Economical interest of a X-rays vision system in a planing mill production chain

Almecija Benjamin*, Choffel Denise**, Daquitaire Renaud***, Bombardier Vincent**, Charpentier Patrick**
*Siat-Braun/CRAN
**CRAN
*** Siat-Braun
E-mail : almecija.b@orange.fr

Abstract. This presentation is the first phase of a more complete study about the interest of the use of an X-ray scanner in the context of a planing mill. This scanner, placed upstream to edging phases of concerned wood products (unedged timber, square edged timber), allows to make visible not perceptible defect of the material by the human operator eye. These new knowledge in correlation with rough materials has to allow an improvement of the valuation of the end products, but also has to indicate the improvement tracks of the production installation. Our first tries aim at validating this hypothesis.

1. Introduction
In wood industry, yield increase and improvement of the qualitative classification represent important financial gains. Various ways to improve the industrial process are followed: automation of jobs, production operators training, implementation of decision-making tools and means of control. The study presented here links the automation of working posts and implementation of decision-making tools. The application case is about SIAT-BRAUN planing mill and aims to improve the qualitative sort out of a production chain.

2. Context of the study
A planing mill makes wooden products with high added value such as brackets or mouldings. The raw material is unedged timber or square edged timber in 15 % of relative humidity. This raw material is also said "Chose wood", i.e., it contains few defects (knots, marrow, compression wood, heart wood, cracks, and tints). It is necessary to valuate at the best this expensive raw material. To do it, two main ways are followed: (1), from a quantitative point of view, reduce the losses to increase the yield and, (2), on a qualitative point of view, estimate the characteristics of every board to maximize the associated financial gain.

To make profitable an industrial installation aiming at these objectives, big volumes must be treated there. Time granted for every product and the decision-making are thus weak.

In the entrance of the planing mill, we find a dryer and an edging chain. This last one consists of:
   - A supply post in unedged timber or in square edged timber by variable dimensions,
   - A valuation workshop of the board on the length by a purge and a selection of the standard lengths of finished products stemming from the board and the cuttings into sections which ensue from it,
   - A valuation workshop of the board on the width by a selection of zones of homogeneous quality of variable width.
The edging patterns are obtained by means of an optimization taking into account quality zones. They allow to obtain wood pieces of small rectangular sections (pre-cut). The pre-cut are then sorted out and manufactured on moulding machine to obtain finished products.

One of the key points of the transformation process is in the definition of homogeneous quality zones on the width of every board.

The study, presented in this paper, concerns this valuation workshop in particular. Zone selection is made by a human operator assisted by technical means. Quality decisions are based on the analysis of the external profile of every board according to five quantifiable criteria:
- Presence or not of a defect,
- Defect type,
- Size of the defect,
- Location on the board,
- Type of finished products which can be made in the thickness of the board.

Evaluation of these criteria for every board is subject, because of the human operator, to decision errors [Buehlmann U., 2002]. These errors are linked to the hardness and the repetitiveness of the task without taking into account the short time to analyse and decide. The objective of the study is to estimate the qualitative and quantitative impact that an intern vision system can have in selection of the homogeneous quality zones.

So, it is necessary to define the various homogeneous qualities used to zoning as well as the current process. Then, it is necessary to justify the choice of an intern vision system able to improve process, and finally, estimate the contribution of this vision system in the application case.

2.1. Defects taken into account for the qualitative sort out
The wood defects are taken into account in the planing mill standards which defines qualities of the sold finished products. Every defect must be analysed and located to predict quality class which will associate to the end product. The qualitative classification (or sorting) is based on six different wood defects. These are, in importance order: (1) knots, (2) curly grain wood, (3) compression wood, (4) warmed wood and tints, (5) cracks and (6) resin pockets.

2.1.1. Knots
Knots are origins of branches (of stronger density than the wood of the trunk) Stemming from buds, knots can be located everywhere in the tree by the tree. Knots can be dead or alive at the moment of the tree cross-cutting. In the dead knots, it is necessary to distinguish those which are linked to healthy wood (white knots) and those which are unhealthy or susceptible to fall from surrounding wood (knots corks of the conifer, the black knots). Knots are locations of strong withdrawal during board drying. This leads to crack or to total unlink of knot. These cracks contribute to unsightly aspect of knots on the finished products. Concerning the influence zone of these knots, peripheral zones of knots where the thread of wood is diverted, they can be the cause of a qualitative displacement but it is about a subjective criterion appropriate for the quality operator.

2.1.2. Curly grain wood
Curly grain wood is mainly located in the footing of the trunk. The aspect of the grain is contorted, of a sinuous grain in irregular and muddled curves. Its presence is avoided in the production of brackets or high-quality mouldings because of its aspect. Furthermore, this wood is breakable and can create difficulties during manufacturing.

2.1.3. Compression wood
This wood results from a natural reaction of the vegetable to compression strength. The physical properties of this wooden type are such as it results deformations due to release of the internal tensions, irreversible collapses in the drying, bad surface aspect, or cracks . Furthermore, this wood is tinted in some species such as Fir or Spruce. All these factors make that a safety margin must be taken during the selection of the homogeneous quality zones.

2.1.4. Warmed wood and tints
Warmed or tinted wood often have fungal origins. Attacks, if they are stopped on time, do not affect the mechanical resistances of the wood but tint the wood. Superficial tints can also be due to a prolonged exposure in the direct sun rays (UV).

2.1.5. Cracks
Cracks are due to a rough change of temperature (frost cracks, check or star shake), to a separation of two growth rings (ring shake), to the sun (sunburn or crack of drought) or to an unsticking of fibers (honeycombing). Frost cracks, checks and star cracks develop in the radial direction. The cracks of drought propagate up to the sapwood and are characterized by flows of resin leading to a tanning of the wood. Cracks, more at least long and deep, can, besides the unsightly aspect, be a reason to breakage of products after or in the course of manufacturing.

2.1.6. Resin pockets
Resin pockets are present only in evergreen wood. Resin pockets are internal cracks filled with resin. These pockets raise problems more aesthetic than structural even if the resin presents complications during the manufacturing (fouling of tools). These pockets can be inside the end product but don’t have to be visible on end products of high quality.

2.2. Qualitative zoning of the production chain
In production, zoning is made by a human operator who pilots a measurement station. This station is linked to optimization software which establish the edging patterns and to a multi-blades edging machine. The operator selects the zones of homogeneous quality through a laser and through a control panel. These homogeneous quality zones are defined, at the same time, by the direction of the grain and by a variable width, i.e., for an unedged timber, 2 different zonings (several parallel zones) are necessary as the Figure 1 shows it.

In the experimental case of the study, there are 5 different qualities:
- The quality "OA", the highest, which contains no defect and outcome exclusively from a straight wood grain on all the length. A little deviation of the grain (subjective criterion) is however accepted.
- The quality "OB", the second, which can contain black knots of diameter lower than 5 millimetres, knots white with diameter lower than 7 millimetres, with tints, with collapses or crack lower than 0.3 millimetres, compression wood with straight grain and some curly grain wood, resin pockets lower than 2 centimetres, bark pocket lower than 3 millimetres. All these criteria are the maximal tolerances of the quality but they cannot be all combined on the same zone because this one would present too much defects. In that case, the zone is downgraded towards the "Relegated" quality (see after). On the other hand, values of these tolerances decrease according to the dimensions of finished products, or
families of products, to which the thickness of the board linked. There is a subjective criterion concerning the general aspect of the zone and the definition of this quality,
- The lowest, "Relegated" quality, which accepts the 6 types of defects regardless to their size,
- The quality "OA to cut" which links the criteria of the quality "OA" with a purge in one side (maximum 50 centimetres) allowing to eliminate a penalizing defect,
- The quality "OB to be cut" which links the criteria of the quality "OB" with a purge in one side (maximum 50 centimetres) allowing to eliminate a penalizing defect.

The qualities "OA to cut" and "OB to cut" are respectively included in the qualities "OA" and "OB" during the analysis of the production.

3. State of art

3.1. Contribution of the means of visions

Plentiful literatures tries to show that the use of industrial vision means during the first manufacturing of the wood generate financial gains [Thawornwong S., 2003; Rinnhofer A., 2003; Schmoldt D.L., 2000; Lundgren N., 2007]. These studies are applicable to the manufacturing of boards in pre-cut.

There are two types of industrial vision: (1) the external vision and (2) the internal vision. By misuse of language, the vision initially linked to the sensor "eye" is henceforth said internal when it is a question of obtaining a representation of the internal structure (measure of density, for example) products via a technique of non-destructive control working by transmission in the material.

3.2. External vision

The main external vision means used in industrial environment are laser and digital camera (Manufacturer and designer referents: Microtec-Springer, Luxscan-Weinig, COE Newnes / McGehee). These means of detection allow obtaining images of external shape. Afterward, algorithms of detection and, sometimes, interpretations of the defects are applied. The results concerning the detection of defects depend on algorithms which are associated to it but also dimensions of the scanned products. Funck [Funck J.W., 2003] realized a comparative study where results of correct detection of defects extend from 80 % to 99 % according to the algorithms. There are also new techniques as the fuzzy reasoning method [Bombardier V., 2007; 2009] which proposes to translate the subjectivities of the human language in a numerical language by “fuzzy sensor”. This new kind of classification algorithms have better results than the others and, in addition, it need less training samples, and finally, calculation times match to industrial process times. This type of vision requires necessarily the use of algorithms of prediction (interpretation) for internal analysis of the material. In the case of log, it is possible to interpret the forms of the shape [Mäkelä A., 2003] to suppose (to predict) underlying defects. The results remain however little satisfactory because scanned logs always presented shape defects which perturbed the analysis (missing bark, mistletoe bump). In the case of boards, the interpretation of defect behaviour, visible on the shape, inside the material is much simpler because the dimensional and geographical variation of the defect is limited by the weak thickness of the product and the shape defects are reduced because of the already realized manufacturing. However, external vision never allows to display and to locate non-visible defects on shape such as pockets of resin.

3.3. Internal vision

Internal vision of the material is possible by technological means using the properties of gamma rays [Hampel U., 2007] still in the study, of the nuclear magnetic resonance (NMR) for molecular analyses [Maunu, 2002], ultrasounds [Linen C-J, 2008], microwaves for the detection of defects [Yu G., 2009] or X-rays for the localization and the labelling of defects [Sarigul E., 2003a and 2003b; Longuetaud F., 2005]. These methods of vision have results on a macroscopic or on a microscopic level (analysis of the molecules which constitute some material). Each of these techniques has their advantages and their drawbacks. At the moment, NMR technique is dedicated for the molecular vision while techniques based on X-rays, ultrasounds, microwaves, although useful in molecular vision, are rather dedicated for the industrial world for the macroscopic vision.
According to comparative studies, the X-ray imaging is the most successful and the most promising method on an industrial point of view [Skatter S., 1998; Wei Q., 2009]. Furthermore, towards the context of the study, this method is compatible with the environment of wood manufacturing (dust, vibration, climat).

3.4. The vision by X-ray scanner
The imaging by X-rays allows localization of several wood defects. Combined with detection algorithms, this method allows obtaining a mapping (labelling) of the material which can, in theory, be used in every manufacturing stage of the material.

More specific studies for every type of defect were led. These studies concern mainly improvement or creation of detection algorithms. These algorithms use statistical models, intelligent systems of "online" type ("dynamics") or artificial neurones network (ANN), pre-treatments or post-treatments of images, mathematical operators or still, detection results of the defects.

From the X-ray imaging, it is possible to detect and to qualify knots, as concludes it Oh J-K [Oh J-K., 2009] which specifies that a precise determination is not yet possible. The cracks detection, limits between sapwood and hardwood, compression wood, wane, embedded bark or resin pockets is also possible. It is also possible to consider the density of particular zones to analyse causes or consequences [Leban J.M., 2004]. This type of imaging still allows to estimate the mechanical resistance of wood from the characteristics of knots [Ohman M., 1999] or from models, as Brännström M. made by correlating the density, the width of rings, the module of elasticity and the resistance in flexion [Brännström M., 2007].

Reliable and strong algorithms of detection require however long time of calculations and are often useful for one single type of defect at the same time. So, there is a time accumulation for all the detection on every image. On the other hand, the acquisition, in an industrial environment, is generally made with a linear source / detector system (range of X-rays) perpendicular to the scanned piece and not use the reconstruction of the volumes, the tomography, which is much more precise (resolution raised in 3 dimensions).

![Figure 2: Zoning localisation](image)

Times of acquisition to realize a tomography are indeed long. The study of Magnusson Seger M. in 2003 encourages exploitation of the cone of X radiation in the industrial circles by developing, in laboratory, fast algorithms and able to reconstruct volume with high production speed [Magnusson Seger M., 2003]. It becomes now possible to use reconstructions in 3 dimensions to detect more easily and more exactly the defects.

However, the imaging by X-rays does not allow visualizing tints (aesthetic criteria) because these present a too tiny difference of density.

In this study, X-rays imaging is used for its capacity to detect and to localize internal and external defects of the wood.
4. Experimental method

4.1. Objectives
The study presented here aims to three objectives: estimate the impact of a X-ray scanner in identification and sizing (1) of visible defects by the operator but also (2) of non-visible defects, and finally, consequences due to its introduction in the edging chain (3). To do it, an experiment was led in a real scale: the following paragraphs describe this one.

4.2. Sampling
We selected randomly and among stocks, one parcel of square edged timber in dry mixed Fir-Spruce whose nominal thickness is 24 millimetres and 4 meter long, then one parcel of unedged timber in mixed Fir-Spruce of 32 millimetres thickness and 5 meters long. These two thicknesses represent 50 % of the production of the edging chain.

Boards are cut up in a fixed length of 2.5 meters because it is the length of the most sold products, the most representative. Among these boards, a group of 29 boards is selected for the analysis by X-rays. These boards are chosen for the defects which they contain. The purpose is to have the biggest proportion of defects in a minimum of samples. In this way, among 29 boards, 14 have a 24 millimetres thickness and 15 have a 32 millimetres thickness. Then, the boards of width superior to 50 centimetres are edged (in two) because their passage is impossible in the X-ray scanner (truncated images). This operation carries the number of products scanned in 32.

Boards not selected for the analysis by X-rays (more than 70) are visually analysed to evaluate presence or not of defects and so, establish general statistics based on the proportions of every defect according to the thickness of boards. In this way, the results obtained with experiment samples are generalized at 50 % of the planing mill.

4.3. Measure of the samples by X-ray scanner
X-ray scans are acquired by means of a medical scanner named Brightspeed 4 from General Electrics. Scans are made in two steps because the displacement of the scanner is lower than length of boards. Furthermore, to limit the acquisition time, several boards are scanned at the same time; they are piled and separated by low density foam.

4.4. Treatment of the measures obtained by X-ray scanner
The measures obtained by the scanner were manually processed to:
- Separate the boards of the same scan,
- Put the two half-scans together to obtain an image of the board of all length.

The difficulty of the operation results from variations of orientation and from location due to the manual reversal of piles to scan the second half-length. Every volume (board) is then handled with manual threshold. Thresholds allow to eliminate or to highlight grey level ranges by means of colours or luminosity. The method of thresholding bases itself on the spectres of the levels of grey of boards.

4.5. Qualitative zoning from the X-rays imaging
The widths of homogeneous quality zones are measured with a tool issued from the software as the Figure 2 shows it. Furthermore, beginning of thezonings, whose are located regard to the board edge in both extremities, are the distances b1, b2, b3 and b4. We also note the distances m1 and m2 whose localise the end of the first zoning made on the board.

4.6. Qualitative zoning in production
Location of zones is known only by the computer and is not accessible by the user. However, order and widths of the various quality zones selected in the same zoning are accessible by computer checking production statistics.

Quality zoning, manual and in the course of production, is done in the same way as the zoning made with the imaging by X-rays: distances b1, b2, b3, b4, m1 and m2 are found. It is possible to know quality zones selected on the real board by the operator of production.
5. Results and analyses

5.1. Comparison of both zonings

A dimensional characterization and a geographical localization of all visible defects are made out of production. This statement is confronted with the zoning made in production and with the one made by the X-rays imaging. This comparison highlights:

- Not visible defects from the outside but visible with the X-rays imaging,
- Visible defects from the outside but not seen by the operator,
- Visible defects from the outside but not visible with the X-rays imaging,
- Visible defects from the outside, seen by the operator and visible with the X-rays imaging.

The comparison between quality zones selected in production and with the X-rays imaging is made according to two criteria:

1. the selected quality
2. the dimensions and the location of zones.

The analysis of zonings, the one in production and the other one based on X-rays imaging allows to obtain Table 1 and Table 2.

We notice 3% deviation between the total surface zoned in production and that one zoned by means of the X-rays imaging (See Table 1). This deviation is due to the various locations of zonings (slopes to follow the straight grain) made either visually and or with the X-rays imaging. Indeed, some degrees of slope furthermore or at least echo on the zoned total surface. Furthermore, this table shows a distribution of the similar qualities with both used means of vision.

The Table 2 informs causes of the displacements made during the passage from one to another vision means: visual and X-rays. We notice that 45% of the zoned total surface undergoes a change of quality class according to the used vision mean; the vision means do not thus influence qualitative choice of operator on the rest of the surface.

The operator changes 32% quality on the 45% of the total surface displaced in spite of visible elements with both means. The causes of these changes of class are mainly: diverted grain (9.7%), brown spots of strong density (8%), compression wood (2.8%), curly grain (1.5%) and a group of isolated defects or the material not identified under the other categories (8.4%). We also notice a deviation from total 1.6% of the
surface due to the accumulation of several variations, some millimetres, from the location of the borders of zones. We explain all these changes of classes by different properties of the material according to the used vision system. Indeed, some defects are more contrasted with the X-rays imaging than visually and conversely.

With X-rays imaging, operator access to internal characteristics of the material; so he downgrades 23 % of the total surface towards qualities lower than that he zoned visually in production. Among these 23 %, displacements are of:
- 8 % are a displacement of quality OA (visual) towards quality OB (by X-rays imaging),
- 14 % of quality OB towards Relegated quality and,
- 1 % of quality OA towards Relegated quality.

Besides displacements due to factors explained previously, 4.7 % of the total surface is downgraded by presence of resin pockets (2.4 % of total zoned surface) and by presence of crossing or little visible knots (2.3 %) detectable only by X-rays imaging.

Conversely, by basing itself on the visual aspect, operator downgrades 22 % of the total surface zoned from X-rays imaging. The main cause of the visual displacement is wood tint (8.9 % of the total zoned surface) because X-rays imaging does not allow to visualize characteristics, as tints, which do not affect material density.

Experimentally, the X-ray scanner allows to improve qualitative classification on approximately 4.7 % of the total surface but it also implies loss of information about the tint which is the cause of the displacement of 8.9 % of surface zoned.

Statistical analysis on presence of defects is showed in the Table 3. It allows generalize the experimental results in 50 % of the production of the planing mill. The displacements due to tints are thus worn in 8.57 % of half production, and those due to internal defects in 2.29 %.

5.2. Additional result: threshold characteristic
As show in example Figure 3, every spectre consists of a strong presence of low levels of grey (black: 0) which represents the background of X-rays images.

Figure 3: Board grey level spectre
The spectre shows two central peaks representing all the grey levels of the studied board. After analysis, we noticed that the levels of grey correspond to 4 defects of the wood decomposed into 4 ranges: wood without visible defect by scanning, compression wood, knots and resin pockets. Thresholds are defined by the intersection between the curve and the maximal value of peaks multiplied by a coefficient function of the defect ($C_{compression\ wood}$, $C_{knot}$, $C_{resin\ pocket}$). These 3 coefficients are defined in an empirical way by comparison between human perception and result obtained by threshold.

Range of "wood without defect" begins when the spectre is minimal between the levels of grey of background of the image and the first central peak; the abscissa of this point is named $x_{wood\ without\ defect}$.

Other ranges begin in the points of abscissa $x_{compression\ wood}$, $x_{knot}$, $x_{resin\ pocket}$ according to the following mathematical definitions:

If $f$ is function of the grey levels spectre and $M$ the maximal value of the central peak,

$M = \max (f (x)) = f (x_{\max})$, with $x > x_{wood\ without\ defect}$

$f(x_{compression\ wood}) = C_{compression\ wood} \cdot M$, with $x > x_{\max}$

$f(x_{knot}) = C_{knot} \cdot M$, with $x > x_{\max}$

$f(x_{resin\ pocket}) = C_{resin\ pocket} \cdot M$, with $x > x_{\max}$
Thresholding analysis showed that spectres of grey levels have a similar profile and that threshold coefficients are equivalent from a sample to another. The analysis allows determining an empirical value for every coefficient:

\[ C_{\text{compression wood}} = 0.363, \quad C_{\text{knot}} = 0.036 \quad \text{and} \quad C_{\text{resin pocket}} = 0.009 \]

However, abscissas of the thresholds of every defect are different and become confused from a sample to another as the Figure 4 shows. Thresholds representing the knots are included in those representing the compression wood. We obtain better result, as shows in Figure 5, by deducting the appropriate threshold of the wood without defect in three thresholds representatives of the defects. The ranges of thresholds are reduced but there is always a strong inclusion between ranges.

These inclusions are essentially due to the fact that the grey levels spectres associated to every part have dimensions which extend from 647 to 3745 levels of grey. On the other hand, a light overlapping is accepted between thresholds because defects have closed densities (grey levels) or even confused in certain cases.

Thresholding can be improved by calibrating all the spectres on the same range of grey levels and by improving definition method of the characteristic coefficients in thresholds.

6. Conclusion and discussion

Comparative analysis of the qualitative zonings of 32 wooden boards made from two various means of vision allowed to highlight that 45% of the zoned surface undergoes a change of class according to used vision mean, either human eye or X-ray scanner. The experiment demonstrated that the use of a single X-ray scanner in the production chain is penalizing. Indeed, X-ray scanner does not allow detection of wood tints which are the cause of 8.9% of the visual displacements. Therefore, if the scanner is combined to a colorimetric vision system, such as digital cameras or human eye, then it allows to improve qualitative classification on 4.7% of the surface zoned experimentally. The analysis also showed that visible defects by both vision means do not lead obviously to the same allocation of quality (32% of the surface zoned experimentally) because of the contrasts on the material are not the same visually and by X-rays imaging. Interpolation of experimental results shows that contribution of the X-ray scanner concerns 2.29% of the surface of 50% of the production of Siat-Braun planing mill. So, it is necessary to continue a statistical study concerning all the production, more than 9 thicknesses, to know the real contribution of X-ray scanner.

Characteristic thresholds of every defect tried to be unsuccessfully updated: it is necessary to add a step of spectre calibration to succeed. It should be possible, after this stage of calibration, to establish fixed average thresholds which allow generalizing thresholding according to specie and to board thickness. The first calculations, not presented here, realized on the thresholds of a single thickness of board show a decrease of the inclusion of the threshold ranges between them (especially for the 24 mm thickness). However, to conclude on the generalization of thresholding, it is necessary to diversify...
widths and types of boards of the sampling because that experiment deals with the same type of product of small width.

7. Acknowledgement
The authors gratefully acknowledge the financial support of the CPER 2007-2013 “Structuration du Pôle de Compétitivité Fibres Grand’Est” (Competitiveness Fibre Cluster), through local (Conseil Général des Vosges), regional (Région Lorraine), national (DRRT and FNADT) and European (FEDER) funds. The authors want to thank the INRA (National Institute in Agronomical Research) and, particularly, Jean-Michel LEBAN and Charline FREYBURGER for the use of their X rays scanner.

References
1. Bombardier V, Mazaud C, Lhoste P, Vogrig R 2007 Computers in Industry 58 355
2. Bombardier V, Schmitt E, Charpentier P 2009 Measurement 42 189.
3. Brännström M, Oja J, Grönlund A 2007 Scandinavian Journal of Forest Research 22 (1) 60
4. Buehlmann U, Thomas R E 2002 Robotics and Computer Integrated Manufacturing 18 197
5. Funck J W, Zhong Y, Butler D A, Brunner C C, Forrer JB 2003 Computers and Electronics in Agriculture 41 157.
6. Hampel U, Bieberle A, Hoppe D, Kronenberg J, Schleicher E, Sühnel T, Zimmermann F, Zippe C 2007 Review of scientific instruments 78, 103704.
7. Leban J M, Pizzi A, Wieland S, Zanetti M, Properzi M, Pichelin F 2004 J. of Adhesion Sci. and Technology, 18 (6) 673
8. Lin C-J, Kao Y-C, Lin T-T, Tsai M-J, Wang S-Y, Lin L-D, Wang Y-N, Chan M-H, 2008 Int. biodeterioration and biodegradation 62, pp.434-441, 2008.
9. Longuetaud F, Mothe F, Leban J M, 2005 Détection et analyse non destructive de caractéristiques internes de billons d’Epicea commun par tomographie à rayons X », Ph.D. Thesis, INRA-ENGREF, France.
10. Lundgren N, Brännström M, Hagman O, Oja J. 2007 Wood and Fiber Science 39 167.
11. Magnusson Seger M, Danielsson E 2003 Computers and Electronics in Agriculture 41 45
12. Mäkelä A, Mäkinen H 2003 Forest Ecology and Management 184 337
13. Maunu S L, 2002 Progress in Nuclear Magnetic Resonance Spectroscopy 40 151.
14. Meder R, Franich R A, Callaghan P T 1999 Solid state Nuclear Magnetic Resonance 15 69
15. Oh J-K, Shim K, Kim K-M, Lee J-J 2009 Journal of Wood Science 55 264.
16. Öhman M 1999 Planck grade indicators in radiograph images of Scots pine logs, Holz als Roh- und Werkstoff 57, pp.359-363.
17. Rinnhofer A, Petutschnigg A, Andreu J P, 2003 Computers and Electronics in Agriculture 41, 7.
18. Sarigul E, Abbott A. Lynn, Schmoldt Daniel L, 2003a “Progress in analysis of computed tomography (CT) images of hardwood logs for defect detection”, ScanTech, November 3-4, Washington, USA.
19. Sarigul E. et al., “Rule-driven defect detection in CT images of hardwood logs”, 2003b Computers and Electronics in Agriculture, pp.1-19.
20. Schmoldt D L, Scheinman E , Rinnhofer A, Occena L.G, 2000 “Internal log scanning: Research to reality”, Hardwood Symposium Proceedings, Asheville, NC, May 11-13, 2000.
21. Skatter S, Hoibo O A, Gjerdum P 1998 “Simulated yield in a sawmill using different measurement technologies”, Holz als Roh- und Werkstoff 56, pp.267-274.
22. Thawornwong S, Occena L G, Schmoldt D L 2003 Computers and Electronics in Agriculture 41 23.
23. Wei Q, Chui Y H, Leblon B, Zhang S Y. 2009 J. of Wood Science 55 175-180.
24. Yu G, Kamarthi SV 2010 Engineering Application of Artificial Intelligence 23 196.