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Using Machine Vision to Improve the Efficiency of Lumber Mills

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Using Machine Vision to Improve the Efficiency of Lumber Mills

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Abstract
This work provides rationale for the implementation of a machine vision-based approach for promoting timber processing efficiency. With efforts to combat the climate change, criteria for the success of wood industries shifted. Now, they need to ensure economic efficiency while taking the reduction in carbon intensity into account. This may be achieved in either of two ways, through the improvement of energy efficiency in production and by minimizing waste. So far, the traditional methods for the improvement of timber processing efficiency became obsolete. Hence, using advances in electronic engineering and machine vision may be viewed as a promising step.

Keywords: timber treatment, industrial process optimization, machine vision, timber mechanics.

1. Introduction

In Russia, wood industries distinguish the following priority areas for development: deep mechanical and chemical processing of wood with energy generation; investment acceleration, primarily in the construction of pulp and paper mills; large-scale mill modernization; the use of resource- and energy-saving technologies; and productivity improvement[9]. The investment scenario of timber industry development provides for the fundamental changes in the structure of the industry. These changes include the scaling up of pulp and paper production. The newly created industry complex will consist of facilities where logs are cut and processed and where the particleboards are produced [14]. In most instances, the largest wood enterprises that specialize at deep wood processing, e.g., pulp and paper mills and particleboard mills, are part of the vertically integrated system. Facilities in this system provide thousands of employees with jobs, ensure significant inflows into different-level budgets, and support social stability wherever they were launched.

Overwhelmingly, particleboard mills as well as pulp and paper mills utilize waste wood particles (i.e., wood chips) that come from the timber processing units. In this regard, the quality and number of items produced by these mills will largely depend on the lumber mill efficiency and on the quality of resultant wood chips. With often-changing physico-mechanical properties of woody material, high turnover of the lumber mill results in non-optimal outcome, excessive waste, and increased energy costs. So far, the currently accepted operations in wood chip production are not optimal and need improvement, as they often lead to significant losses of wood and the overuse of energy [12].

The quality of wood chips is defined in terms of water content and the presence of mineral impurities [10]. They can be produced immediately at the cutting site, e.g., during forest thinning. Chipped woody material that comes out of the wood chipper is sorted to either of three categories: large, small, and acceptable. Large particles are assigned for the second chipping session in the same chipper or in a special disintegrator. Small particles are considered waste and are removed from the production line. The acceptable wood chips fall with the GOST (grades TS-1, TS-2, TS-3, etc.) or contract requirements. Generally, better yielding of acceptable wood chips means higher efficiency of the wood industry.

2. Materials and Methods

The highest requirements are imposed on wood chips in the pulp and paper production (Table 1). The quality of wood chips was evaluated on samples (at least six) that have been collected at equal intervals after sorting. From the total sample, a representative portion weighing about 2.5 kg was selected by quartering. The sample was sorted by size using an ALG-M laboratory chip analyzer for one minute. The analyzer was equipped with sieves (opening diameters: 30, 20, 10, and 5 mm) and a tray. Chips from different size groups were weighed and the fractional size distribution was determined. The GOST 15815-83 outlines a range of specifications for different-grade wood chips. Tables 1 and 2 present a summary of these specifications.

Table 1. Quality Requirements for Wood Chips, Fractional Size Distribution

Mass fraction of particles retained on the sieve with an opening diameter of:	Grade Standard, %		
	TS-1	TS-2	TS-3
≤30 mm	3.0	5.0	6.0
20 to 10 mm	86.0	84.0	81.0
≤5 mm	10.0	10.0	10.0
Mass fraction of particles retained on the tray	1.0	1.0	1.0

Measuring the amount of woody waste that is left after operations such as chipping, disintegration and sorting of wood chips is a tougher task. In this case, chips must be taken both before and after sorting. The number of samples must be at least 120. The amount of waste sorted out is calculated as ratio of the fractional composition of wood chips before and after sorting. The amount of waste by size is calculated according to the following formula:

$$A = E - E' \quad (1)$$

Where: A – the waste proportion, %; E – the amount of fine particles before sorting, %;
E' - the amount of fine particles after sorting, %.

This kind of work can be carried out over several shifts (days) because one laboratory assistant is not able to collect and analyze more than 30 samples in the span of one shift [1].

Table 2. Quality Requirements for Wood Chips, Debarking Degree

Grade	Bark Content, %	Bark Content per 1 m^2 of the Chip Surface, %				
		Spruce	Pine	Birch	Aspen	Larch
TS-1	<1.0	<1.0	<0.8	<0.7	<0.7	<0.5
TS-2	<1.5	<1.5	<1.3	<1.2	<1.2	<1.0
TS-3	<3.0	<3.0	<2.6	<2.2	<2.2	<2.0

Source: [6]

Scanning wood chips before sorting permits the assessment of the chipper efficiency. When the chipper knives wear down, the number of small and large chips increases. Consequently, this leads to greater losses at the sorting stage. With information about the quality of wood chips before sorting, the chipper operator may avoid the production of unacceptable-size chips by replacing or sharpening the chipper knives. In addition, the excessive amount of small fractions can interfere with the sorting machine operation, i.e., small chips that were not separated from the overall mass of chips in time will make the entire batch defective.

To regulate the production of wood chips, the acceptable range for wood chip quality parameters must be set depending on wood species, harvesting season, etc. By contrast, insights about the quality of wood chips after sorting contribute to the maintenance of sorter screens. When the holes in the sieve are clogged up with wood chips, the sorting unit does not produce items of required size. If the quality of wood chips decreases, the sorter operator may turn off the sorting machine for cleaning the sieves.

3. Results

Information about the amount and quality (fractional composition) of wood chips was obtained by scanning a moving single-row layer of chips placed on a dark flat surface, e.g., a rubber conveyor belt. Readings that were gathered in this way include the total area (m^2) of large, acceptable and small particles that pass through the scanning installation per unit time.

The data processing unit that came with the scanner was set to distinguish:

- acceptable fractions with the bright area value 300 to 600 mm^2;
- small fractions with the bright area value <300 mm^2 - fine fraction;
- large fractions with the bright area value > 600 mm^2.

The area value was defined as a product of the length and width of the wood chip surface that is bright against the dark background of the conveyor belt.

A uniform single-row layer of wood chips can be made mechanically using devices such as a screw unit and a shutter (Figure 1).

The ***pilot line*** for the production of wood chips [7] that provides for the wood chip quality control consists of four workstations (Figure 1).

Workstation I. The Chipping Line uses a feed conveyor 2, which takes woody material 1 (logs, wood waste) to a chipper 3 powered by a power unit 4. The wood chips enter the conveyor 5, which takes them to the second workstation.

Workstation II. The Scanning Unit consists of a device for creating a uniform single-row layer of wood chips 6, a rubber conveyor belt 7, and a scanner 13. The rubber conveyor belt 7 transfers the wood chips to the next workstation.

Workstation III. The Sorting Unit comprises a sorting machine 8 powered by a power unit 12, a conveyor belt 9, which takes large fractions back to the first workstation for re-chipping, and a conveyor belt 11 that removes waste from the line. Among these, the workstation III uses a conveyor belt 10, which carries the acceptable-size wood chips to the next workstation.

Workstation IV. The Scanning Unit 2 uses a device 6 for creating a uniform single-row layer of wood chips, a rubber conveyor belt 7, and a scanner 14, which is similar to that placed at the workstation II.

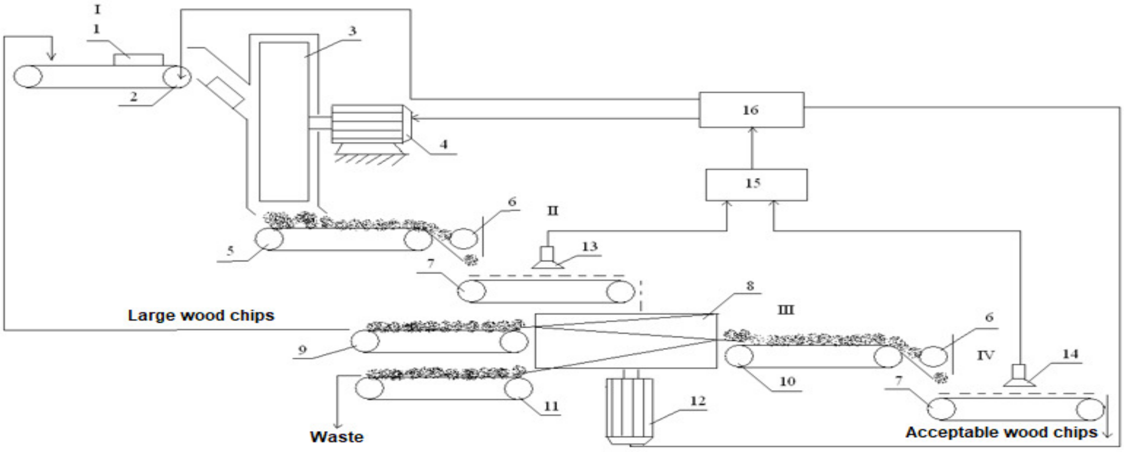

Figure 1. The Wood Chip Production Line [on the basis of source [8]
1 – woody material; 2 – feed conveyor; 3 – chipper; 4 - power unit powering the chipper; 5 – conveyor carrying wood chips; 6 – device for making a uniform single-row layer of wood chips; 7 – rubber conveyor belt; 8 – sorting machine; 9 – conveyor carrying large wood chips; 10 – conveyor carrying acceptable-size wood chips; 11 – waste conveyor; 12 – power unit powering the sorting machine; 13 – scanner; 14 – scanner No. 2; 15 – data processing unit; 16 – control unit.

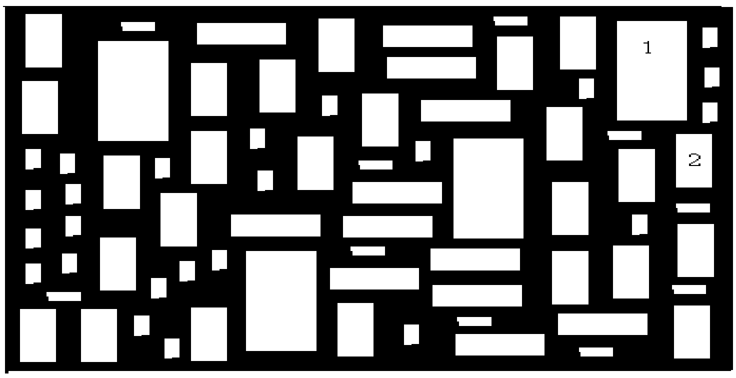

Figure 2. A Uniform Layer of Wood Chips on Scan: *1 – a large wood chip; 2 – an acceptable-size wood chip.*

When the wood chips are scanned, information about their quality and number (Figure 2) is transmitted to a data processing unit 15 and then to the control unit 16, which sends the corresponding signals to the power units powering the feed conveyor 2, the chipper 3, and the sorting machine 8. If the malfunction of chipper knives or sorter screens was detected, the control unit 16 will "turn off" either of the mechanisms necessary.

Another option for the production line modernization was proposed in Lokshtanov[7]. Designed for the treatment of low-grade timber, this pilot line consists of workstations for debarking round forest material, for chipping debarked wood, and for sorting the resultant wood chips into large, small and acceptable categories (Figure 3). To yield high-quality (TS-1 grade) chips, the sorting workstation is equipped with a device that organizes wood chips in a uniform manner (e.g., a screw) and has an inclined transparent section for the wood chips to slide down from one conveyor belt to another. To identify the presence of residual bark in the batch of acceptable-size wood chips, the inclined section is illuminated from below and above and has scanners mounted above and beneath it. These scanners are connected to data processing and control units. The control unit is connected with the power units that regulate the process of debarking. The continuous scanning of wood chips that pass through the transparent section permits a rapid and automatic quality control. In addition, the use of this system eliminates the need for chip sampling and laboratory analysis.

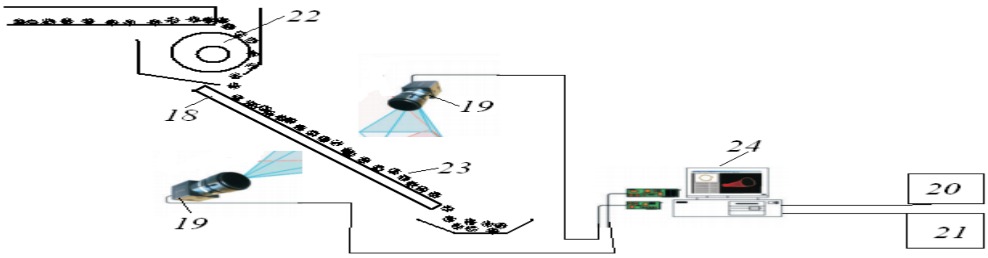

Figure 3. The Sorting Workstation with Scanning Equipment, pilot production line No. 2 [6].

For instance, a shutter installed in a drum debarking machine will automatically close if a poor-quality wood chip is detected. If the production line uses a rotary debarker, the signal from the control unit will be transmitted to the feeder to change the log rate. This allows for the production of high-quality wood chips with maximum productivity and minimal losses. In addition, the use of this system eliminates the need for chip sampling and laboratory analysis.

The high-quality wood chip production line No. 3 operates as follows (Figure 4). The conveyor belts 2 and 4 deliver forest material from a plate feeder 1 to a loading hopper 5 of a drum debarking system. Those forest materials that are partly rotted are pre-splitted using a hydro-splitter 3. At a debarking drum 6 exit, the log sorting takes place by means of a metal detector 7. The conveyor belt 8 takes well-debarked logs to the chipper 10 while the poorly debarked ones are thrown over the tray 16 upon the conveyor belt 17. After the chipping operation, the wood chips pass through the shaving separator 15 and reach the sorting system 14. The acceptable-size wood chips are transferred from the sorting workstation to inclined transparent section 18 by means of a distribution screw 22 (Figure 3). Once the wood chips contact with the inclined surface, the scanners 19 can read them. After scanning, the layer of wood chips 23 (Figure 3) enters the lock feeder 12 and then the pneumatic conveying system, which is equipped with a fan 13.

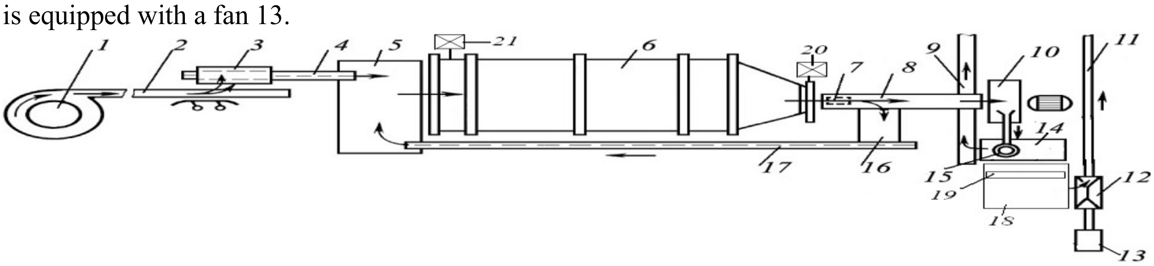

Figure 4. The Wood Chip Production Line, a detailed view: *1 – plate feeder; 2, 8 – conveyor belts; 3 – hydro-splitter; 4 – conveyor belt; 5 - loading hopper; 6 – debarking drum; 7 – metal detector; 9 - waste conveyor; 10 – chipper; 11 – pneumatic pipe; 12 – lock feeder; 13 – fan; 14 – sorting system; 15 – shaving separator; 16 – tray; 17 - return conveyor; 18 – inclined transparent section; 19 – scanning system; 20 – power unit powering the shutter; 21 – power unit powering the fluid supply system.*

Based on the real-time data, the data processing unit 24 (Figure 3) performs the calculation of all adjustments necessary. Afterwards, the debarking speed and the fluid injection rate will be automatically corrected.

The efficiency of a debarking system refers to the amount of bark that was removed and to the quality (appearance) of a debarked surface. The quality of debarking depends on many factors, e.g., the physico-mechanical properties of wood, moisture, temperature, the wood-bark bond strength, tree species, the characteristics of debarking equipment, etc. Despite this, one of the major tasks in debarking is to reduce wood losses while ensuring a good-quality output[8]. This necessitates the creation of effective debarking mechanisms and methods for the real-time process control that would allow the reduction of wood losses [3].
Layers of debarking residues (similar size fractions) scanned at certain intervals vary in color, which allows judging the wood-bark ratio of the waste (Figure 5).

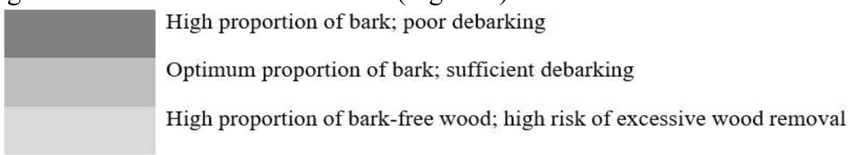

Figure 5. The Color Spectrum of Debarking Residues on Scan.

The analysis of weighed samples after debarking showed variation in the color of woody residues depending on the wood-bark ratio. For instance, imagine a spruce log with a bark layer accounting for 10% of the log. At the beginning of the operation, 90% of residues from debarking such a log will be bark particles and thus a layer of them will be colored brown. Once the session is 70 to 75% complete, the bark will make up an 80% portion of residues. When 80% of tree bark is removed, the bark portion of residues is 70% and the color becomes pale brown. At debarking degree of 90%, the amount of bark in the mass of residues is less than 60% and its color becomes pale gray. Finally, when debarking is more than 95% complete, the residues become as bright as debarked wood.
For this, different-color debarking residues, those swept from under different sections of the drum (Figure 6c) and those carried by the waste conveyor, will provide understating of the log's progress. If the residues are brown, then debarking may be considered insufficient. Very light residues suggest excessive debarking. The pale gray color is postulated to be the most acceptable. The log's progress through this color range must be controlled automatically, if possible.

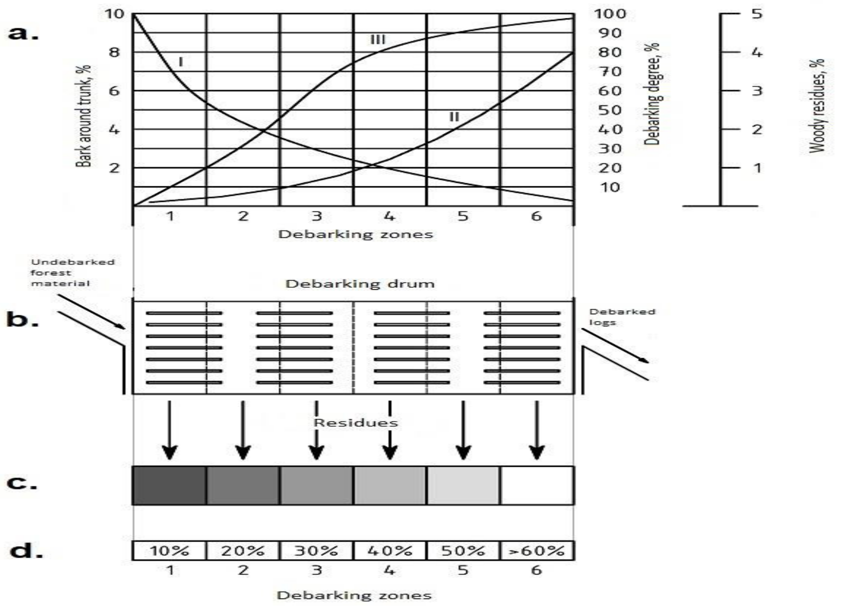

Figure 6. The Color Spectrum of Residues in Debarking: *a – the amount of bark around the log (I), the amount of residues (II), and debarking degree by drum sections (III); b – a schematic view of a debarking drum and debarking zones; c – color spectrum +of residues by zones; d – the wood loss.*

Since debarking residues consist of various components, they need to be chopped to form a homogeneous mix. In addition, they must travel on the conveyor organized in a layer of a certain thickness because the color of items on the conveyor depends on this particular parameter.

Based on the above patterns, a ***specific debarking device*** was developed (Figure 7) [6]. This workstation allows improving the efficiency of log debarking, i.e., separately removing cork and phloem, that is layer-by-layer, so that the recycling stage of production could be more efficient. Its disadvantages include complex design, low productivity, and the lack of a wood loss control system. Its strength is that it allows a continuous investigation of the composition of residual mass. With an automatic process control system, this workstation fulfills the task to operate with greater efficiency.
The debarking line in point resembles a set of sequentially established units such as a log feeder, a drum debarker, a fluid supply system, a shutter, a log unloader, a waste stream-handling unit, and a scanning system (data processing and control units included). A waste stream-handling unit is equipped with a chopping device and a waste conveyor. The scanners are placed above the waste conveyor and a data processing unit is set to analyze information about the color of residues.
This particular device works as follows (Figure 7). A feeder 1 that is powered by a power unit 3 provides forest material 2 for debarking. Logs enter and exit an open-type drum debarker 4 through the specially designed openings 5 and 6. The shutter 7 regulates the movement of the logs. When the log is being treated inside the debarking machine, the shutter is in the closed position. After the operation is complete, the shutter moves up and a debarked log 13 is fed to an unloading section 12. The power units 8, 9 and 10 are connected to the debarking machine 4, the fluid supply system 11, and the shutter 7, respectively.

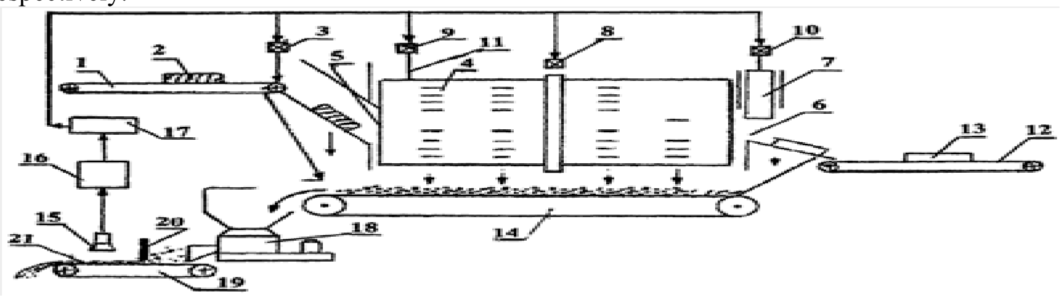

Figure 7. The Pilot Debarking Line, provides no risk of excessive debarking [on the basis of source (Lokshtanov et al., 2013)].

Residues originated from debarking (bark and wood particles) fall onto the waste conveyor 14, which carries them to the chipping device 18. After being chipped, the residues are discharged onto a waste conveyor 19 and a device 20 flats the final mass out to form a layer 21 that is suitable for being scanned. The scanning unit 15 is placed above the waste conveyor 19 and transmits data about the color of residues to the data processing unit 16, which is connected with the control unit 17. When the signs of poor debarking are detected, the power units 3, 8, 9, and 10 turn off in response to the control signals. With such a design, a debarking workstation will allow for the reduction of wood losses in production, specifically at the debarking stage.

The Rapid Response Monitoring of Chipper Knife Wear

The wood chip production line includes the following operations:

- Cutting log into short lengths (1.0 to 2.0 m);
- Debarking;
- Chipping;
- Sorting wood chip fractions by size.

Large wood chip fractions can be fed back to the chipping machine. During such an intense operation, the chipper knives may last up less work shifts. The early wear of chipper knives leads to a decrease in the yield of acceptable-size wood chips.
In the modern-day production, the chipper knife wear is identified by measuring the knife's cutting-edge radius during the scheduled inaction periods (two per shift in winter; one per shift in summer). Each period of inaction means a significant loss of time due to the labor-intensive inspection, especially if the chipper houses 10 to 16 knives. Such an approach does not take into account many often-changing factors, e.g., timber species, its quality, and load.
To test the inactive chipper knife sharpness, the following methods are used: visual inspection; feeling the edge with a finger; and making blade casts on lead plates.
The most sensitive indicator of the chipper operation is the chip fraction size (Figures 8-10). Therefore, chipper knife wear can be determined through the analysis of the chip fraction size. This necessitates

the use of a modified production line with a weight-measuring device and a computational module to evaluate knife sharpness.

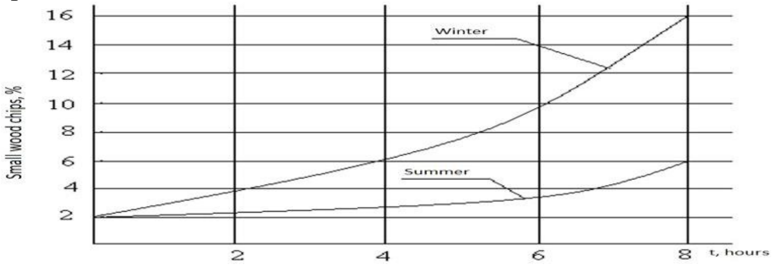

Figure 8. The Proportion of Small Wood Chip Fractions, % of the chipping duration at a constant feed rate: the spruce logs fed to the chipper belong to the 1st grade category.

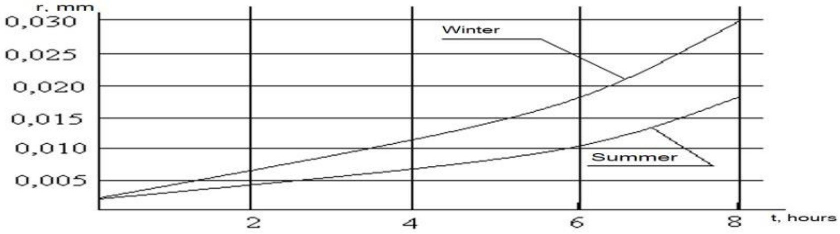

Figure 9. The Single-Shift Blunting Radius (r) of the Chipper Knife Blade at Constant Feed Rate.

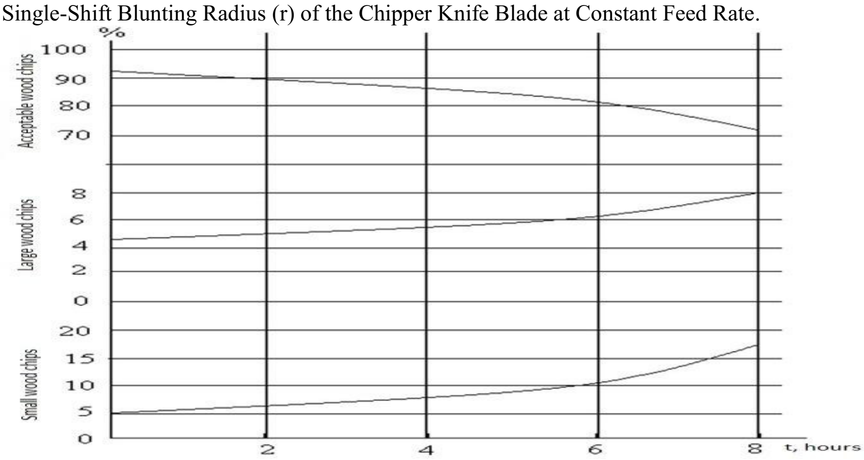

Figure 10. The Single-Shift Patterns in the Production of Wood Chips at Constant Feed Rate: the spruce logs fed to the chipper belong to the 2st grade category.

Table 3. The Total Yield of Different-Grade Acceptable-Size Wood Chips (B) and the Allowable Portion of Small Particles (φ) in Lumber Production

	Summer, %		Winter, %	
	Output	φ	Output	φ
TS-1 Wood Chips from Grade 1 Logs				
Spruce	95	5	93	7
Pine	94	6	92	8
Aspen	93	7	91	9
Birch	93	7	91	9
Larch	94	6	86	14
TS-2 Wood Chips from Grade 2 Logs				
Spruce	93	7	91	9
Pine	91	9	89	11
Aspen	90	10	88	12
Birch	89	11	87	13
Larch	91	9	83	17
TS-3 Wood Chips from Grade 3 Logs				
Spruce	90	10	85	15

Pine	89	11	84	16
Aspen	88	12	82	18
Birch	87	13	82	18
Larch	88	12	80	20

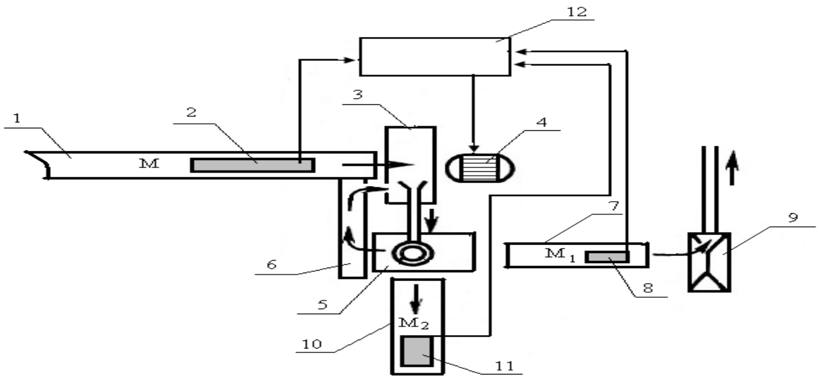

Figure 11. A Schematic View of a Device for Measuring Chipper Knife Sharpness [on the basis of source [5]: *1 – log feeder; 2 – log weight measuring device; 3 – chipper; 4 – power unit; 5 – sorting system; 6 – return conveyor; 7 – conveyor carrying acceptable-size wood chips; 8 – the back pressure measuring device; 9 – take-away conveyor; 10 – conveyor carrying small wood chips (waste conveyor); 11 – back pressure measuring device; 12 – computational module.*

The computational module identifies the chipper stopping time by the following dependencies:

$$B = \frac{M_1}{M}100\ ;\ B = \frac{M_1}{M_1 + M_2}100 \qquad (2)$$

$$\varphi = \frac{M_2}{M}100 \le [\varphi];\ \varphi = \frac{M_2}{M_1 + M_2}100 \le [\varphi]. \qquad (3)$$

Where: B – the total yield of acceptable-size wood chips (output), %; φ – the proportion of small wood chips (waste), %; $[\varphi]$ - the allowable proportion of small wood chips, %; M – the weight of woody material being fed; M_1 – the weight of output; M_2 – the weight of waste, kg.

This module does not take into account the large fractions because they are carried back to the chipper for a second treatment.

Because with dull knives, the production of small wood chips increases, the computational module can inform the operator about the critical condition of the blades when the amount of small fractions reaches the maximum permissible point (see table 3).

Note that weight measuring devices that were used in ***this debarking machine*** are adjustable and may be replaced with the machine vision devices (scanners), which are able to perform the same task (i.e. determine the percentage ratio of different-size wood chip fractions).

4. Discussion

There is a sufficient amount of papers devoted to the problem similar to one tackled here. For instance, the work of Wooten [16] introduced a machine vision-based system with a sophisticated image analysis algorithm that extracts the texture of the wood chips from the image and decides on the sorting. In contrast to the solution presented here, one can notice that their approach is rather complex. That is, in our opinion, knowing only the color of the wood chips will be enough to ensure a proper sorting. Our algorithm is much simpler and less demanding on computing resources, camera quality, and on light intensity at the workplace. Moreover, the texture analysis algorithm under discussion was intended to improve the quality of the fuel material and this is when wood chips of such a high quality could be utilized in the particleboard production. In this regard, the following findings look intriguing [4]. Authors conducted an analysis while taking into account perhaps the fullest range of life cycle stages through which a wood chip goes before the carbon dioxide emission. When sorting wood chips intended to be a fuel source, sensitivity to specific steps of the sorting algorithm was detected. In the context of our study, this finding suggests that the wood chip-sorting algorithm needs further improvement, even if the wood chips being sorted will be set to fire, rather than used in production. Although, many papers

view wood chips as a fuel source[11, 15], we see this resource as too valuable to just burn it. One may find many suggestions to use wood chips in the production of constructional materials [2, 13].
Thus, this article is consistent with the current state-of-the-art and provides a unique and simpler technological solution for the production of valuable resources as compared to similar works in this field.

5. Conclusions

The wood chips production lines with the automatic wood chip quality control and debarking process control systems that were proposed here permit the harvest of wood chips made from low-grade with less energy consumption and less wood losses. A solution for the monitoring of the chipper knife wear will improve the accuracy of the knife sharpness assessment and thus the yield of acceptable-size wood chips. This technology allows for the reduction of the chipper downtime, which contributes to higher productivity.

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