Tracking Logs with RGB Images within the Wood Supply Chain: A Preliminary Study on Image Acquisition

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Abstract

In addition to the fact that actions have been taken by the European Union and the World Bank to impede illegal logging worldwide, full traceability of logs would also be of benefit to the timber industry and market participants. Therefore, in this study, basic conditions for RGB image acquisition are derived for tracking roundwood by means of biometric features on log end faces within the wood supply chain from stump to sawmill. For this purpose, 24 logs were initially photographed in the forest after felling and photographed a second time 8 weeks later in the sawmill. Difficulties in image acquisition were analyzed qualitatively as well as quantitatively by comparing the images made in the forest with those made in the sawmill. The quantitative evaluation was carried out using different measures that are well established with respect to digital image processing. Tracking efforts solely by means of these measures turned out to be unsuitable. However, the shape measures performed best and are assumed to be supportive in combination with other methods. Therewith, conditions for a practical implementation in the future can be deduced.

As the timber industry is exposed to fierce competition owing to market globalization and rising customer demands, improvements in the planning and control of materials and information flows in the wood supply chain have become increasingly important. Highly mechanized processes in the forestry and sawmill industry have certainly contributed to secure competitiveness; however, optimization potentials can still be located regarding the points of intersection between the actors within the log supply chain from stump to mill (Korten and Kaul 2008, Häkli et al. 2010, Murphy et al. 2012).

A log tracking system in conjunction with a real-time managed database would enable improvements in logistics within the log supply chain (Fig. 1). Such an approach could possibly lead to cost reductions, for example, owing to more efficiently managed inventories or by avoiding duplication of steps, such as multiple measurements of roundwood.

Furthermore, since March 2013, European market operators have been obliged to adhere to the European timber regulation EUTR No. 995 2010 (European Parliament and the Council of the European Union 2010) claiming disclosure of the provenance of timber and timber products that are placed on the European market in order to impede deforestation and illegal trading of timber. Tracking efforts along the supply chain are not restricted to roundwood and timber products; they are actually imposed to a greater degree in many different industrial sectors (Schwägele 2005, Fisher and Monahan 2008, Johnson 2008). Thus, an implementation of a log tracking system could support positive legislative and economic developments in the forest products industry.

Many marking methods have been applied for tracking logs throughout the supply chain, including punching, paint, bar codes, DNA fingerprinting, radio-frequency identification tags, and others. However, each method is restricted in its application because of costs, weather conditions, or practical implementation (Tzoulis and

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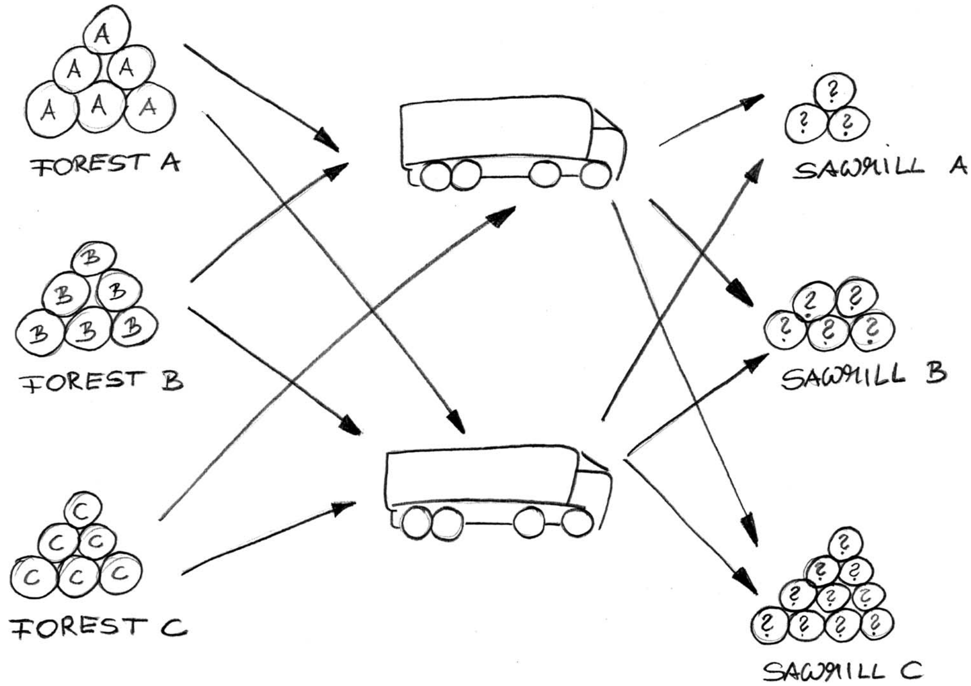

Figure 1.—Schematic diagram showing the supply chain from the forest to the sawmill.

Andreopoulou 2013, Tzoulis et al. 2014). In further studies, log characteristics, such as knots, annual rings, and pith location, were used as unique features, similar to a human fingerprint, for log identification. Although more research efforts must be made in this scientific field, recent results have shown suitability of wood characteristics on log and timber surfaces for a digital log fingerprint (Chiorescu et al. 2003; Chiorescu and Grönlund 2004; Flodin et al. 2008a, 2008b). A recent study (Schraml et al. 2014) showed that log end faces can be differentiated by their annual ring pattern using Gabor filters. Many difficulties that are directly and indirectly linked to biometric feature extraction are the subject matter of current scientific work (Schraml and Uhl 2014); admittedly, image acquisition in these studies was carried out under controlled conditions. A practice-oriented access and a contribution to addressing problems in image acquisition that may arise thereby are still pending.

The fundamental idea is to identify a log by means of two digital images of the same log whereby the first image is taken immediately after tree felling and the second in the sawmill. Capturing images at different locations within the wood supply chain can lead to varying image quality resulting from different recording conditions and the different appearance of log end faces caused by log manipulation, storage, or transportation conditions. To assess disturbing factors occurring in practice in terms of image acquisition, images of log end faces were taken in the forest. Images of the same log end faces were taken again in a sawmill in order to have an image data set suitable for comparison purposes. The objective of the study was to determine disturbing factors in image acquisition by means of image properties related to the shape, pixel values, and the histogram of the pictured log end faces. The results of the data collection were analyzed both qualitatively and quantitatively.

Materials and Methods

Image acquisition

For this purpose, 24 spruce logs (*Picea abies*) were initially photographed near Gastein, Austria, before truck loading on the forest road and photographed a second time in a sawmill named ''Entacher'' (Salzburg, Austria) 8 weeks later.

The timber transport from the location of felling to the forest road was carried out with a truck equipped with a cable yarder system named ''Turmfalke,'' which has been developed most notably for operations up and down the mountain, and with a processing unit named ''Harvester Woody 50.'' After debranching and cutting in length, the logs were stored along the forest road. While the logs were in the truck's gripper arm, the loading process was shortly interrupted to take a picture using a GoPro HERO 3 with an image resolution of 12 megapixels. The camera was mounted on a specifically produced wooden device that was designed for quick handling and rapid imaging and is schematically illustrated in Figure 2 and shown in Figure 3. Thereby, the wooden side elements and the stopper in the center ensure a fairly perpendicular positioning of the device to the log end face. Several recesses in the arm allow the camera to be set up at different distances to the cross section of the log. After the image was taken, the log was marked with paint at the stopper's location in order to recover the original position of the log more easily and to have a reference point for corrections in perspective.

The logs were delivered to the Entacher sawmill, properly stored outside, and thus exposed to outdoor conditions for 8 weeks before the log end faces were photographed a second time. Before proceeding with the initial processing steps in sawmilling, the log ends were crosscut in order to protect the saw blades from dirt. Because of this very first cut, which is hereinafter referred to as a chop, two image series were made in the sawmill. In the first iteration, the log end

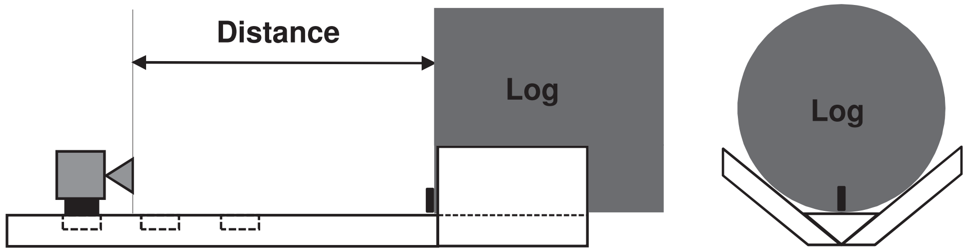

Figure 2.—Illustration of the specifically produced wooden device for image acquisition.

faces were photographed as found, and in the second run, the log end faces were crosscut with a chainsaw and then photographed again (Fig. 3). For this, the logs were brought into the same position as in the forest using the paint mark. Owing to the way the images were made in the forest, they could be compared with the images in which the original log end face was pictured after delivery and with the images showing a cross section of a log around 3 cm behind the original end face.

Image data evaluation

As a first step, factors occurring in the image acquisition process in the forest and that possibly pose a handicap for further log tracking efforts were highlighted qualitatively. In a second step, obstructions in image acquisition were determined by comparison of the series made in the forest and in the sawmill quantitatively by means of established image property measures. Finally, the chosen measures were evaluated on the basis of their reliability and suitability for tracking efforts. Furthermore, disturbing factors in image acquisition were highlighted by means of these measures. All measures refer to the pictured surface of the log and were computed using MATLAB software (MathWorks 2014). The background of the images was removed manually, and the calculations were carried out on the basis of grayscale images with intensities ranging from one to zero.

All in all, eight measures were chosen, from which three describe the shape properties, two are related to pixel value measurements, and another three are histogram-based descriptors. The shape-related measures chosen in this study were circularity, eccentricity, and elongation, all of which are well-established measures in terms of digital image processing, being invariant to translation, rotation, and scaling.

The circularity is defined in this study as the ratio between the area A and the squared diameter D of the surface and is normalized by multiplying the ratio by $4/\pi$. In case the shape is a perfect circle, the circularity results in one:

$$Ci = \frac{A}{D^2} \times \frac{4}{\pi}$$

As the pictured log end faces show very unsteady geometries in terms of their shape, the length of the major axis of an ellipse was used as diameter D. Because the calculations of the major and minor axes are implemented in the MATLAB image toolbox, no additional calculations were required in this context. According to the implementation in MATLAB, the length of the major axis of an ellipse shows the same second moments as the surface region. The determination of this axis basically follows the idea of a principal component analysis (Simoncelli and Olshausen 2001, Backhaus et al. 2011). The second shape-related measure is the ratio between the distance between the foci and the major axis length of the ellipse and was implemented in MATLAB as well. The third measure is the ratio between the minor axis and the major axis. All shape-related measures were scaled between zero and one.

The mean and the variance were chosen. Thereby, the mean describes the average brightness in an image, and the variance represents the dispersion of the pixel values in the appropriate image.

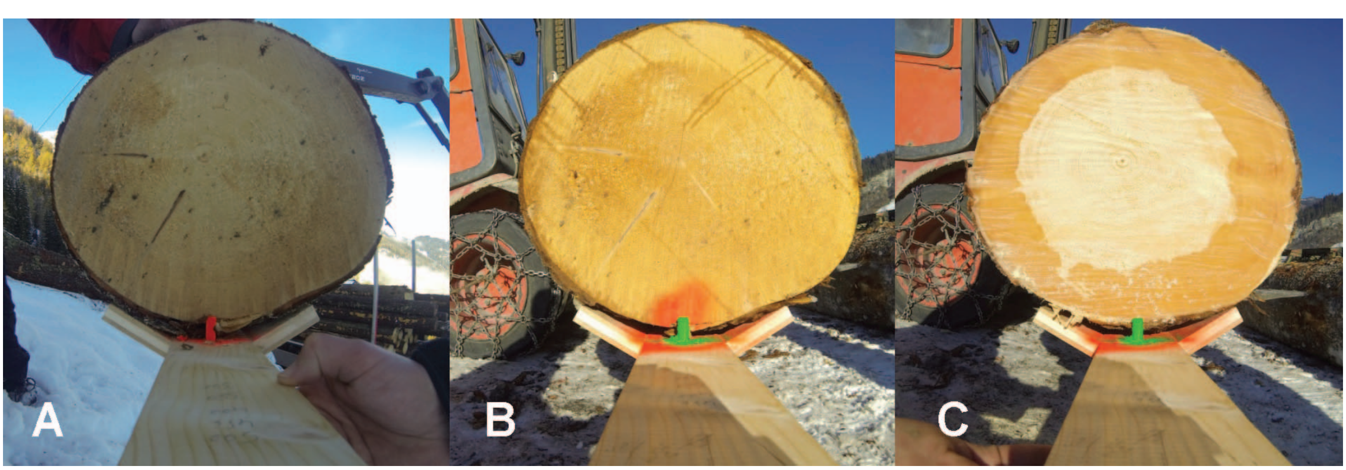

Figure 3.—A log end face in (A) the forest, (B) the sawmill, and (C) the sawmill after chop cutting using a chainsaw. (Color version is available online.)

The histogram-based measures include the interquartile range (IQR) as well as the range between the maximum and minimum intensity values. The third measure describes the ratio between IQR and the median, which technically corresponds to an empirical variation coefficient (Hartung et al. 2005). These measures were particularly selected because as many difficulties as possible should stress qualitatively derived conclusions in terms of image acquisition in practice for log tracking efforts within the wood supply chain.

Results and Discussion

Owing to different camera positions in the forest and the sawmill, perspective-based distortions could be corrected. The wooden device was therefore designed in such a manner that the distance of the camera to the log and the angle of the camera may be readily examined.

Log end face images offer unique features that seem to be suitable for digital fingerprints, such as log shape, annual rings, and location of the pith. Therefore, these features need to be detectable on both images, namely, on the images made in the forest as well as on the images made in the sawmill. On the basis of the present image data set, general conditions for image recording in future can be drawn, and difficulties in practical implementation can be highlighted and are discussed in the following two sections. As a last point, the measures are discussed in the third section of this part related to the shape, the pixel values, and the histogram-based index numbers.

Images made in the forest

According to Figures 4A and 4C, the image comprises the whole log end face, while the surface of the log is just partially pictured in Figure 4B. In order to use the log shape as biometric information, it is necessary to ensure that the whole log surface is shown on the image. As the image acquisition should be as non–time-consuming as possible for economic reasons, the distance should be preselected in such a manner that the log surface is entirely displayed. Another possibility would be to design a continuously adjustable recording device.

In Figures 4A and 4C, laterally protruding wooden parts may complicate shape detection; thus, the logs should be cut properly in order to facilitate further analysis and thus enable accurate results in terms of digital image processing. To be precise in terms of shape as a biometric feature, further considerations are required. The bark is certainly an external component of trees but can easily fall off during the forwarding process. Therefore, all further considerations in terms of log shape should be made without bark. In terms of spruce logs, the bark shows dark color values and thus may be well distinguished visually from the rest of the wooden surface. Thus, an important general prerequisite for further image analysis procedures is fulfilled; however, according to Figure 4D, protruding wooden parts showing the same color values as the log's surface would complicate this procedure. This fact emphasizes the need for a clear-cut after felling. In Figure 4E, the felling notch is recognizable on the right side, and thus the original shape is not represented. This fact can be neglected as long as it can be ensured that the falsified shape has the same geometry in the sawmill; hence, this condition can be met only before the usual chop cut. A further condition for accurate shape detection is a background that should contrast clearly with the log. And finally, all images in Figures 4D through 4F show impurities that may hamper a successful separation of the bark from the log in terms of digital image processing. Snow (Fig. 4D) and dirt (Figs. 4E and 4F) cover parts of the bark and the rest of the surface. Small amounts of dirt possibly can be corrected via interpolation methods; however, as soon as greater areas cover a log's surface and bark, segmentation results might not be precise enough for recognition algorithms.

The problem of dirt in the form of snow or earth also compromises unique features, such as annual rings and pith location. According to Figures 4G through 4I, different degrees of soiling are shown, all of which impede or even make it impossible to determine annual rings (Figs. 4G and 4I) and the location of the pith (Figs. 4H and 4I). Beyond that, the image in Figure 4I shows the felling notch, in which the border can hardly be determined visually owing to great areas of soil covering the right part of the trunk.

Comparison of images made in the forest and in the sawmill

After identifying difficulties when recording log end faces in the forest by an RGB camera, the images made in the forest are now compared with those made in the sawmill. Differences that appear on the log ends resulting from storage, transportation, and other circumstances can be subsumed under the term ''cross-section variations.'' An example of the changes that might occur through transportation and delivery is given in Figure 5. Initially, a laterally protruding wooden part is recognizable in the image made in the forest (Fig. 5A), which is missing in the image made in the sawmill prior to crosscutting the trunk a second time with a chainsaw. As previously mentioned, first, laterally protruding wooden parts are harder to distinguish from the plane surface owing to very similar color values, and second, the original shape is barely identifiable in both images. Admittedly, parts of the shape might be sufficient for successful log identification; however, as long as no research efforts are made in this context, a conservative approach seems suitable. The painting added in Figure 5B compromises the annual ring pattern because late wood in RGB images of spruce logs usually clearly differs in color from early wood. This differentiation, which is based on color information, is therefore hampered, so information required for any purposes should not be applied on cross sections of logs.

After crosscutting the log in order to simulate the chop cut in the sawmill industry, a knot appeared on the left side, shown in Figure 5C. Because this can happen to a much greater extent than in this example (Fig. 5C), and because this might also happen the other way around, meaning that knots appear on the image made in the forest and that no knots appear on the image taken in the sawmill, knot detection in order to omit them in such investigations must be considered a prerequisite for further analysis as well.

Another example is given in Figure 5E (compare with Figs. 5D and 5F) showing cracks occurring on the log's surface as a result of progressive drying in the course of outdoor storage, specifically at the log end faces. As the process from the time of felling until delivery and primary processing in the sawmill usually takes several weeks, naturally occurring cracks cannot be avoided; thus, algorithms in terms of digital image processing should be

Figure 4.—Images made in the forest showing various types of shape and surface illustrations: (A) the whole shape, (B) part of the shape, (C) laterally protruding wooden elements, (D) surface covered with snow, (E) surface covered with earth and showing the felling notch, (F) surface covered with dirt, (G) whole surface affected by dirt, (H) pith location affected by dirt, and (I) parts of surface affected by dirt. (Color version is available online.)

able to detect and exclude them for further analysis. Discolorations also occur on log ends as a natural consequence of the outdoor drying process (compare Figs. 5D through 5F), but there is no documented research as to how far discolorations in RGB images impair annual ring detection.

Light and illumination conditions are of major importance in further scientific analyses. The light conditions should ideally be the same in the forest as in the sawmill. Those in the forest might vary considerably; for example, the log surface may easily be subjected to shading. By means of a flashlight, this confounding factor (Figs. 5G and 5H) could be reduced or even completely avoided.

Evaluation of the image data set by measures

The measures related to the images made in the forest are denoted in Figures 6 and 7 as "forest," and those related to the sawmill are labeled as "Sawmill 1" and "Sawmill 2"; "Sawmill 1" refers to images before and "Sawmill 2" to images after the chop cut.

All shape-related measures are supposed to outline the ovality of the logs expressed by normalized index numbers.

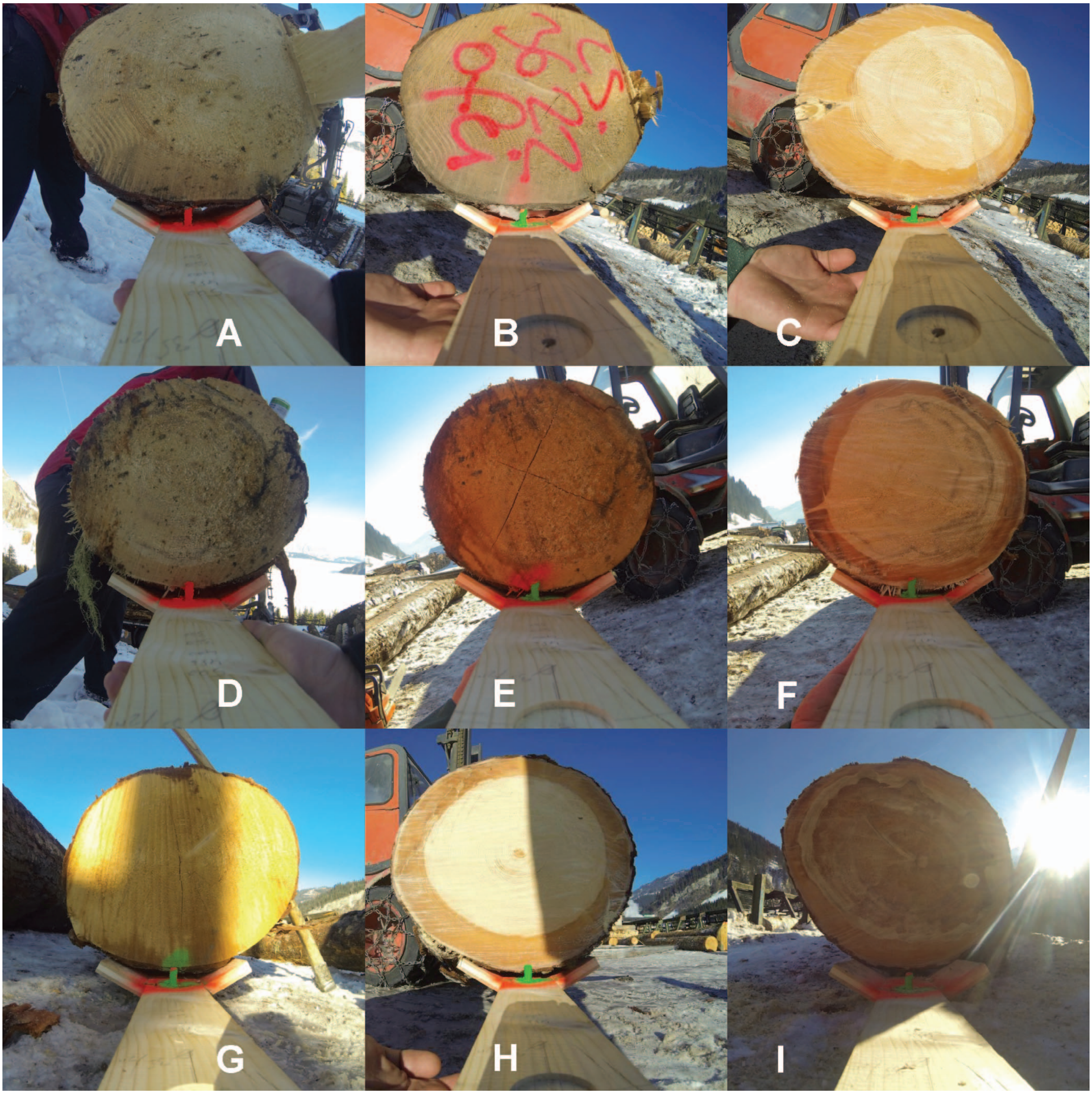

Figure 5.—Images made (A and D) in the forest, (B and E) in the sawmill prior to chop cut, and (C and F) in the sawmill after chop cut using a chainsaw and showing cross-section variations, such as (B) paintings, (E) cracks, (G and H) shading conditions, and (I) backlight conditions. (Color version is available online.)

Because the shape measures yielded similar results, further explanations are related to circularity. Laterally protruding parts were removed together with the background and ignored. As shown in Figure 6, the images made in the sawmill show similar empirical distributions in terms of circularity, but compared with the shape measures gained for the images in the forest, a comparatively large scattering can be observed. Nevertheless, it is clear that shape measures for partially pictured log ends, as exclusively given in the forest, differ considerably from fully displayed log ends as in the sawmill. It turned out that the scattering in terms of shape measures could be reduced within the images made in the forest by leaving out those images showing a partially pictured log end face.

Owing to the fact that the matching results between forest and sawmill are similarly unreliable compared with the results between Sawmill 1 and Sawmill 2, the chosen shape measures were deemed unsuitable for this study.

In terms of pixel value measures, the mean brightness shows great scattering in the sawmill and considerably less scattering in the forest. When comparing the means resulting from the forest with those values gained in the sawmill, these differences can be attributed to the lighting conditions. Although the mean values in the image series

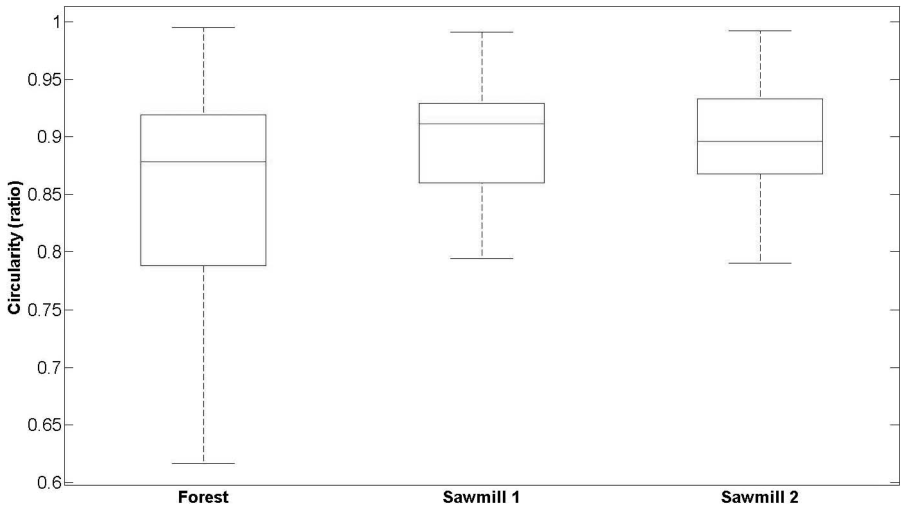

Figure 6.—Box plots showing the circularity for the image series made in the forest and the sawmill in each case.

show nearly the same range in terms of their IQR and whisker ends, respectively, the positions of the medians are rather distinctive. Because the conditions in image acquisition were the same for both series in the sawmill, the shift of the median can therefore be explained by a difference in information content. Considering the image examples of Sawmill 1 and Sawmill 2 in Figure 5, two main reasons can be deduced to explain the shift in median (Fig. 7).

First, it was observed that heartwood can be distinguished from sapwood in Sawmill 2, which necessarily results in different histogram distributions, and second, dirt that still may occur after delivery in the sawmill is completely missing in the image series of Sawmill 2. The results obtained by the measure variance are the same with the exception that the pixel values scatter much more in Sawmill 1 than in Sawmill 2, which stresses the impact of dirt and other impurities occurring on the log end surfaces.

The histogram-based measures make up the IQR and the range between the maximum and minimum pixel values as well as the ratio between the IQR and the median.

However, in order to draw conclusions on the reliability with respect to tracking efforts of log end faces, the computed measures were sorted by size and then ranked. In this manner, correctly assigned log images with respect to their locations (i.e., forest, Sawmill 1, and Sawmill 2) could be determined. The measures turned out to be very poor in terms of tracking efforts because hardly any log image was correctly assigned. However, the coefficients of correlation and the 95 percent confidence intervals were computed for all logs and all measures in terms of their different locations, and these are presented in Table 1. According to Table 1, it is clear that shape-related parameters perform best. It can also be observed that correlation is highest between Sawmill 1 and Sawmill 2, although the log end faces were, strictly speaking, different owing to the chop cut. The correlation between Sawmill 1 and Sawmill 2 is even higher than the correlation between the forest and Sawmill 1, although the same log end faces were compared with each other.

These observations allow the conclusion that some unknown conditions obviously have a greater impact on shape accordance than a chop cut. This is supported by the fact that the least amount of correlation was between the forest and Sawmill 2. Theoretically, this conclusion seems to be a paradox; however, closer inspection of the image

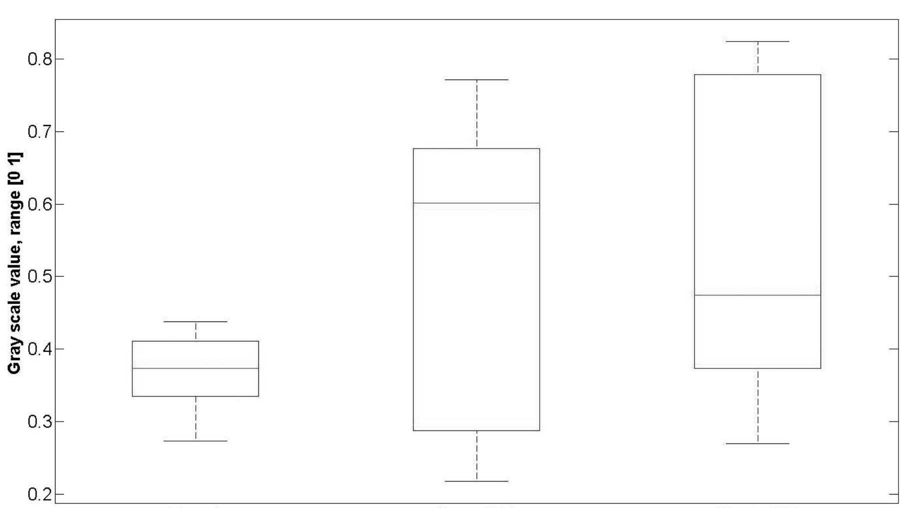

Figure 7.—Box plots showing the mean brightness for the image series made in the forest and the sawmill in each case.

Table 1.—Coefficients of correlation (COC) and 95 percent confidence intervals (CI) given for all measures with respect to all locations.

Measure	Relationship: Forest and Sawmill 1		Forest and Sawmill 2		Sawmill 1 and Sawmill 2	
	COC	95% CI	COC	95% CI	COC	95% CI
Circularity	0.76	[0.52, 0.89]	0.62	[0.29, 0.82]	0.89	[0.77, 0.95]
Eccentricity	0.79	[0.58, 0.9]	0.69	[0.4, 0.85]	0.9	[0.79, 0.95]
Elongation	0.76	[0.52, 0.89]	0.62	[0.3, 0.82]	0.89	[0.76, 0.95]
Mean brightness	0.05	[−0.35, 0.44]	0.01	[−0.38, 0.41]	0.83	[0.64, 0.92]
Variance	0.32	[−0.08, 0.64]	0.35	[−0.05, 0.66]	0.41	[0.01, 0.7]
Interquartile range (IQR)	0.15	[−0.26, 0.52]	0.12	[−0.29, 0.5]	0.47	[0.08, 0.73]
$Delta_{max\text{-}min}$	0.19	[−0.22, 0.55]	0.27	[−0.14, 0.6]	0.71	[0.43, 0.86]
IQR/median	−0.06	[−0.45, 0.35]	−0.16	[−0.53, 0.25]	−0.08	[−0.47, 0.32]

data set revealed that protruding wooden parts, fallen dirt on bark, and fallen bark owing to wood manipulation are the main reasons for that observation. These results suggest that logs should be properly cut and be free of dirt and other impeding factors, which is an important finding for practical implementation.

Conclusions

The experimental assembly had a great emphasis on practical activity, and apart from the time and date, no other agreements were made in advance with the operators. The wooden device that was constructed turned out to be efficient because all images could be taken quickly, and although two pictures were always taken in the same mode, no image could be found that was blurred or of poor quality. Therefore, the GoPro HERO 3 proved to be a suitable tool for this investigation and seems to be worth testing directly mounted on a Harvester because the camera can be managed via remote control and placed in a shock-absorbent plastic housing. If a different camera system is used in the sawmill, the camera-specific distortions have to also be corrected because the GoPro camera system usually has wide-angle lenses integrated. Compared with the different tracking methods mentioned in the introduction, tracking by imaging is a promising alternative because (1) recent research efforts showed the feasibility of this method (Schraml et al. 2014), and (2) many known methods in terms of biometrics and human fingerprints have not been tested for their suitability for tracking log end faces of timber.

During this study, it became clear that the logs varied considerably in diameter. There was not enough time in the forest to adapt the camera to various positions, and for this reason, not all logs were entirely captured on the image. If recognition algorithms are developed in such a manner that the whole shape is not necessary (unless pith can be found on the image), no improvements with respect to the wooden device would seem to be necessary. A different possibility would be a continuously adjustable device with the corresponding distance marked on the bracket or a camera equipped with a lens and autofocus.

With respect to the images made in the forest, several restrictive factors could be determined from which marginal conditions can be derived. First, it is appropriate to ensure a clear surface cut without laterally protruding parts. Second, the surface should be free of snow, dirt, and other cover. Third, backlight should be avoided at all costs. In terms of illumination, a flashlight could contribute to images being free of any kind of shading; however, this might cause undesired side effects during snowfall or heavy rainfall.

The conditions for image acquisition are certainly easier to manage in sawmills; however, depending on storage time and storage circumstances, discoloration and cracks resulting from drying must be taken into account. Furthermore, snow and earth on the logs' surfaces are also confounding factors and therefore are arguments for taking the image after the usual chop cut. Alternatively, an image acquisition before the chop cut would show an image with the same log shape geometry as in the image made in the forest, which might be of particular interest if, e.g., the felling notch is part of the original image. As already mentioned, bark in this context is not considered part of the log shape because bark can easily fall off during transportation and manipulation. Therefore, shooting an image before and after chop cutting seems to be the most appropriate option.

According to Figures 5C, 5F, and 5H, annual rings and the location of the pith can be seen more clearly than in rough-cut surfaces. Furthermore, discolorations may complicate the annual ring recognition; thus, algorithms may work with the annual ring pattern including, for example, the orientation and frequency. In any case, recognition algorithms should prove to be resilient to all types of cross-section variations.

In addition, the borderline between sapwood and heartwood is clearly discernible and possibly displays another valuable biometric feature. A precondition, however, is the possibility of determining that borderline on rough log end faces too, which is, as yet, not the case in forestry. Another possibility would be to significantly increase the cutting quality in the forest to such an extent that this borderline can be determined by means of digital image processing.

The evaluation of the image data set by means of measures as described in the ''Materials and Methods'' shows the difficulties in image acquisition and emphasizes the conclusions made qualitatively. Above all, log end faces should be free of disturbing factors, such as dirt, snow, or shading. The assumption that varying outdoor conditions, such as lighting, overspread the information contained in the log end faces is only partially true because the conditions in image acquisition in Sawmill 1 and Sawmill 2 were the same, and hardly any identification by means of image measures could be achieved. This leads to the conclusion that, first, conditions in image acquisition should be determined in order to impede strong variations being location dependent; second, it might be reasonably assumed that several measures are required in order to capture unique features of log end faces (however, those measures applied in this study turned out to be less expressive, so different descriptors have to be found); and, finally, because many disturbing factors in image acquisition occurred owing to forwarding, weather conditions, and other factors, further research efforts are required, particularly in terms of blind image quality assessment (BIQA), where the term ''blind'' refers to image quality assessment without reference image. With reference to BIQA, a basis for the decision would be formed whether the current image has to be discarded and a second image shot is required.

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