensor activated by the passing log. The images are transmitted to the detection computer for software processing. The decoded log image is then stored together with the log data from the forest and from the measuring scanner.

Our investigations indicated that no commercial vision software system was available that could directly handle our detection scenario. To have as much development freedom as possible, an open-source platform combined with a commercial software tool was initially chosen. Our software design uses C++ libraries from Sapera Essential Version 5.7 (www.teledynedalsa.com/mv/products/saperaessential.aspx) and OpenCV (opencv.willowgarage.com) as software tools to detect the code. The Sapera software was chosen for its compatibility with the selected camera. The Sapera libraries have several functions that can be used to process the acquired image from the camera and to read the code. Sapera has a built-in library that can be used to decode standard codes, though it is not sufficient for the present case. The uniqueness of our detection scenario meant that customized software had to be developed. The basic layout of the detection scheme is depicted in Figure 7.

The Customized Barcode Module 1 in the vision scheme (Möller 2011) is applied to the acquired image to detect the barcode. The marked code consists of printed paint bars as

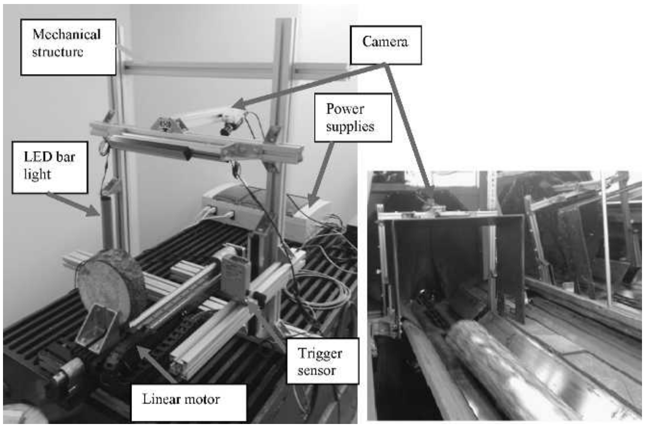

Figure 6.—Laboratory setup of the detection equipment (left) and the log code detection equipment installed in a sawmill with a longitudinal conveyer (right).

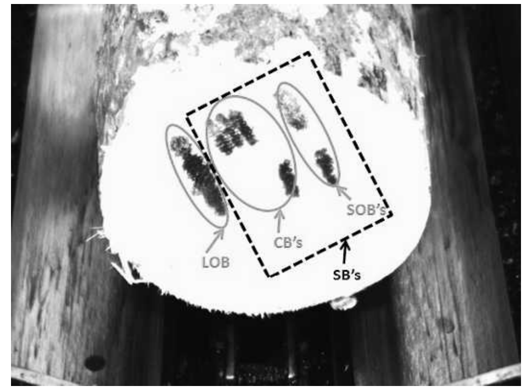

Figure 8.—Customized barcode bar types comprise the Large Orientation Bars (LOBs), Small Orientation Bars (SOBs,) and Code Bars (CBs).

depicted in Figure 5. These bars are categorized as Large Orientation Bars (LOBs), Small Orientation Bars (SOBs), and Code Bars (CBs), as shown in Figure 8. The LOBs and SOBs are intended for detection of the position and orientation of the code, whereas the CBs constitute the actual value of the code and are used to compute it.

In the event of duplicate codes or uncertainty as to code identity, a parameter scheme (i.e., log measurement comparison scheme) can be executed. For this purpose, the physical properties of a log are of interest. As mentioned, log parameters (i.e., length and diameter) measured at both the harvester and the scanner in the sawmill are available for the detection equipment. These log measurements can be compared to increase the possibility of identifying a marked log.

Field Test

The field test was performed in Malå, Sweden, as a part of the I-Key project. The marking equipment and the reading equipment were installed on the harvester machine and at the sawmill, respectively. The harvester and harvesting area were supplied by Sveaskog. Conducting a field test comprising a harvester machine, sawmill, and data communication involves several companies and results in production time loss and, thus, cost. The marking and reading equipment was therefore carefully tested in both the laboratory environment (Möller 2011) and in field-like conditions before the actual field test. Good code marking quality and detection rates of over 70 percent in the controlled laboratory environment were promising. A controlled laboratory environment and the real world, however, are quite different for this equipment, which indicates the importance of a field test.

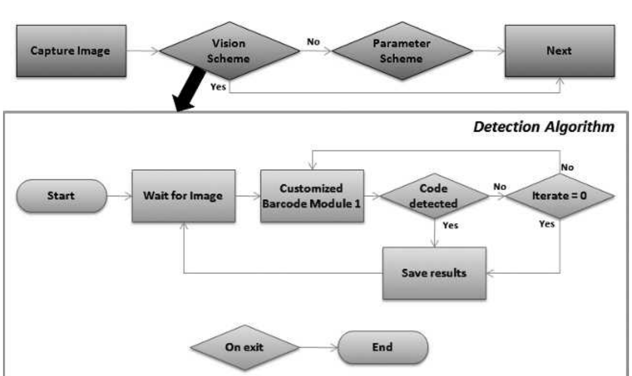

Figure 7.—Detection scheme for barcode-marked logs.

The harvesting was done during the winter season at a final cutting area. The trees were mainly pine, with root diameters varying from 130 to 300 mm. Due to the harsh weather conditions and some unanticipated technical problems, the number of marked logs was fewer than planned. According to the harvester production files (Arlinger et al. 2011), 210 logs were marked during the test. These production files were uploaded to the ICT service provided by SDC to facilitate download at the sawmill.

After transportation from the forest to the sawmill log yard, the separate batch of marked logs was run through the sorting station while capturing, synchronizing, and storing data from the three-dimensional (3D) scanner and images from the detection equipment. Each log end surface was captured in five consecutive images acquired using different camera exposure times to increase the detection rate (Fig. 9).

Applying the vision scheme to the batch of logs resulted in a detection rate of 40 percent. Source images with a 150-microsecond exposure time were used (see Fig. 9). It was observed that close to 55 percent of the codes were severely distorted in some way, and a large number of these codes were impossible to decode automatically. The main reason for the distorted codes was an unforeseen communication problem (Möller 2011) between the applicator and the harvester control system. Below a certain log diameter, the transmission of the saw bar angle, on which the code application is based, was stopped. This resulted in distorted codes on logs with smaller diameters (see Images 2, 4, and 5 in Fig. 10). Unfortunately, the trees at the harvesting site were small, which resulted in 110 logs (52%) with distorted codes. Without this unforeseen problem, the detection rate would have certainly been higher. Examples of codes from the test batch are depicted in Figure 10.

The detection problem was related mainly to the following:

- Quality of the applied code. Distorted codes due to small diameter (mentioned above) decreased the overall quality

Figure 9.—Five consecutive images of a log end surface acquired using various camera exposure times (i.e., 650, 500, 350, 250, and 150 μs). The same light intensity was used when acquiring all images. The coded number is 545.

of the code. Printed CBs on frozen sapwood (winter season) smeared the CBs for 20 percent of the logs.

- Limitation in the search approach. The orientation and position of the code were identified by a search approach of the LOBs and SOBs (see Fig. 8) in the detection software. This proved to be difficult (Möller 2011) with the selected commercial software.

It was not possible to alter the qualities of the applied codes at the time of harvesting due to restricted access to the harvester's data communication. One of the main factors that influenced the detection was the orientation and location of the code. As depicted in Figure 10, orientation and location were sometimes correct but the quality of the CBs was poor; hence, the code number wrongly computed. In addition, code damage resulting from the cutting procedure and log handling cannot be entirely removed; however, these problems appeared to be relatively small compared with the impact of printing quality.

Ocular inspection of the images resulted in 156 (74%) detected codes, which were further verified by means of parameter comparison. The remaining logs were either undetectable or presented uncertainty. Thoroughly comparing the parameters of the logs for which uncertainty remained increased the detection rate to 87 percent (183 logs). This clearly indicates the potential advantage of a parameter scheme. However, the manually achieved detection rate is unapproachable with an automatic scheme given the current code quality. A large number of these codes were manually detected based on knowledge such as unused code numbers and known printing errors. However, as discussed in the ''Conclusions,'' a number of known technical improvements based on existing technology may drastically increase the automatic detection rate. This is true both for the type of barcodes discussed here and for the primary matrix code alternative.

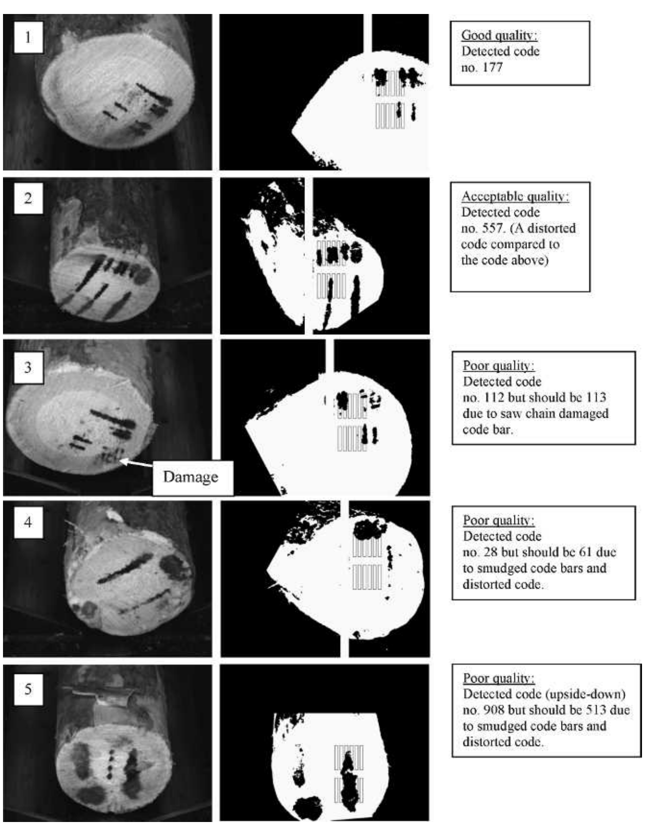

Figure 10.—Examples of codes with good, acceptable, and poor quality.

Log Measurement Verification: A Traceability Feature

The forest industry has problems keeping track of harvested and delivered volumes, causing problems in, for example, correctly pricing deliveries to sawmills. Therefore, it would be useful to monitor the quality of log measurements made by the harvester. Today, this is manually performed in the forest on a daily basis and is therefore cost-ineffective. The following demonstrates how this can be achieved automatically, in this case by using the collected data (traceability data) for the 210 logs.

The log measuring procedures at the sawmill (usually 3D scanners) and on the harvester (Möller et al. 2002, Möller 2011) are somewhat inaccurate, giving rise to uncertainty. The following comparisons, based on manual detection, exemplify one use of traceability data, in this case for analyzing the quality of harvester head measurements. The data from the scanner and the harvester were compared, and the results are presented in Figures 11 and 12.

Recommendations for the accuracy of measurements made by harvester heads in Sweden (SDC 2009) state that 60 percent of the harvester length measurements (Fig. 11) should be within 2 cm of the 3D scanner measurements made by SDC-certified personnel; the standard deviation (SD) should be below 3 cm. In addition, 50 percent of the harvester diameter measurements (Fig. 12) should be within 4 mm of the 3D scanner measurements made by SDC-certified personnel, and the SD should be below 6 mm.

The correlation for length and top diameter measurements is good. Table 1 relates the test results to the limits set by SDC. The data presented in Table 1 indicate that the length and top diameter measurements are within the specified limits. These two parameters have a fairly low SD and should also be suitable for use in a parameter scheme distinguishing between codes for which uncertainty still remains after applying the vision scheme.

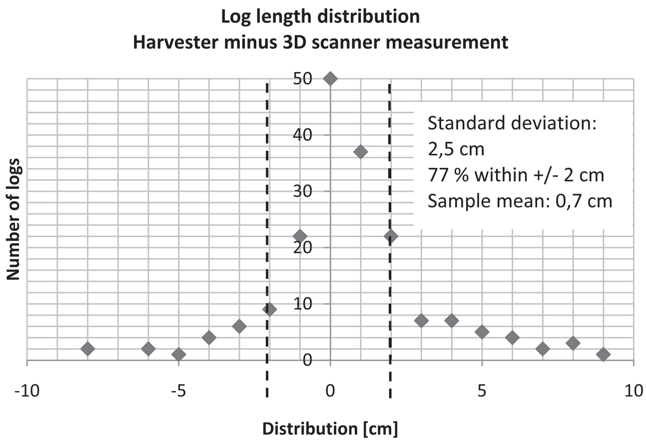

Figure 11.—Log length difference between the harvester and scanner for the 210 case study logs. Dashed lines represent length distribution ±2 cm.

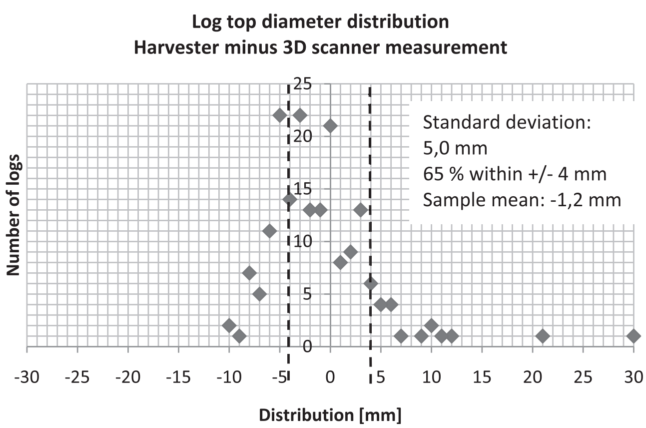

Figure 12.—Top diameter difference between the harvester and scanner for the 210 case study logs. Dashed lines represent diameter distribution ±4 mm.

Conclusions

The main field test performed was affected by certain technical problems and limitations, mainly related to proprietary systems (harvester head control system) in combination with process conditions not anticipated (frozen sapwood). Still, traceability could be demonstrated at an automatic detection rate of approximately 40 percent. This suggests that the designed marking and reading system will function robustly after some further refinement.

The code applicator produces high-quality printed codes under normal conditions. In the current design, however, the codes were applied too close to the edge of the log to handle small logs. Better access to the harvester head control system (saw bar angle sensor and log diameter readings) and, potentially, reducing the code size or increasing the minimum log diameter to mark would facilitate code marks in the center of the log end surface (avoiding sapwood). This would increase the code appearance quality and substantially increase the detection rate.

Table 1.—Comparison of test results and SDC limits for length and diameter.

Variable	Length		Top diameter	
	SDC limit	Test result	SDC limit	Test result
Percentage[a]	>60%	77%	>50%	65%
Standard deviation	<3.0 cm	2.5 cm	<6.0 mm	5.0 mm

[a] Percentage within 2 cm for length and within 4 mm for diameter.

A major challenge of the applicator design, apart from achieving high-quality code printing, is mechanical robustness to withstand the severe loading and environmental conditions. The prototype used during the field test proved to work satisfactorily during the limited testing period but needs more examination before valid conclusions can be drawn regarding its mechanical design.

The developed detection equipment has performed as intended under normal operating conditions at the Malå sawmill. The detection rate achieved from the field test using the custom-designed barcodes is considered to be good, taking into account the poor quality of the code marks.

An obvious problem with printed codes on log end surfaces is frozen sapwood, knots, rough surface structure, and surface contamination by dirt and/or snow (Fig. 13). These effects are present in the real world and warrant further attention. Knots can appear randomly on the log end surface, but they proved to have little effect when printing barcodes. In the winter, however, the water content in the sapwood can cause the code to smear when applied. This can be avoided by placing the code in the center of the log, as mentioned above. Also in the winter, there will always be a certain number of logs that are partially covered with snow or ice before being scanned in the sawmill. If the snow layer is thin, the code can still be detectable using regular paint as the marking substance; if the snow layer is thicker, this will be impossible. One alternative is to add fluorescent substances to the paint. This has been investigated (Uusijärvi 2000, Seidla and Uusijärvi 2004) in recent studies demonstrating that up to a certain thickness of ice or snow, the code remains visible. In the spring, when the ground is wet, mud-related problems may appear; Image 4 in Figure 13 is an extreme illustration of this effect. Under such conditions, the code is impossible to detect. The only solution is to clean the log end before detection or accept that the code is undetectable. Mud-related problems are also undesirable as they increase the wear of cutting equipment; therefore, they are avoided where possible. Discussions with sawmill personnel indicate that while mud-covered log end surfaces are encountered, they do not constitute a large-scale problem.

Two important aspects of log marking stressed by the industry are the cost per marked item and the time needed to apply the mark. The forest industry produces high volumes of items with a fairly low item value, at least under Swedish conditions. A tree can be processed into four or five logs in less than 30 seconds. Even taking an additional second to apply each mark would add up to a substantial time loss. This is one major advantage of the designed applicator: no time loss. The method is also cost-effective in terms of marking cost compared with, for example, transponders, which was the other alternative considered in the I-Key project. A 5-m-long pine log with a diameter of 200 mm has an approximate value of €8 (Sweden) to the forest owner if the log is suitable for lumber. If transponders costing an estimated €0.2 (high volume) per mark are used, the marking cost would correspond to 2.5 percent of the total

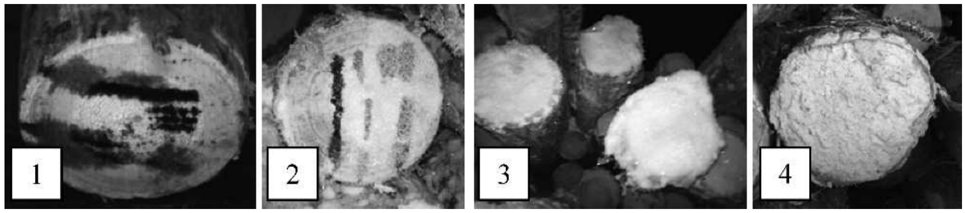

Figure 13.—Problems with printed codes on log end surfaces: smeared lines due to wet/frozen sapwood (1), snow problems (2 and 3), and mud covering the log end (4).

log value. The log marking system presented here has a 100-times-lower marking cost, meaning cost could be a determining factor favoring its use for large marking volumes with low item value. In addition to this, applying a transponder with zero time loss has turned out to be very difficult.

A low-cost traceability system brings a number of additional possibilities for improving the operation of the whole wood value chain. This, however, is beyond the scope of the present article.

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