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IMAGE ANALYSIS IN WOOD TESTING – SELECTED EXAMPLES

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ABSTRACT

This paper is a review article which presents examples of application of the image analysis in wood testing. The objective of the paper was to present selected research methods with the use of image analysis used in the research on anatomy and macro-structure of wood carried out in the Department of Forest and Wood Utilization of the Institute of Forest Utilization and Forest Technology of the University of Agriculture in Krakow. In the part concerning research on wood anatomy the following areas of application of the image analysis were indicated: identification of wood species and variability of the selected parameters of the anatomic structure with special attention to coniferous trees. In the part concerning the research on macro-structure of wood, methodology of collection and preparation of wood samples and measurement of the most important properties of the macro-structure was described with the use of the image analysis program. Moreover, the selected areas of practical application of the results of such analysis were indicated.

Introduction and the objective of the paper

It is estimated that wood may be presently used in approximately 30 thousand various manners (Strykowski, 2012). Such varied possibilities of use result to a great extent from multi-trend research on this raw material. Developed new research techniques allow even more detailed knowledge on wood and its properties, which is strictly related to its further use. Also techniques based on the image analysis can be applied in the research on wood. Dynamic development of these techniques has resulted in recent years in even newer and more advanced research tools in the form of new programs or their subsequent improved versions. Articles which describe the research tools in detail along with examples of their practical application in the wood research are relatively rare in the professional literature. Thus, the objective of this paper is description of the selected method of image analysis which serves for determination of some wood properties and indicates possibilities of practical use of research results.

Image analysis in the research on wood anatomy

Despite developed techniques of wood species identification with the use of DNA analyses (Nowakowska et al., 2010) still, methods, which may be considered as classic, are used i.e. based on the analysis of wood macro-structure, properties, and if only its small fragments are available - analysis of anatomic properties.

Research on the anatomic structure of wood is preceded by making a good quality microscopic preparation which is a complex process and requires the use of a precise device for obtaining thin wood scraps i.e. a microtome and chemical reactors which enable proper preparation of the tissue for microscopic observation (Braune et al., 1975). A ready preparation after placing under a microscope is photographed with the use of a video camera or a camera. The authors of this article use for this purpose Jenaval Carl Zeiss microscope with a mounted analogue camera Sony CCD connected to a computer through a video card which enables digitization of the analogue image. Catching A microscopic image is caught with the use of MultiScan program (CSS Scan., 1999). Identification of the wood species and strictly its type consists in the eyesight analysis of the microscopic image and perception of specific wood properties such as: presence or lack of the elements of the anatomic structure (e.g. resin conduits in coniferous trees), their dimensions and shape (e.g. lumen in cell walls) or a mutual system of elements in a given cross section (e.g. vessels in deciduous tree). Three anatomic cross sections i.e. diagonal, longitudinal, tangent or radial longitudinal are observed. In case of some deciduous species of trees, particularly those which have a ring and vessel wood structure, analysis of the cross section suffices for correct determination of its type. A detailed observation of all three anatomical cross sections is indispensable for wood identification of coniferous trees and some deciduous with a disperse vessels structure. Studies concerning identification of wood species are most often carried out for external entities. The most interesting works from this field carried out in the laboratory of the present Department of Forest and Wood Utilization include identification of the wood piece found in general Władysław Sikorksi's skull during exhumation of his body (Wąsik, 2009); wood roots, where a piece of meteorite stuck (Socha et al., 2014); canvases from Henryk Siemiradzki's paintings which are in the collection of the National Museum in Krakow (Wąsik, 2012) or wooden elements of the historic range in Wola Justowska in Krakow (Bednarz and Wąsik 2014). It should be mentioned that identification of wood species based on the analysis of a microscopic image is very crucial in case of court proceedings related to illegal tree cutting.

Previously mentioned MultiScan program is a tool which enables not only catching images from under the microscope but also carrying out measurements of image elements. Before starting with measurements the program should be scaled. In the laboratory of the Institute special microscopic preparation by Carl Zeis Jena is used. In this preparation a 1 mm fragment was divided into 100 equal parts. After scaling the program measurements can be taken. In the research on the anatomy of wood of coniferous tree species, dimensions and shape of ducts, which constitute the main element of a trunk are essential. A single duct may be characterized with the following dimensions: external and internal diameter, thickness of the cell wall and length. Three first parameters are measured at the cross section. Since in the annual increment ring in the coniferous timber there are two zones: spring and summer, which have a slightly different anatomy, measurements are taken in each zone separately. In the papers written in the Department of Forest and Wood Utilization a methodology was adopted which assumes measurement of 30 spring wood ducts and the same amount in the late wood i.e. in total 60 ducts in each annual growth. Parameters of ducts on the cross section are measured in two directions: i.e. radial and tangential. In the summer wood zone a well visible middle lamella occurring between the cell walls of neighbouring ducts enables measurement of single cell diameters. Half of the external and internal diameter measured in the specific anatomic direction constitutes thickness of the cell wall. In case of the spring wood zone where the middle lamella is difficult to notice, measurement of the external diameter is slightly more complex. Since a distance, which is a sum of the internal diameter and a fourfold of cell wall thickness, is measured in both directions (Fig. 1), and afterwards with the same thickness of the cell walls of neighbouring ducts the cell wall thickness and external diameter of the duct is measured.

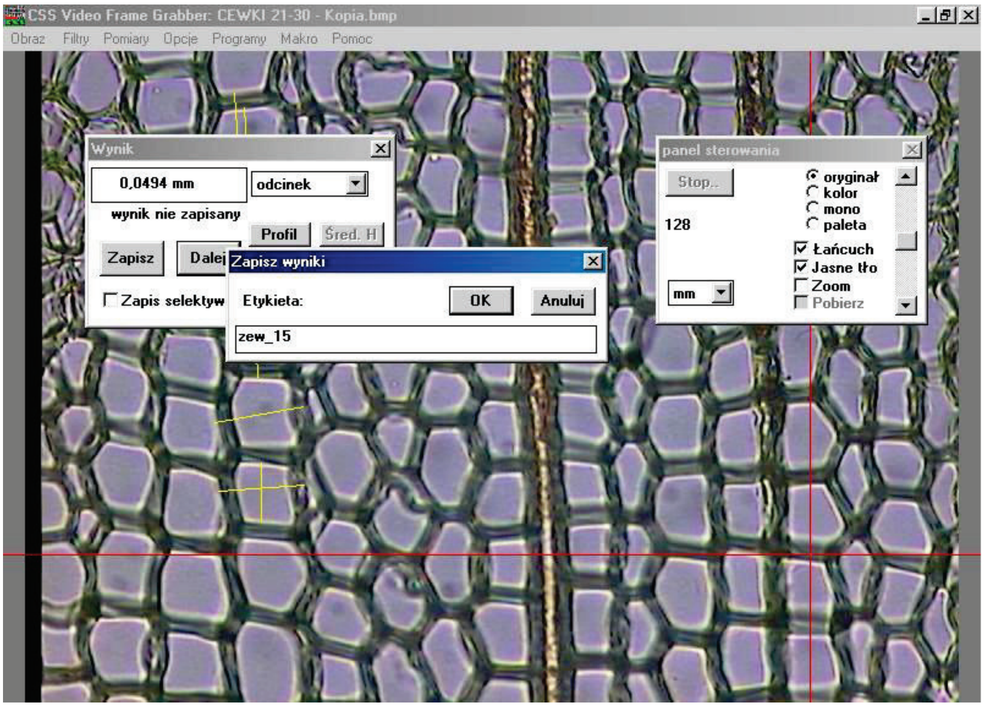

Figure 1. The image of the MultiScan program during measurements of early wood ducts parameters on the cross section. (photo R. Wąsik)

Knowing the thickness of the cell wall and diameters (external and internal) of a duct, one may calculate numerous indicators such as: stiffness indicator, stiffness acc. to Runk, flexibility, compactness or Mühlsteph's indicator. Knowledge on the above values of indicators is precious from the practical point of view. Since, the higher is the flexibility indicator and stiffness indicators, Runk's stiffness indicators and Mühlsteph's indicator are lower, paper formation properties of wood are better (Lachowicz, 2010, 2011; Lachowicz and Paschalis, 2011).

Length of a duct is its important parameter. This dimension may be measured after wood maceration, i.e. after dissolution of middle lamellas which bind neighbouring ducts. To analyse variability of ducts length in both zones of annual growth, spring and summer wood is macerated separately. As a result of maceration, loose groups of ducts are obtained, and a microscopic preparation is made thereof. Also in case of this parameter, 30 ducts in each zone of an annual ring are measured. Measurement of a single duct length is not a simple activity. First of all it is due to the fact that ducts in the preparation overlap each other, which impedes separation of each of them by sight. Therefore, it is very important to distribute single ducts on the surface of the preparation glass very carefully when making the preparation. Secondly, ducts arrange in the preparation in a non-rectilinear manner which makes the use of the "curve measurement" option in MultiScan program necessary. When this option is selected, the program scans the length of rectilinear fragments connected in a broken curve, which a measuring person draws between both ends of a duct (Fig. 2). Thickness of a duct in the middle of its length is another parameter which may be measured in ducts of macerated wood (Fig. 3). This dimension constitutes a component of an important property of the duct shape, namely the fineness ratio which is a quotient of duct length and thickness. Except for the previously mentioned indicators, the fineness ratio is also an important element, taken into consideration for assessment of wood usefulness in paper production. Since, the higher is its value the paper formation is better. The length of a duct is also an important parameter which influences the properties of fireboards. Longer ducts connect with each other on greater surfaces during the process of board pressing as a result of which the product has better strength.

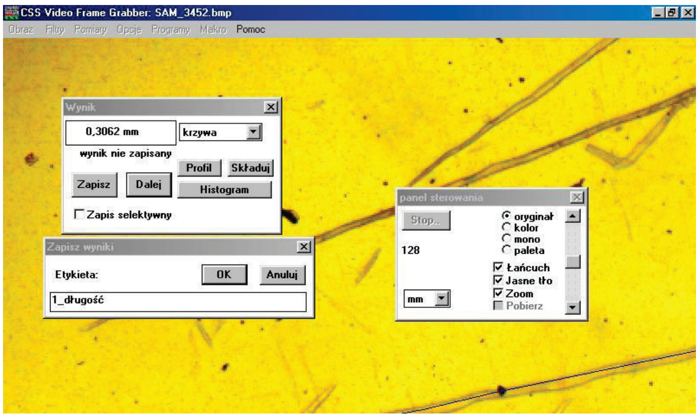

Figure 2. The image of MultiScan program during taking the length of wood duct with the use of "measurement of a curve" option. (photo R. Wąsik)

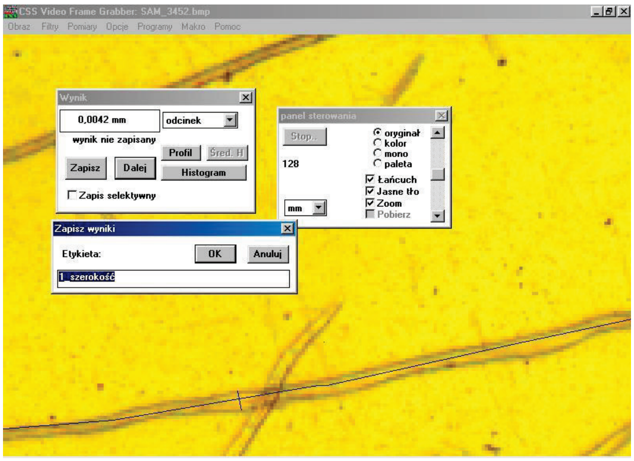

Figure 3. View of MultiScan program window during measurement of wood duct thickness. (photo R. Wąsik)

Image analysis in the research on wood macro-structure

The wood macro-structure is a group of such properties, which may be observed with a naked eye or possibly with the use of a magnifying glass. Thus, one may mention here the presence or absence of coloured heartwood, its participation on the radius of the surface of the cross section of a trunk, width of annual increment rings and participation of spring and summer wood in the increment. The last mentioned property is defined for species in whose rings one may indicate clearly visible two distinct zones: porous, which constitutes spring wood and compacted which is summer wood. The mentioned zone may be distinguished in the wood of coniferous trees such as pine, spruce or larch and a ring and vessel structure in deciduous trees e.g. oak, ash or locust. Wood macro-structure properties may be defined in rings obtained from cut trees. Material for analysis may be collected also with the use of an increment borer; thus, there is no need to cut trees. A sample collected from a trunk from the height of 1.3 m from the ground (ring) constitutes a radius which represents a cross section. To emphasise the clarity of annual increment, a sample is placed in a special grip and cut with a segmentary knife (a scalpel) with a thin approx. 1 mm thick wood piece perpendicularly to the course of wood fibres (Fig. 4).

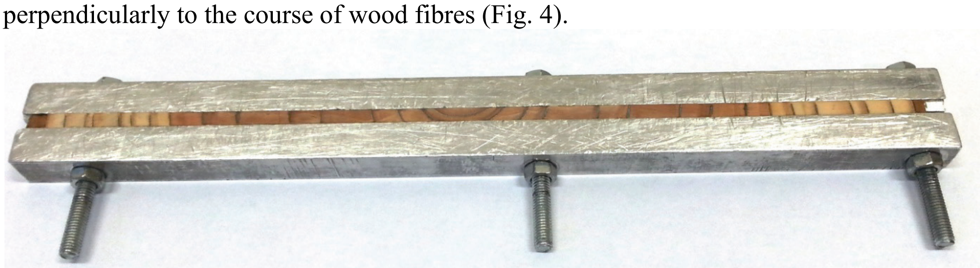

Figure 4. A sample placed in a special alluminium grip. (photo R. Wąsik)

Then, the obtained cross-section of a sample is scanned in a high resolution scanner (usually 1200 dpi). The obtained electronic image in the format of a bitmap constitutes an input file where macro-structure properties are measured. In the department of Forest and Wood Utilization “Przyrost WP” program is applied for such measurement (Biotronik, 2001). Before taking measurements, basic data identifying the measured sample may be entered (Fig 5) in particular a wood species, place from which a sample was collected (number of the division in a forest district), a sample symbol and the last name of a person who takes measurements (operator)

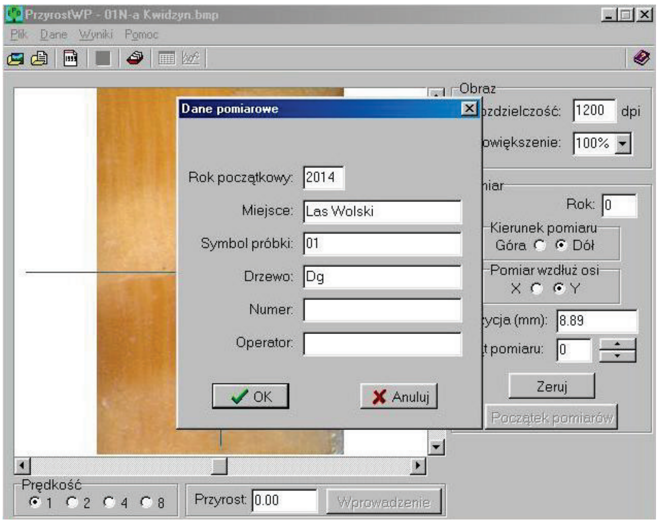

Figure 5. The view of the window of Przyrost WP program during entering identification data of the measured sample. (photo R. Wąsik)

The mentioned data are not required to start measurements. However, they facilitate further analysis of results. Nevertheless, it is more important to enter in the measurement data a year, when a sample was collected from a tree. It enables dating increments, i.e. automatic assignation by the program of the width value of particular rings and spring and summer wood zones to specific years. It is indispensable to carry out possible dendrochronological analyses. If the trunk sampling was made during the vegetation period, the youngest not fully formed growth, is the most often omitted in the measurements. Then, one should remember to enter the year preceding the date of trunk sampling as the first year of measurements. Upon entering the measurement data one should select a horizontal or vertical axis along which measurements will be taken and their direction i.e. left or right if the horizontal axis is marked and up or down if the vertical axis is marked (Fig. 6). Measurements should be taken from the youngest ring (from branch) to the pith.

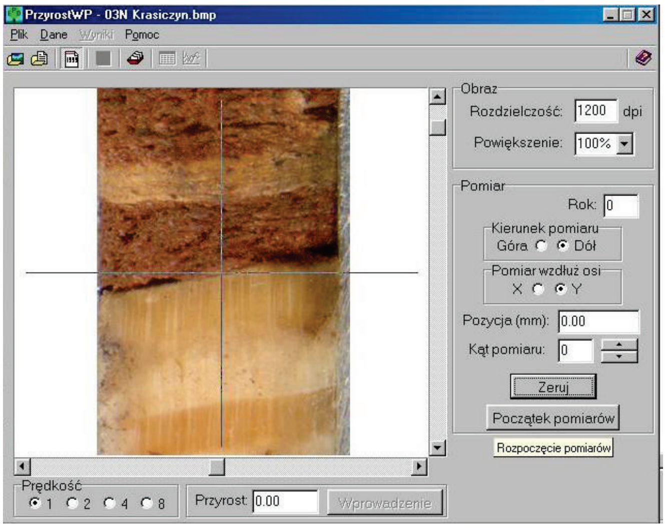

Figure 6. View of the window of Przyrost WP program – selection of axis and direction of measurements. (photo R. Wąsik)

In each ring, firstly the summer wood and then spring wood width is measured. Such order is forced by the direction of measurements which, as mentioned earlier, are carried out from the bark towards the pith and summer wood is a part of an increment which is closer to bark. After the measurement of the width of the spring zone of a ring, the program automatically sums up the width of both parts of an increment and gives the result in a table in the right bottom of the program window (Fig. 7).

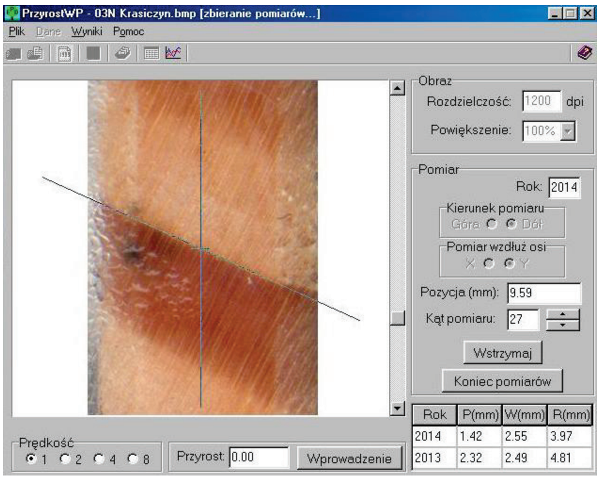

Figure 7. View of the window of Przyrost WP program during measurements. (photo R. Wąsik)

An operator who takes measurements should check every several measured increments whether the widths of spring and summer zone, marked by him in the electronic image, are placed in the table in columns appropriate for these data (in the column heading assigned for the width of the summer wood zone there is letter P, and for spring wood - W). If the measurements are carried out by the same operator for a longer time a mistake can be made caused by human error resulting from tiredness and lack of concentration. Such mistake usually occurs if an operator omits one increment zone. Then, following zones marked by an operator will be incorrectly entered into a table i.e. width of the summer zone will be entered into column "W" and reversely. It will also cause false results of the width of all annual increments. Thus, verification of the correctness of carried measurements is so important. “Przyrost WP” program enables measurement of the width of rings which run at the angle different than the right angle in comparison to the measurement axis. Since, an operator can turn the measurement line (combination of ctrl+del keys) and adjust it to the course of increments’ borders (Fig. 7). Then, the program calculates the width of particular zones including the angle at which a measurement axis in declined towards the axis of the measurement direction. Such function is very useful especially for measurement of rings located close to a pith whose bending is usually considerable. After measurements are carried out, the results are recorded in the text file (signs separated by spaces). There is a possibility of correction of the recorded results in "Przyrost WP" program.

The program has simple graphic tools which facilitate interpretation of the obtained results of measurements. Since, it may, based on the obtained data, create the so-called real chronologies namely graphs of the course of width of particular zones and entire rings in particular years. It may also calculate a moving average (average from 3, 5, 7 and 11 years) and place curves of the course of these averages on real chronologies (Fig. 8).

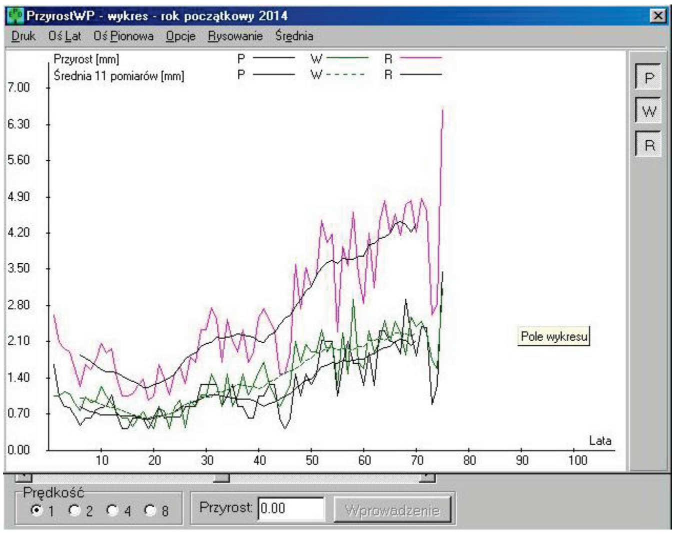

Figure 8. View of the window of Przyrost WP program - real chronologies along with the moving averages from 11 years. (photo R. Wąsik)

Data recorded in the previously mentioned result file may be processed and analysed in any calculation sheet. These data are particularly useful for determination of variability of wood density at the radius of the cross section of a trunk. In the Forest and Wood Utilization Department wood density of various tree species is investigated with the use of a dendrochronological method based on the measurement data obtained in “Przyrost WP” program. After the width of rings is measured in this program, a trunk sample is divided into sections which include a constant number of increments -usually 5. For each section a relative density of wood is described (Wąsik, 2007a). Then, wood density for the entire cross section is calculated as an average of density of all sample sections weighted with their participations in the surface area of the cross section. This participation is calculated based on the following: diameter of the trunk without bark and length of the sample section. The last mentioned value is calculated based on the data obtained in “Przysrost WP” program.

For the wood of tree species which form coloured heartwood (e.g. pine, larch, Douglas fir, oak, ash tree) also participation of both zones is determined i.e. alburnum and heartwood both on the radius and on the surface of the trunk’s cross section. This participation is calculated similarly to the above described participation of the sample section in the surface area of the trunk’s cross section. In this case, also diameter of the cross section without bark and the total width of increments which constitute the alburnum, calculated based on the data included in the result file of "Przyrost WP" program, is taken into consideration (Wąsik, 2007b).

Average values of macro-structure properties and density obtained during the above mentioned measurements are recognized as basic data which describe wood. They are often related and influence other properties of this raw material. Here, we can mention a relation of annual rings with wood density (Niedzielska, 1995; Wąsik, 2007a). In case of coniferous species, processed extensively in the timber industry along with the increase of width of rings, wood density drops. It consequently influences the mechanical properties of wood, which are generally better if the wood density is higher. Knowing the above relations certainly resulted in introduction of limitations concerning the width of the annual increment for round wood of the highest quality in the European standards (PN-EN 1927-1, 2008; PN-EN 1927-2, 2008; PN-EN 1927-3, 2008).

Using the above mentioned methodology of wood research with the use of "Przyrost WP" program one may investigate the increment reaction of trees to various external factors both biotic and abiotic. Analysis of data obtained during measurements of wood increments with a dendrochronological method in relation to data which characterize climatic conditions under influence of which a tree grew in a specific year, may lead to very interesting conclusions. Since it turns out that such climatic stimuli as draught, long and severe winter, cold and rainy summer or other events (insects outbreaks, avalanches, volcano eruptions), which have a direct impact on shaping the growth conditions usually leave its trace in the form of a narrower or a few narrower annual increments in wood. Knowledge on the increment reaction of trees to particular external factors allows, based on the analysis of the annual increment width, reconstruction with probability, of climatic conditions and anomalies which took place in the past (Lempa et al., 2014; Michałowicz et al., 2014; Janecka and Kaczka, 2014).

Example of the use of image analysis in court proceedings.

In the Department of Forest and Wood Utilization a very interesting court expertise was carried out. It concerned a proceeding on wood theft. On account of the fact that the proceeding has not been finalised (2016) the authors do not disclose its details. The Court requested the Department to answer the following question: whether the wood logs secured at the property of the person suspected of its theft may come from tree stumps located in the forest, which belongs to the accusing party and whether the trees which logs and stumps come from could have been cut in October when according to the accusing party, the theft was committed? In order to carry out relevant analyses, the court sent to the Department approximately 40 discs of wood cut from the mentioned stumps and logs. In order to determine the wood type, from each disc and its peri-circumferal part a piece which includes a few annual increments, was cut out with the use of a hand saw. In order to analyse anatomic structure properties, microscopic preparations were made and pictures of particular anatomic cross sections were carried out with the method described in the chapter "Analysis of the image in wood anatomy research". Based on the analysis a wood species of each disc was determined. In the group of discs from stumps the following wood type was reported: birch, alder, oak and poplar. On the other hand in the group of rings from logs: birch, oak and pear. Thus, both in the group of stumps and logs wood, which did not have a corresponding piece in a given group was eliminated. Then, observation of the width of the youngest annual rings was carried out by comparison of its width with the width of a few closest older increments. Width of the youngest ring close to the width of older rings proved that the tree was cut after the vegetation period, thus it is possible that it was October. If a ring is clearly narrower than in case of older rings, it means that a tree was cut during the vegetation period i.e. in spring and summer months. In this manner, rings, in the wood of which not fully formed youngest increment was found, were eliminated. Then, the dendrometrical analysis (measurement of the disc circumference) was carried out and the number of discs in the wood was determined. On this basis, other discs were eliminated from further research. In the last stage of work, the measurement of the width of annual increments was carried out in discs, which were not eliminated. Measurements were carried out along four radiuses (crossing). Cross section of rings along the mentioned radiuses, were prepared analogically to sampling (cutting of a thin layer of wood with a sharp segmentary knife) and measurements were carried out according to the principles presented in the chapter "Analysis of the image in the research on wood macro-structure". Based on the obtained data real chronologies of width of annual increments of the analysed radiuses of each disc were made. The obtained chronologies of discs from stumps group were compared to chronologies of discs from logs group. As a result it was found that the chronology of increments of only four discs cut off logs is similar to the chronology of two discs from stumps. In the conclusion of the expertise, it was stated that it cannot be excluded that the mentioned four discs come from stumps of two trees cut in the forest, which are the property of the accusing party. However, on account of numerous doubts which accompany the described analysis, it was suggested to look for the opinion of the institution which carried out DNA analysis of wood. These analyses would concern not only those discs for which clear similarity of the course of chronologies of annual increment discs was determined.

The above presented example indicates a practical aspect of use of the modern method of image analysis in the wood research. In this particular case they were helpful for the Justice.

Conclusion

The above presented examples indicate a possibility of wide application of the modern method of image analysis in the wood research. The presented selected measuring programs are considerably simple in operation and give an opportunity of precise measurements. It is also significant that they are Polish products which should be taken into consideration by people who are interested in the purchase of such research tools. However, it seems to be obvious that technological development will bring new solutions, which will allow carrying out in the future simpler, faster and more precise wood properties measurements. The offer of some foreign producers of this type of tools includes solutions which enable automatic numerous measurements, which in exemplary programs described in this article, are carried out manually. Therefore, to constantly improve those tools, their authors should obtain the users' opinion which would allow better adjustment of programs to expectations. Opinions and ideas of persons, who use such tools in the research work, could also be an inspiration for program producers in searching for new solutions which would help to better know this precious raw material which would results in development of its new applications.

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ANALIZA OBRAZU W BADANIACH DREWNA – WYBRANE PRZYKŁADY

Streszczenie. Niniejsza praca jest artykułem przeglądowym, prezentującym przykłady zastosowania analizy obrazu w badaniach drewna. Celem pracy było przedstawienie wybranych metod badawczych z zastosowaniem analizy obrazu, wykorzystywanych w badaniach anatomii i makrostruktury drewna, prowadzonych w Zakładzie Użytkowania Lasu i Drewna, Instytutu Użytkowania Lasu i Techniki Leśnej Uniwersytetu Rolniczego im. Hugona Kołłątaja w Krakowie. W części dotyczącej badań anatomii drewna wskazano na takie obszary zastosowania analizy obrazu jak: identyfikacja gatunku drewna oraz zmienność wybranych parametrów jego budowy anatomicznej, ze szczególnym uwzględnieniem gatunków iglastych. W części dotyczącej badań cech makrostruktury drewna opisano metodykę pobrania i przygotowania próbek drewna oraz pomiaru najważniejszych cech makrostruktury przy pomocy programu do analizy obrazu. Wskazano także wybrane obszary praktycznego zastosowania wyników takiej analizy.

Słowa kluczowe: anatomia i makrostruktura drewna, analiza obrazu