Digital technique for objective determination of color space of wooden chips used to control delignification process

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ABSTRACT

Identification of wood species of chips mat is very significant for technological kraft pulp boiling process. Used RGB color space is suitable for determination of wood species from chip mat images. Ability of specifying of wood species based on color analysis can form foundation for wood quality sorting and together with other wood properties, such as permeability, it can be used in setting of the delignification process. Controlling of delignification process is based on assumption of significant color differences between wood with high permeability (easier to process) and wood with low permeability (harder to process). The proposed method during processing the pulp wood is based on chips color properties identification and solves a problem of inline wood identification, transformation of digital images of chips to cumulative distribution frequency of RGB, comparison with database and continues updating wood chip color database.

INTRODUCTION

In the process of the craft pulp production, different kind of wood species are presented and their proportion has significant influence on duration of a delignification process. Increased craft pulp production in Slovak republic results in utilizing of heart wood species such as oaks and black locust. These species are unique in chemical and anatomical composition. The heartwood is almost impermeable for water due to storage of the extractives in the structure elements (Čunderlík 2003, Čunderlík and Hudec 2007, Kurjatko, Hudec and Mamoňová 2004, 2006). This makes process of penetration of chemical solutions into oak wood rather difficult. Heartwood species typically contain high amount of the extractives compare to heartless wood species such as beech (Geffert et al. 2006). The extractives influence chemical and mechanical properties of wood, especially color stability and fire resistance (Blažej et al. 1975, Kačíková 2007).

Wood species are characterized by differences in the microscopic structure anatomy, which explains different requirements for craft processes as well as mechanical properties of produced pulp.
Oaks are typical hardwood of Slovak forests. Heartwood and sapwood of oaks differ in structure, chemical composition and durability. Dead heartwood mechanically supports the tree and is more fungi resistant and harder than sapwood. The structure and chemical composition of sapwood are responsible for severe degradation in improper storage condition compared to heartwood, which is mostly impermeable due to the propagation of tyloses (Fig. 1). Heartwood is rarely attacked by fungi for the content of phenols, alkaloids and tannins - toxic for most fungi. Oaks are very rich in hydrolyzed tannins. A content of tannins is higher in heartwood than sapwood. Terpenes and some glycosides have protection function. They chemically and mechanically protect plants against biotic impacts (Solár 2001).

The most common wood species of the Slovak forest, beech, covers 31.2% of Slovak forests. Unlike oaks, the beech wood behaves differently in pulp batch. The beech has high permeable wood tissues and is very permeable especially in the sapwood. A significant drop in permeability is observed in the false heartwood where, similarly to oaks, vessel elements are filled with tyloses (Čunderlik and Hudc 2007).

Long term storage of the beech wood in inappropriate conditions can lead to scald resulting in tylose formations (Chovanec et al. 1990).

Non-homogenous substance of wood affects color variety among wood species as well as within species. There are color differences between heartwood and sapwood, spring and late wood within one annual ring, rays, some wood defects and anatomical and physiological peculiarities. This is resulting in wood texture characteristics of each wood species. The objective of this study was to determine species origin of wood chips using RGB color space. The knowledge of the wood species and their amount in a delignificating digester could implicitly improve boiling process of the kraft pulp technology. Recent descriptive and comparative methods of evaluation of wood color did not allow direct and precise diagnostics of wood species. The objective determination of wood species is necessary for specification of parameters for delignification process.
The precise color is given by three independent characteristics in three chromatic RGB space. The space RGB is specified by coordination R, G, B according to the following equations (Babiak et al. 2002, Skala 1993, Dojčar 2003):

\[
R = \int_{0}^{\infty} \varphi \cdot \bar{r} \cdot d\lambda; \quad G = \int_{0}^{\infty} \varphi \cdot \bar{g} \cdot d\lambda; \quad B = \int_{0}^{\infty} \varphi \cdot \bar{b} \cdot d\lambda.
\] (1)

where \( \varphi \) is relative spectral density of the illumination flow, \( \bar{r}, \bar{g}, \bar{b} \) are colorimetric coefficients of the spectral impulse of red (wave length \( \lambda = 780\text{nm} \)), green (\( \lambda = 546,1\text{nm} \)) and blue (\( \lambda = 435,8\text{nm} \)).

**METHODOLOGY OF MATERIAL SELECTION**

At least three logs of the each listed wood species were taken from locality of the Forest Enterprise of the TU in Zvolen: Common beech (Fagus sylvatica L.), Hornbeam (Carpinus betulus L.), Aspen poplar (Populus tremula L.), Black locust (Robinia pseudoacacia L.) (7 logs) and Sessile oak (Quercus petraea (Matusch.) Liebl. (5 logs). The logs where processed into chips. For species Oak and Black locust, the heartwood and sapwood were carefully separated. For experiments, volume of 0,25 m³ of chips were randomly taken from each wood species.

**METHODOLOGY OF COLOR SCANNING**

For determination of the chips color, the digital camera CANON 350 D DIGITAL was used. Objective determination of color is based on assumption of constant conditions of camera parameters, fixed camera to object distance and homogenous white illumination source. The stability of the image color was secured using simultaneous capturing of reference white and black color (Babiak et al. 2002).

The chip mat was made by random spreading of chips to a container, 60x450x35mm, (Fig. 2) from 1,5m high level. Images of chip mat were captured together with the reference black and white color standards. Constant white light ATLAS TLL 1200 - D65 illuminated the scanned objects.

*Figure 2: A container with chips of black locust heartwood with the reference black and white color standards before color correction.*
The reference white color was made by pressing titanium oxide into the surface of a carrier. RGB constants of the white were set to be [237, 238, 239]. The reference black color was made of carbon smut. This was set to be the minimal value of RGB space, [0, 0, 0]. The correction of RGB components of a captured digital image was performed using image analysis software LUCIA G on VGA Version 5.00 (Fig. 3). A result of this image analysis was an RGB corrected image. The image was cut to the size of 1000x1600 pixels (Fig. 4) resulting in a unique histogram of the sample. One hundred images were scanned and analyzed for each wood species.

![Image of a scanned chip mat (1000x1600pxs) of the black locust heartwood after correction](image)

**Figure 3: Correction of the red extract (Quercus cerris L.) from the image analysis using the software LUCIA G**

**Figure 4: Image of a scanned chip mat (1000x1600pxs) of the black locust heartwood after correction**
Fig. 5 shows red extract histograms of 100 black locust chip mats. An average histogram is black highlighted. The purple curve represents required number of scanned images with precision of 5% on confidence interval of 95%. Please note that each wood species is characterized by three histograms of the R, G and B color extracts.

Figure 5: The red extract histogram of chip mats of black locust heartwood with frequency distribution curve of required images on confidence interval of 95%

For comparison of differences between wood species, the transformation of histograms to cumulative distribution frequency was done (Fig. 6a, 6b and 6c). The results were tested using Student’s t-test.
Figure 6a: Cumulative distribution of average red extracts of scanned mats

Figure 6b: Cumulative distribution of average green extracts of scanned mats
The test showed congenial histograms, repeatability of measurements on significance level 0.05 by comparing the first half of the histograms with the second one (Klein et al. 1997).
For the measurements, the calculated t statistics were compared to critical value $t_{0.001}$ (3,5) on significance level 0.001.

**Table 1: Maximal t statistics of the Student’s t-Test**

<table>
<thead>
<tr>
<th>Species</th>
<th>R</th>
<th>G</th>
<th>B</th>
<th>Number of images</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black locust sapwood</td>
<td>2.91</td>
<td>3.36</td>
<td>2.78</td>
<td>100</td>
</tr>
<tr>
<td>Black locust heartwood</td>
<td>2.98</td>
<td>2.75</td>
<td>2.02</td>
<td>100</td>
</tr>
<tr>
<td>Beech</td>
<td>2.04</td>
<td>1.97</td>
<td>2.88</td>
<td>100</td>
</tr>
<tr>
<td>Oak sapwood</td>
<td>1.54</td>
<td>1.62</td>
<td>1.51</td>
<td>100</td>
</tr>
<tr>
<td>Oak heartwood</td>
<td>0.85</td>
<td>1.22</td>
<td>1.58</td>
<td>100</td>
</tr>
<tr>
<td>Hornbeam</td>
<td>2.56</td>
<td>1.97</td>
<td>2.39</td>
<td>100</td>
</tr>
<tr>
<td>Aspen polar</td>
<td>3.85</td>
<td>3.87</td>
<td>3.49</td>
<td>100</td>
</tr>
<tr>
<td>Beecha</td>
<td>4.82</td>
<td>5.49</td>
<td>7.87</td>
<td>23</td>
</tr>
<tr>
<td>Hronbeamb</td>
<td>3.83</td>
<td>6.56</td>
<td>7.43</td>
<td>30</td>
</tr>
</tbody>
</table>

Notes: *MC=19%→8 %, bMC2FSP, wet

Test showed that all sampling populations of a species (Black locust sapwood, Black locust heartwood, Beech, Oak sapwood, Oak heartwood, Hornbeam and Aspen polar), are unique on the significance level of 0.001.
**Effect of moisture content (MC) on color of chip mats**

An effect of MC was checked by two experiments: continuous drying of fresh beech chips and moisturizing of hornbeam chips using sprayed water mist. The test showed significant differences of all RGB color extracts due to MC change.

Inequality given in Table 1 for beech was caused by drying. During the experiment the MC of chips dropped down from 19.2% to 8.6%. Frequency distribution of wet chips showed lower intensity in all RGB extracts.

Inequality of hornbeam chips was caused by water absorption, followed by darkening of chips during absorption. Results showed that it is very important to stabilize moisture changes during process of image capturing. After this analysis, the data of cumulative distribution frequency among wood species were tested.

**Table 2: Validity of significance differences between species given in % of intensity level of cumulative curves in R, G, B space**

<table>
<thead>
<tr>
<th>Species</th>
<th>R</th>
<th>G</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bl_Bls</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Bl_Be</td>
<td>97.7</td>
<td>78.5</td>
<td>76.6</td>
</tr>
<tr>
<td>Bl_Oa</td>
<td>100</td>
<td>100</td>
<td>75.8</td>
</tr>
<tr>
<td>Bl_OaS</td>
<td>96.5</td>
<td>82.8</td>
<td>99.2</td>
</tr>
<tr>
<td>Bl_Hb</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Bl_Ap</td>
<td>100</td>
<td>97.7</td>
<td>90.6</td>
</tr>
<tr>
<td>Bls_Be</td>
<td>100</td>
<td>100</td>
<td>98.8</td>
</tr>
<tr>
<td>Bls_Oa</td>
<td>100</td>
<td>100</td>
<td>64.1</td>
</tr>
<tr>
<td>Bls_Hb</td>
<td>100</td>
<td>100</td>
<td>80.5</td>
</tr>
<tr>
<td>Bls_Ap</td>
<td>83.2</td>
<td>76.6</td>
<td>90.2</td>
</tr>
<tr>
<td>Be_OaS</td>
<td>91.8</td>
<td>100</td>
<td>98.4</td>
</tr>
<tr>
<td>Be_Hb</td>
<td>70.7</td>
<td>93.8</td>
<td>98.8</td>
</tr>
<tr>
<td>Be_Ap</td>
<td>100</td>
<td>98.8</td>
<td>90.6</td>
</tr>
<tr>
<td>Oa_Bls</td>
<td>100</td>
<td>100</td>
<td>98.8</td>
</tr>
<tr>
<td>Oa_Be</td>
<td>95.3</td>
<td>83.6</td>
<td>70.7</td>
</tr>
<tr>
<td>Oa_DbB</td>
<td>96.1</td>
<td>100</td>
<td>89.5</td>
</tr>
<tr>
<td>Oa_Hb</td>
<td>99.2</td>
<td>89.1</td>
<td>82.8</td>
</tr>
<tr>
<td>Oa_Os</td>
<td>100</td>
<td>98.8</td>
<td>90.6</td>
</tr>
<tr>
<td>OaOs_Os</td>
<td>100</td>
<td>97.7</td>
<td>90.2</td>
</tr>
<tr>
<td>Hb_OaS</td>
<td>95.7</td>
<td>90.2</td>
<td>52</td>
</tr>
<tr>
<td>Hb_Ap</td>
<td>100</td>
<td>98.8</td>
<td>90.6</td>
</tr>
</tbody>
</table>

Notes: black locust – heartwood, (Bl), black locust – sapwood (BlS), beech (Be), oak – heartwood (Oa),
oak – sapwood (OaS), hornbeam (Hb), aspen poplar – sapwood (Ap)

Table 2 consequentially shows that statistical significant differences exist between wood species. Moreover, the analysis of RGB color space of chip mat results in unique wood species identification.

Please note that analysis covers of all three color extracts in the intensity interval from 0 to 256.

Most probably, not all values of color extracts are presented in wood. This is typical for high
intensity levels of the blue extract. The limitation of this level will emphasize significance differences between wood species.

**Figure 7:** Differences between cumulative distribution frequency of black locust heartwood and hornbeam in the red extract with selection of significant differences (blue points)

**Figure 8:** Differences between cumulative distribution frequency of black locust heartwood and hornbeam in the green extract with selection of significant differences (blue points)

**Figure 9:** Differences between cumulative distribution frequency of black locust heartwood and hornbeam in the blue extract with selection of significant differences (blue points)
Design of apparatus for wood color determination in the form of chips using CCD camera directly in the processing line

For continual determination of the wood chips color in the processing line, several options have to be met:

- Fixing the CCD camera working in RGB color space above transporting line of chip mat at the constant distance.
- Placing the white and black standard etalons in the field view of the CCD camera and keeping it in a dust free space together with the camera
- Lighting the chip mat and the etalons with constant white light.
- Acquiring bit maps of images into a memory of the computer.
- From black and white colors should be evaluated average levels of brightness extracts of R, G, B.
- Zeroing the image brightness based on the black surface calibration.
- Leveling the white color based on correcting RGB characteristics of white color. This stabilizes the color of an image according to white and black calibration numbers.
- Collecting histograms of the chip mat color extracts during the filling time of a pressure boiler. High accuracy results are guaranteed by continuous image acquiring.
- Based on the specific color of wood species the amount and quality of filled batch will be evaluated. The information controlling batch process will be unique and based only on composition and quality of incoming chips

Each batch will lead to bigger decision making database of wood chip color RGB space for further batch processing control. Proposed method will minimize subjective detection of volume and quality of wood species in the batch and allow self expanding and self learning automatic kraft pulp processing.

This method was tested in laboratory conditions, apprising statistically significant differences between “clean” wood species and its blends. The preliminary tests showed significant differences between “clean” wood species mat and a blend mat consisting of two or more species. Moreover, not significant differences of the species blend and calculated linear combination of RGB images of “clean” wood species in given ratio was confirmed.
CONCLUSIONS

Based on results of this study in wood chips color determination one can concludes that:

- Selected wood species have typical color in the RGB color space, which allow exact reproduction of wood color information
- Ability to determine color of wood chips leads to wood species identification and can lead to quality and classification of wood according the specified requirements (for example according to permeability).

The experimental design showed that:
- It is possible to precisely indentify species of chip mat from CCD camera
- Moisture content is showed to be significant factor in determination of wood chip color.
- MC at the surface is also the significant factor.
Chips from black locust heartwood and oak heartwood are statistically different compared to other selected wood species.

Since the black locust and oak are hard to process in kraft pulp batches, it can be concluded that these difficult to process wood species are easy to detect with sufficiently high probability.

The results of this study move forward into a design of the wood chip color space measuring apparatus using a continual and cumulative way of controlling the delignification process. The apparatus is a matter of a patent application (Application Number 153-2007)

REFERENCES


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