Chapter 3

Experimental Methods

3.1 Overview

This chapter details the experimental methods used to collect data and describe how wood features are represented by color, shape, and density parameters. The measurement of these parameters was attained using a color line scan camera and a x-ray line scan detector. Images of wood features for red oak, (*Quercus rubra)*, Eastern white pine, (*Pinus strobus)*, and sugar maple, (*Acer saccharum)* were collected using the lumber scanning system described in the section below. Parameters for color (red, green, blue, hue, saturation, and intensity), shape (aspect and roundness), and x-ray attenuation (gray-scale values) were quantitatively measured from the images. Statistical methods were then used to describe the relationships of the measured parameters. The affect of species and resolution on parameter relationships was also examined. Discriminant classification functions were developed and used to determine the contribution of each parameter in differentiating feature types, to model the features using the measured parameters, to determine classification errors, and compare color spaces. An outline of the experimental methods is presented in Figure 3.1

3.2 Multi-Sensor Vision System at Virginia Tech

The parameters measured for each feature were collected on equipment designed at Virginia Tech for multi-sensor scanning of lumber (Conners et al., 1997). The system has the ability to scan a lumber specimen with dimensions up to 17 feet long, 12 inches wide, and 2 inches thick. By adjusting the imaging geometry for each of the sensors and the speed of the specimen through the system, different image resolutions can be attained. The image scanning system assembled at the Brooks Forest Products Center at Virginia Tech employs a multiple sensor defect detection system and consists of the following components: 1) a

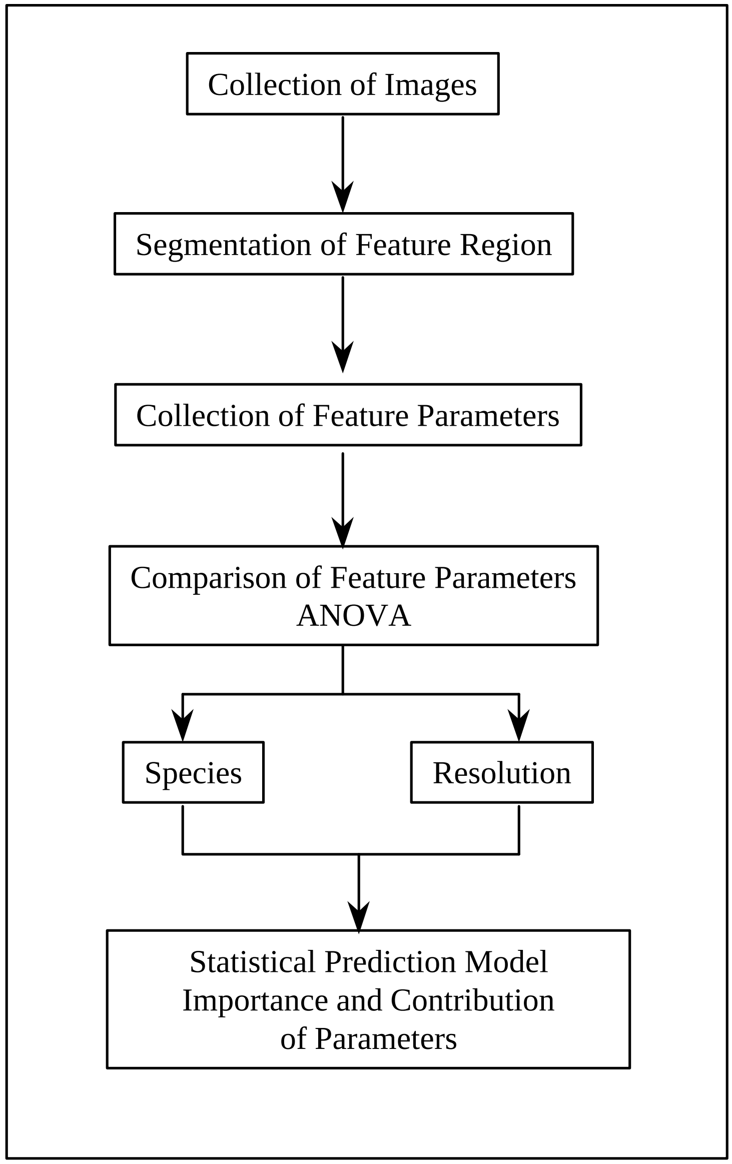

Figure 3.1. Outline of experimental methods.

precision handling system, 2) a computer system, 3) a laser-based ranging system, 4) a color scanning system, and 5) an x-ray scanning system as seen in Figure 3.2. Kline et al. (1993) and Conners et al. (1997) present a complete review of this system and its components.

The lumber handling system is capable of handling full sized lumber at speeds of up to 4 feet per second. Lumber moves through the system pinched between rollers from above and below. The lower pinch rollers drive the lumber through the system while the upper pneumatic rollers hold it flat during transport. A stepper motor powers the lower rollers, which is under complete computer control with positioning accuracy of ± 0.01 inches. The images used for this research were collected at a speed of 1 foot per second. This speed was chosen for optimal image quality.

The computer system controls the lumber handling system, controls each of the scanning systems, and collects image data. Each of the scanning systems are multiplexed onto a Direct Memory Access (DMA) board so that image data can be collected while the board is moving through the system. The DMA board is able to place data in the computer's main memory at the rate of 2 Mbytes per second. The PC-based computer system has 64 Mbytes of main memory so that it has the capacity to collect from all sensors for the largest piece of lumber. After an image is collected, the data can be stored onto the hard drive for further analysis and processing. Over 6 Gbytes of on-line disk space are available for storing image data. An in-house facility is available that can store image data on Compact Disks for archival purposes.

The color imaging system employs one Pulnix TL-2600RGB color line scan camera and controller. Conners (1990) and Ng (1993) discuss the selection of this particular camera for the system in detail. The camera is equipped with a 50 millimeter focal length lens. The camera is a charged-coupled device; therefore, it has a high response to red and infrared components of the electromagnetic spectrum. An infrared filter has been added to reduce this sensitivity.

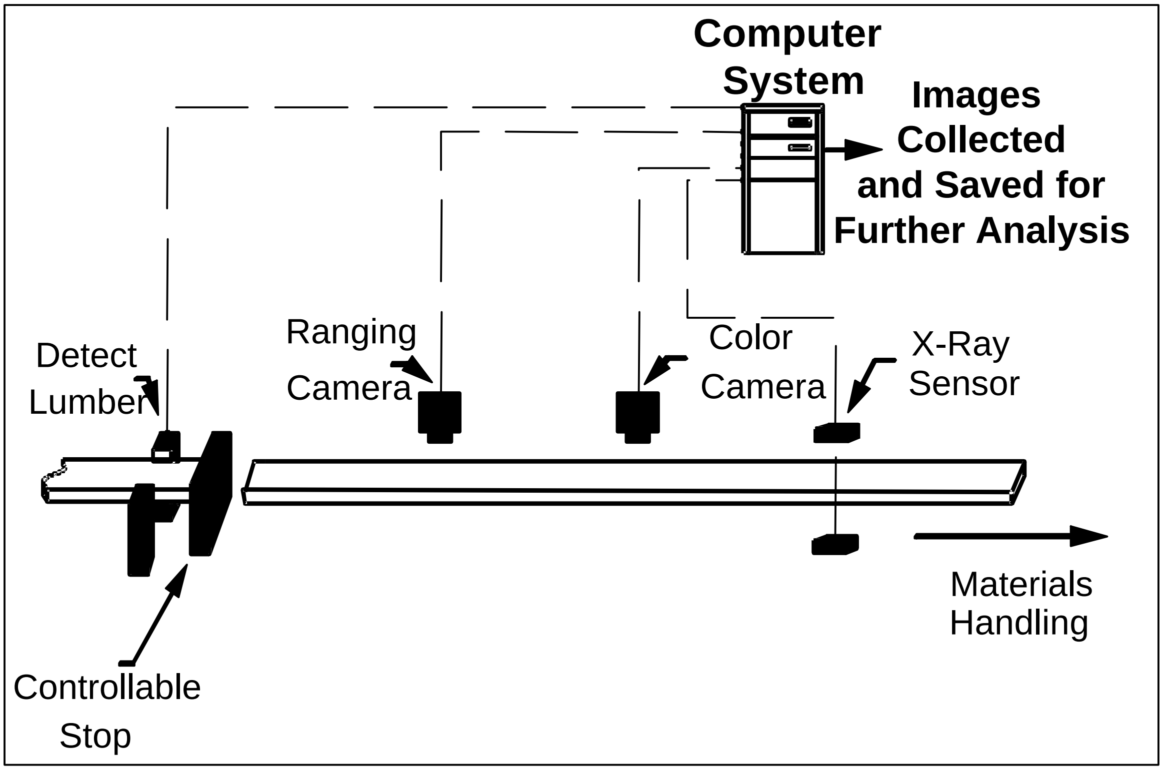

Figure 3.2. Diagram of the sensor layout on the scanning system used to collect images.

Two blue filters have also been added to compensate for the high red color content induced by the tungsten halogen bulbs that are used for illuminating the scanned surface. A shade compensation is applied to the color image to eliminate any uneven lighting conditions that occur, which also improves the uniformity of the three color channels (Ng, 1993 and Shawchuk, 1977). While no color camera produces a perfect response in all three color channels, the combination of the filters and the shade correction produce a color image that is relatively free of color channel bias, allowing the parameter relationships determined in this study to be applicable to color information collected from other cameras. The controller sends the image data to the multiplexer board. The camera contains 864 color sensitive pixels and can scan at a rate of 2.5 Mhz. for very high downboard resolution. Light sources for illuminating board surfaces use 150 watt, 21-volt tungsten-halogen incandescent bulbs. The light from a bulb is transferred to the board surface through fiber-optic cables. A detailed description of the lighting system is described in Conners (1990) and Ng (1993).

The laser-based ranging system employs two EG&G Reticon 128 x 128 high-speed array cameras that can scan at a rate of 384 frames per second. The laser light source is generated with a 16 mW Helium Neon gas laser at a 632.8 nm wavelength. A 24-facet polygon scan mirror rotating at approximately 30,000 RPM is used to sweep the laser light across a lumber specimen. A controller board synchronizes the two cameras and sends image data to the multiplexer board. The cameras are arranged such that the two view the top for a field of view of 8 inches. Laser images were not collected or used for this research.

The x-ray scanning system consists of an EG&G Astrophysics tungsten x-ray generator and controller. The generator has a maximum voltage of 160 keV and maximum beam current of 1 ma. For the collection of regional attenuation parameters, 100 keV and .8 mA were used. How these settings were selected is discussed in the next section. The x-ray detector is a linear detector array (1.6mm x 2.0mm) with a minimum integration time of 2.6 ms. The detector controller sends x-ray image data to the multiplexer board. A signal shade correction is applied to the x-ray image. The signal shade compensation consists of two corrections, offset (dark current) and gain (scale) correction. With the offset correction, the offset value of each channel is separated from the composite signal via digital subtraction. The gain correction is used to correct for the detector's sensitivity, any lack of uniformity in the X-ray beam intensity, and for features of the crystal scintillator. A target of UHMW plastic 2.75 inches thick with a density of .92-.94 g/cm^3 was used in the shade correction. Using a target in shade correction increases the mean gray scale value and can also stretch the image histogram resulting in a higher resolution density gradient. The keV and mA settings were chosen based on the visual image quality characteristics, such as high resolution, high definition of defect boarders (radiographic definition), and low image noise. The final selection of these settings was 100 KeV and .6 mA.

Examples of images collected for this research are shown in Figure 3.3. While a specimen passes through the system, image data from each of the sensing modalities are digitally collected in real-time and downloaded to a PC for subsequent processing and analyses. Each color component is depicted by 256 gray-levels (8-bit) giving a total color palette of over 16 million colors. The resolution of the shown color image is 32 pixels per inch (width) by 16 pixels per inch (length). The resolution of the x-ray scan is 32 pixels per inch (width) by 16 pixels per inch (length) by 256 levels of gray (density gradient).

While the system used to collect the data on the parameters of wood features can collect laser range information, this study concentrated only on the contributions of color and density information. The understanding of the importance of laser range information in defect detection in wood is well understood and has been used in the industry for many years for detecting wane and holes. Color and density measures were selected for this study based on the importance and ability of these methods to differentiate between feature types when used separately and based on the hypothesized ability of the combination of them as expressed in literature. The utility of color information for defect detection has been demonstrated by Conners et al. (1985), Silven and Kauppinen (1996), and Brunner et al. (1990). The need for density information has been documented by Conners et al. (1991 and 1992), Araman et al.

Figure 3.3. Examples of red (a) green (b), blue (c), and x-ray (d) images

(1992), and Portala and Cicccotelli (1992). While these measures have been shown to be important, further work is needed to understand how density and color information contributes to the correct identification of wood features. Specifically, there is a lack of knowledge concerning of how individual wood features are represented using color, density, and shape parameters.

3.3 Specimens

Wood features from red oak (*Quercus rubra)*, Eastern white pine (*Pinus strobus)*, and sugar maple (*Acer saccharum*), were examined in this study. These species were chosen for their commercial importance and so that comparisons could be made between species with different anatomical characteristics. Some of the specie differences are listed in Table 3.1.

Lumber containing the various features was obtained in the kiln dry condition (8%MC) from various sources within the Appalachian mountain region. The exact growth site of the material was not known. The purpose of this study was to characterize relative feature parameter differences; therefore, it was not necessary to obtain a representative sample size of all regional color and density differences. The sample size required to represent all variability of different regions is prohibitive. Also, it has been shown that the within-tree and between-tree variations are more significant than between-site variations for those species and parameters studied by Phelps et al. (1983). This indicates that the relationships of color parameters between features will include the large variation from between and within tree variability. This variability will also exist in samples that contain between site variation.

The moisture content (MC) of 8 % was chosen because it is commonly used in the manufacturing of wood products in the United States and will allow for a stable moisture condition while scanning in the laboratory. The moisture content of the lumber was determined from small wood blocks cut from the scanned specimens. For moisture content

Table 3.1. Differences in species used in experimental methods (Hoadley, 1990).

Species	**Heartwood Color**	**Avg.Specific Gravity**	**Latewood transition**	**Other Characteristics**
Red oak	Light brown, flesh colored cast	0.63	Ring-porus	Hardwood
Eastern White Pine	Light, distinctive color	0.35	Gradual	Large solitary resin canals. Softwood
Sugar Maple	Creamy white to light reddish brown	0.63	Diffuse-porous	Hardwood

determination the ASTM 4442-92 oven dry moisture content method was used (ASTM, 1994). All lumber was planed to create a clean surface free of dirt, grease, and surface roughness that could effect parameter measurement and to insure a uniform thickness. Lumber samples varied in thickness from 7/8 inches to 15/16 inches. Minimized thickness variation was sought to reduce variation in x-ray attenuation and color measures. Specimens were sampled for specific gravity using ASTM D2395-93 (ASTM, 1994) methods. The sample moisture contents and specific gravity's for randomly selected samples are presented for each species in Table A1, Appendix A.

The wood features investigated in this study are listed in Table 3.2. These wood features or "defects" were selected based on their frequency and area they occupy in NHLA graded No.1 and No.2 Common red oak (Buehemann, 1997; Wiedenbeck et. al., 1995; and Widoyoko, 1996). Sound knots were included due to their similarity in color parameters to clear wood in red oak and due to the importance in differentiating between unsound knots. While splits are also a common defect in these grade types, they were not included in this study because of the difficulty in detection using the parameters studied. Other, more complicated, methods which are specific to crack and split detection perform better.

An attempt was made to attain twenty samples of each feature type. Smaller sample sizes have been successfully used in experiments to classify wood features by other investigators, (Lakatosh, 1966; Brunner et. al, 1992). The actual number of selected samples for each species and feature is listed in Table 3.3.

Bark pockets, sound knots, and unsound knots were limited to 0.5 inch to 5.0 inches in diameter to reduce variability in comparisons. By limiting the defect size, the samples drawn only have to represent the population of samples in that size range rather than the total population of that particular defect type. This method should have reduced variability in the sample measurements due to size effects.

Table 3.2. Definition of prevalent wood features included in this study.

Feature	Definition
Bark Pockets:	Inclusion of bark within the wood where a knot or wane are not present.
Knots: Sound (1.) and Unsound (2.)	Part of the limbs that are embedded in the main stem. (1.) Alive at the time of inclusion. Tissues are continuous with those of the main stem. (2.) Dead at the time of inclusion. Tissues are not connected with the main stem.
Stain:	Discoloration caused by fungi or bacteria. Initial evidences of decay.
Mineral Streak:	An olive to greenish-black or brown discoloration of undetermined cause in hardwoods.
Clearwood:	Earlywood and latewood are that contains no other features.

Table 3.3. Actual number of samples for each species and feature type.

Species	**Feature Type**			
	Knots	Bark Pockets	Stain and Mineral Streak	Clearwood
Red oak	20	20	20	20
Hard maple	20	14	16	20
White pine	20	12	13	20

3.4 Measurements

The scanning system described in section 3.2 was used to collect color and x-ray images for each sample. The color camera produces a digital image from which the following information was collected: red, green, and blue intensity values for each pixel, valued between 0 and 255. The x-ray detector image produced a digital gray-scale image with pixel values between 0 and 255 representing the pixel’s density. A white target image was collected for the color system before scanning began. This target image was compared to other white target images between scanning sessions to assure that the light geometry and intensity did not significantly change between the collection of images. X-ray target images were also periodically collected and compared for the same reasons. When necessary, changes were made to the lights and x-ray source as required. Once calibration to a known standard was verified, the collection of images began.

Each sample containing a wood feature was scanned using a color line scan camera and a linear x-ray detector as described in section 3.2. The actual measured resolution of color scans was approximately 30 pixels per inch (width) by 16 pixels per inch (length). The x-ray digitized images have a resolution of 30 pixels per inch (width) by 16 pixels per inch (length). The images were scanned at a rate of 1 foot per second in order to obtain higher image quality. After all the features were scanned the images were stored on compact discs.

3.5 Regional Segmentation and Data Collection

After all the wood features were scanned, the images were converted from an ELAS to TIFF format. The ELAS file format was used in the laboratory because of its simplicity, while the Tagged-Image File Format (TIFF) was used to exchange files between applications and computer platforms. The images were then imported into Image-Pro Plus image analysis software (Media Cybernetics, 1995). The spatial resolution was calibrated by measuring the actual width and length of the board and scaling the image pixels. Next, defect coordinates were determined by using length-measuring tools in the software. Regions of wood features were selected using special Area-of-interest (AOI) tools. The region of a feature was defined as the total area of the feature, which has only the characteristics of the particular feature type. For example, an encased knot region would include all fibers that are part of the knot growth and the bark around the branch, but would exclude the grain on the outer surface of the bark. The AOI tools were used to isolate an area of interest from the rest of the image as shown in Figure 3.4. The exact defect location and size was measured manually within 1/16 of an inch and used to verify defect locations in collected images. Defect regions were then encircled using AOI tools. The measurements collected from each region, their notation, and definitions are presented in Table 3.4. The shape measures were calculated using the feature represented in the color image by measuring tools available in the Image-Pro Plus image analysis software. Aspect and roundness were the shape measures collected and are described in section 2.6.

The exact AOI was then imposed on the x-ray image to insure that the same region was selected for measure. While the x-ray image is a grayscale representation of the attenuation of x-rays through the wood, it is also a representation of the density of the material. Hence, this measure will be referred to as the density measure in further discussion. The importance of these measures for wood features and their definitions have been discussed in Chapter 2, sections 2.5-2.6.

3.6 Description of Wood Features

Several difficulties were encountered when the feature measures were being collected. Most of these difficulties were results of differences in feature anatomical characteristics or inadequate feature definitions. These difficulties, how they affected the regional measures, and how they were overcome are described in the next section.

3.6.1. Checking in Knots

The majority of knots in the hardwood lumber sampled contained slight to severe checking. Checking in knots is caused by stresses, which occur in the drying process. Knots have greater shrinkage than surrounding wood, thus causing splits. In color images checks

Figure 3.4. Example of AOI selected knot region for density parameter measure.

Table 3.4. Definition of properties used to characterize wood features.

Property	**Notation**	**Parameter Measured From each region**	**Image Used to Measure**
Color	R_m	Feature red mean	Color
	G_m	Feature green mean	
	B_m	Feature blue mean	
	R_s	Feature red standard deviation	
	G_s	Feature green standard deviation	
	B_s	Feature blue standard deviation	
	H_m	Feature hue mean	
	S_m	Feature saturation mean	
	I_m	Feature intensity mean	
	H_s	Feature hue standard deviation	
	S_s	Feature saturation standard deviation	
	I_s	Feature intensity standard deviation	
Shape	ASP	Feature Aspect	Color
	RND	Feature Roundness	
X-ray attenuation	X_m	Feature attenuation mean	X-ray
	X_s	Feature attenuation standard deviation	

appear as darker regions within the knot, as shown in Figure 3.5 (a), causing feature color parameters to have lower (darker) means and larger standard deviations. Severe checking can also affect the results of x-ray attenuation, as shown in Figure 3.5 (b), were the inclusion of air space in the feature measure of what should be a denser material. Removing the checked area within a knot from the feature measure is extremely difficult and reduces the reliability of the measure to represent the population. Also, checks are a common characteristic in hardwoods that have been kiln dried. Therefore, hardwood knot parameter measures include checks.

3.6.2 Effect of feature angle on regional x-ray attenuation measures

Most defects in wood are somewhat angular in reference to the top and bottom planes of a board. In particular, most knots are angled through a board as a result of both the growing process and the way in which a board was sawn from the log. While the angle of the defect does not affect the color properties of the feature, it does reduce the density profile of the feature in the x-ray image. The larger the angle of a knot through the board, the smaller the percentage of dense knot material per unit volume and the greater the percentage of clear wood included in the x-ray image. Therefore, when the density of a region is measured using x-ray attenuation measures, some of the regional information will contain clearwood. This effect is shown in Figure 3.5. When measuring the regional properties of wood features that exhibit this behavior, it was difficult to determine the best method of regional property measure. Was it better to select the entire known feature region, excluding any clear wood, or to transform the exact AOI region used for color measure to the x-ray image?

To determine the best method of measure, data were collected using the entire known feature region, and by imposing the AOI from the color image for 17 samples of encased knots in white pine. This species and feature were selected because of the ease in determining the exact regional boundaries. Analysis of variance was used to determine if significant differences existed between the two methods of measuring x-ray attenuation properties of the features. Table 3.6 outlines the four ANOVA's tested. An ANOVA was used to compare the

Figure 3.5. Severe checking in a red oak knot.

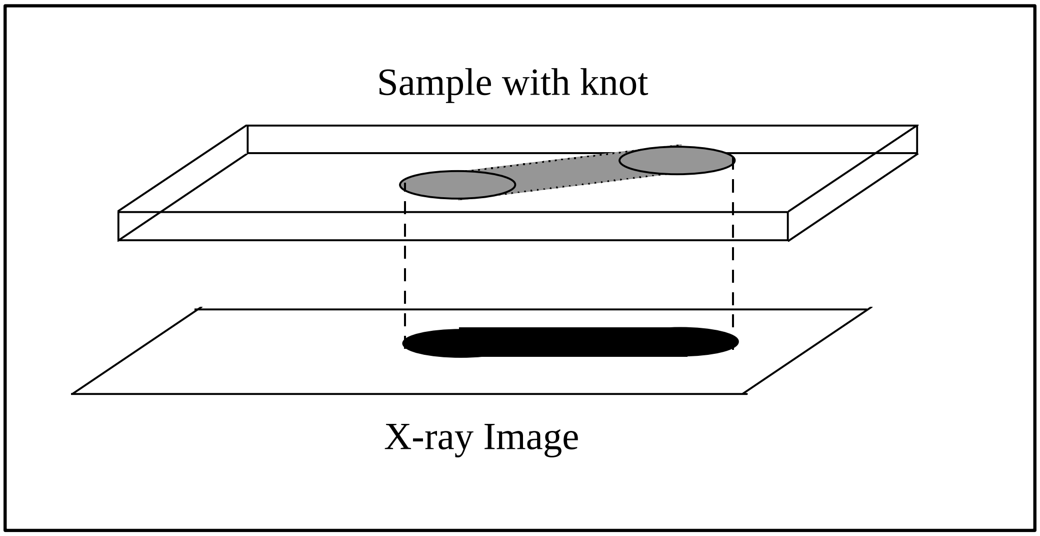

Figure 3.6. Effect of knot angle on x-ray attenuation images.

AOI measure and the identifiable feature region measure for each of the attenuation measures listed in the first column. The feature attenuation properties compared were gray level region mean, standard deviation, minimum and maximum values. ANOVA results showed that no significant difference (α=0.05) was found between any of the measured properties for the two methods used. Therefore, it was concluded that the two methods for measuring the attenuation parameter of a feature are equal. Imposing the exact AOI region used for feature type measures in the color image onto the x-ray image was chosen for simplicity and repeatability.

3.6.3 Anatomical description and feature subclasses

The feature types examined in this study have previously been defined in Table 3.2 based on visual characteristics. Some limitations on the parameter measurement of these features were discussed in sections 3.5.1 and 3.5.2. Features are defined in Table 3.6 based on anatomical characteristics. It is important to discuss the growth characteristics of wood features because they relate to the definition of the defect. When defects in the lumber samples were visually inspected, it became apparent that some features could fall into multiple defect categories, or that several features which differed anatomically could fall into the same category. Part of this ambiguity was due to the National Hardwood Lumber Association (NHLA) defect definitions being based on one face of the board. For example, in red oak, knots could be intergrown on one surface, but not penetrate to the opposite surface. This particular defect is intergrown on one face and encased somewhere between the two faces, and not existent on the other face. While NHLA grading rules define these knots adequately based on observing one face, this research uses density information to compare parameters.

The density information is composed of the entire defect, not just one face. For this study features must be well defined anatomically and similar across species to reduce variability in comparisons. Due to the ambiguity of the provided feature definitions, subclasses of these features were developed. Subclasses were developed for each species. It was discovered that most subclasses are species dependent For example, an encased knot in

Table 3.5. Individual measures used in ANOVA comparisons of feature measurement method.

Attenuation Measure	**Methods Compared for Each Feature Measure (Treatment)**	
Mean	AIO Region	Identifiable Feature Region
Standard deviation		
Minimum value		
Maximum value		

Table 3.6. Anatomical description of wood features.

Feature	Description
Intergrown knots	Knots where the branch remained alive and became intergrown with the main stem (Bodig and Jayne, 1982) .
Encased Knots	When a branch dies and the growth increments of the main stem continue to grow around the branch. Often the dead branch has broken and becomes embedded in new growth tissue (Panshin and DeZeeuw, 1980).
Bark pocket	Any bark filled blemish in the board (NHLA, 1994). Usually an area where damage has occurred to the tree and the cambium has later grown over this damage.
Stain	In hardwoods the word "stain" is used to describe the initial evidences of decay.
Mineral Streak	An olive to greenish-black or brown discoloration of undetermined cause.
Clearwood	Earlywood and latewood growth transitions where no other feature is present.

white pine, where the knot is check free and tight in the wood, was not evident in oak, where drying stresses cause such knots to shrink, split, and often times fall out of the lumber. Defining features in detail is important to assure that each feature class is truly unique both within and between species.

Subclasses were created to ensure well-defined feature groups and are described in Table 3.7 based on each species. Differences in color, shape, and density parameters of each subclass were compared using ANOVA.

3.6.3.1 Red Oak

Knot Class

Red oak knots were segmented into three separate classes based on anatomical differences as described in Table 3.7. Regional color, density, and shape parameters listed in Table 3.4 were compared using analysis of variance to determine if significant differences existed for each subclass. The results of the ANOVA's are presented in Table A2 in the appendix. H_m was the only parameter which was found to be significantly different, (α=0.05), for the three knot classes. All other color, density, and shape parameters were not significantly different. This result was unexpected for the X_m and X_s parameters, which were expected to be significantly different for the individual classes. These results indicate that all parameters describing a knot, except H_m, are not significantly affected by the different knot classes chosen. However, because one parameter was significantly different, the classes were not combined. Knot_A class was used for all other analysis unless otherwise stated because it is represented in each species.

Bark Class

The three bark classes defined in Table 3.7 for red oak were compared in the same manner as knot classes. The majority of mean parameters contained significant differences (α= 0.05) for the three classes, as shown in Table A3, indicating that they are truly separate classes. The standard deviation parameters of the three classes are all found not to be significantly different with the exception of saturation. These results indicate that the three

Table 3.7. Definitions of feature sub-classes for all species.

Specie	Classification	Description of Feature	Differences between features
Red Oak	Knot_A	Intergrown knot with some checking. No decay is permitted. The branch growth is intergrown on both faces.	Uniform density and color properties
	Knot_B	Intergrown knot on the scanned face; however, there is no presence of branch growth on the opposite face.	Density should be lower due to less higher density knot material.
	Knot_C	Intergrown knot with no decay on scanned face. The opposite face contains decay.	Density should be lower due to less dense material within the knot. Color properties should appear darker due to stain.
	True Bark Pocket	An area which contains bark material that is the result of damage of some type where the cambium has overgrown and included bark in the wood material. Is not an area associated with an old encased knot or loose knot.	Higher density, more uniform color properties.
	Bark Pocket / Encased Knot	Scanned face contains very dark stained and decayed material. There is 75% material on face. No holes. May or may not extend to opposite face.	Lower density due to lack of material. Will appear round in shape. Color properties should vary due to wood material.
	Bark Pocket / Knot Hole	An area of bark where an encased knot has fallen out and only the bark surrounding the old knot remains. Often contains cracks filled with bark. Generally round. The hole does not continue to opposite face.	Lower density due to lack of material. Will appear round in shape. Color properties should vary due decayed wood material.
Maple	Knot_A	Intergrown knot on both faces. No decay. No stain on scanned face. Opposite face may contain stain.	Uniform density and color properties.
	Knot_B	Intergrown knot on both faces. No decay. Stain occurs on over ½ of the scanned face. Opposite face may or may not contain stain.	Color properties should appear different due to stain in knot material.
White Pine	Knot_A	Intergrown knot	More uniform density and color properties due to lack of bark.
	Knot_B	Encased knot	Darker mean color and higher standard deviation due to inclusion of bark in region.

bark classes are significantly different from one another and should not be considered as one feature class. The true bark pocket class was used for further analysis unless otherwise stated.

3.6.3.2 Maple

The two knot classes identified in maple (Table 3.7) were found not to be significantly different for any mean parameter; however, the I_s was significantly larger in knot class Knot_B (knots with stain). This increase in the I_s was expected due to the combination of both stained and unstained material in the knot. It is interesting to note that none of the mean color parameters were significantly affected by stain. These results indicate that there is a difference between the knot classes that can be measured using the parameters, hence separate classes are required. Knot class A was used for all further analysis.

3.6.3.3 White Pine

All mean color and density parameters were found to be significantly different for both knot classes as shown in Table A4. Both ASP and RND were found to not significantly differ. Encased knots also have significantly higher standard deviations than intergrown knots. This can be explained by the inclusion of bark on the outer surface of the knot. These results indicate that for white pine the two knot classes differ not only anatomically, but differ in the measured parameters. Knot class A was used for all further analysis.

3.6.4 Summary of Feature Descriptions

For all three species these results indicate that the feature subclasses developed on anatomical differences do have statistically significant differences in some of the measured parameters. None of the feature subclasses were combined into one class for within or between species comparisons as they have been found to differ significantly based on the measured parameters. The parameter differences could potentially be used to classify these features. The subclasses cannot be used to compare between species because they were not found in significant numbers in all three species. Therefore, only the major feature classes of intergrown knots (knots), bark pockets, mineral streak and stain (stain), and clearwood will be used in further analysis. The elimination of feature subclasses did not reduce the sample sizes of features for comparisons as listed in Table 3.3

3.6.5 Determination of Feature Parameter Relationships

Once the color, shape, and density parameters were measured for each feature, the relationships of the parameters were determined using statistical analysis as shown in Figure 3.7. The relationship of the measured parameters was determined within and between species using analysis of variance techniques. The effect of resolution on the parameter relationships was also examined. The assumption of equal variance for the tested groups was verified before each ANOVA.

When parameter differences were found to be significantly different, Tukey's W procedure was used to determine which groups were significantly different. While several multiple comparison methods exist, Tukey's W procedure is more conservative in determining group differences and is able to account for unequal sample sizes (Ott, 1988). SAS (SAS Institute, 1996) statistical analysis software was used for all statistical analysis.

3.6.6 Modeling Wood Features Using Measured Parameters

It is important to understand the contribution of each parameter in differentiating between feature types. Those parameters that do not contribute to feature identification can be left out of algorithms, thus reducing the amount of data required, speeding up the algorithms, and possibly eliminating a sensor type. Those parameters that contribute largely to the classification of a defect type need to be identified so that they are utilized for the identification of that feature. It is also possible to determine the contribution of a parameter to the classification method by comparing the classification accuracies of classifiers with and without the particular parameter.

The relationships of parameters determined using the results of the analysis described in section 3.5.3 were used to develop discriminant classifiers. Discriminant classifiers were developed and tested using SAS (SAS, 1996) statistical analysis software. Classification

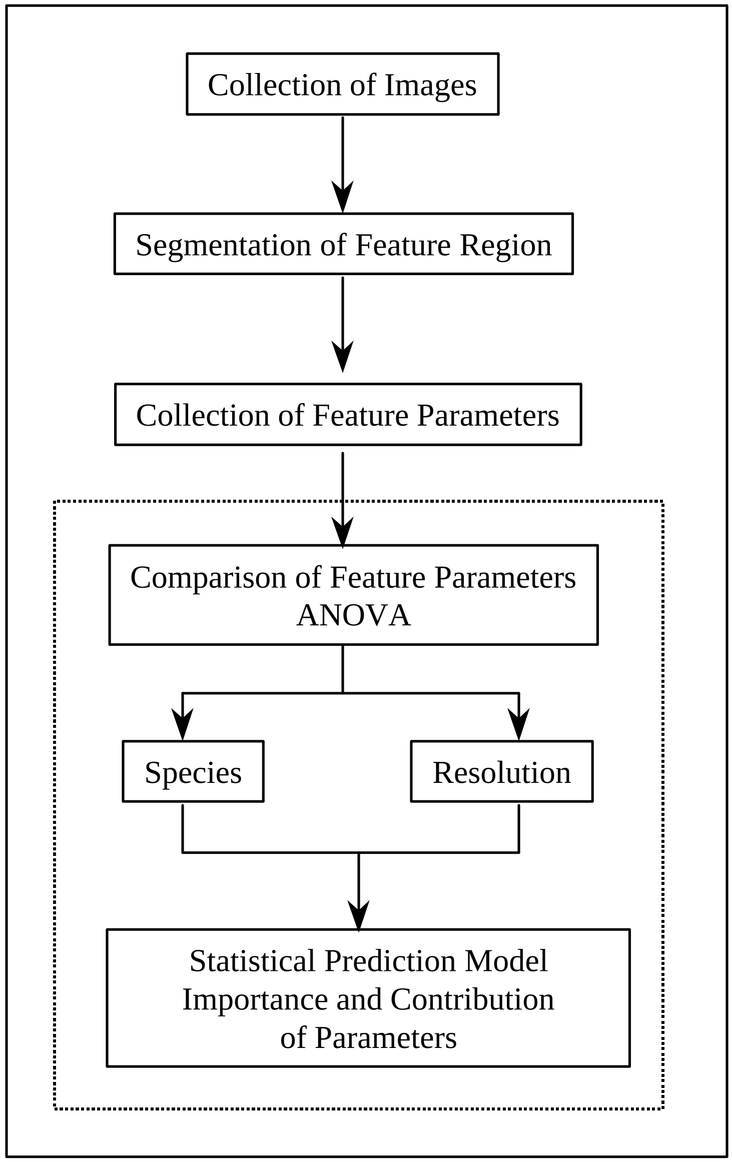

Figure 3.7. Diagram of experimental data analysis.

accuracies for each model were compared. Classification errors were determined using the "leaving one out method". Several classifiers were developed and compared using the discriminant analysis technique to determine the significance in parameters for differentiating between feature types for the various species and are discussed in detail in Chapter 5.