Chapter 1

Introduction

1.1 Background

Wood is a natural material and contains variability within and between species. This variability can lead to features, such as knots, stain, tension wood, and pitch pockets, that are undesirable for certain applications and are therefore considered defects. These features are of economic concern to both producers and users of lumber because the grade, structural integrity, and ultimately price of the material is based upon defect size, location, and type.

The primary material from which many high-demand furnishings are made, including finished floors, cabinets, furniture, millwork, and other household products, is wood. To manufacture these products, higher grades of preferred timber species (e.g. oak, cherry, walnut, and yellow poplar) have traditionally been used. Consequently, woodworking equipment and the skills of the workforce in this industry have been designed to process wood raw materials that were relatively free from defects, easy to process, and inexpensive to waste.

The demand for these high quality premium wood species has been increasing in both the domestic and international markets (Bush et al., 1990; Luppold, 1991) while the supply is becoming limited (Tansey, 1988). These trends have resulted in supply shortages and continued price increases for hardwood lumber (Luppold, 1991). For example, there has been a 40% cost increase between 1990 and 1995 of 4/4 kiln dried Number 1 Common red oak (Hardwood Market Report, 1995). The wood furniture industry uses an estimated 28 % of the hardwood lumber in the US (Luppold, 1991) and 32% of the hardwood lumber internationally (Haas and Smith, 1997) and is greatly affected by any cost increases. With increasing shortages and prices in the raw material, the furniture industry is spending more time and money to inspect lumber and carefully remove those features having a negative impact on the quality and value of the final product. Both price and supply issues have forced the industry to begin to utilize lower grade material that contains more defects. The traditional infrastructure of this industry is not currently suitable to efficiently process these lower-grade raw materials.

As lower quality raw materials are utilized, the importance of accurate defect removal increases. The removal of visual defects in wood is a primary concern in the wood furniture and cabinet industries where clear and uniform sections are desired. Removal of defects is done in the roughmill, where operators must quickly examine a board for defects and then remove them while maximizing the yield for parts. The operators must perform multiple operations at high speed and under difficult conditions. The overall accuracy of roughmill employees to locate and remove defects is about 68% (Huber et al., 1985). This accuracy varies between employees, day of the week, and time during the day.

Detection of undesirable features is also of great importance to the softwood industry, where structural grade is dependent on the type and location of defects. Wood features must be recognized by skilled workers at extremely high speeds. With the loss of old growth timber and the increase in plantation pine production, the number of undesirable features present in softwood lumber is increasing.

Facing price increases reduced quality, and shortages in raw material the wood products industry must aggressively explore new innovative processes if they are to survive in an increasingly complex and competitive environment. A critical need for improved processing in the wood products manufacturing industry is the development of a new system that can efficiently and cost-effectively convert existing wood raw materials into high-quality products. For a long time, the wood products industry has recognized that improved processing systems have an enormous potential to pay for themselves through increased material yields alone. Approximately 40 to 75 % of the cost of producing defect-free parts in a furniture roughmill today is the cost of the raw material. Hence, any increase in the volume of usable parts produced from a given volume of raw material will markedly increase profit margins. The current economic situation along with public pressures to "use less trees" provides a timely opportunity to actively pursue the development of new technologies that maximize the utilization of available timber resources.

The development of new processing technologies will require a sensing system that can automatically inspect wood and accurately pinpoint critical features that affect the quality of the final product. This system would allow accurate and consistent identification of the type and location of defects for either removal or grading purposes. It is suggested that an automatic inspection system need not perform to 100% accuracy, but only perform consistently at or above the human standard. Conners et al. (1985) suggest that an automated system which can locate defects could compute an optimal sawing strategy which maximizes higher value cuttings. Such a system could also reduce labor costs, improve yield, and allow a minimum lumber grade to be used for parts.

Automated defect detection is also beneficial for the introduction of more precise production control methods and new production concepts. Multiple batch processing where the features to be removed from the raw material change from product to product could be better controlled. In this situation, the performance of human operators would be further reduced as allowable defects constantly change with production specifications. New production concepts such as the inclusion of character marks in furniture would become feasible. It has been suggested that an increase in roughmill yield can be achieved through the introduction of character marked material (Buehlmann et. al., 1997). The size of character marks or defects would vary from part to part depending on the location of the defect and the part on the finished product. It would become extremely difficult for a human sawyer to remember the sizes allowed for all the parts required, much less what features may be allowed in those parts. An automated cutting system using machine vision for defect detection would be needed to accomplish this task.

An automatic defect detection system would require some type of scanning technology. Many different sensing methods have been applied to inspection of wood including optical, ultrasonic, microwave, nuclear magnetic resonance, and x-ray sensing (Szymani and McDonald, 1981; Portala and Ciccotelli, 1992). While research on each of these sensing methods has produced marked results in recent years, commercial applications based on these methods have not been able to meet the industry's expectations. Accurate and reliable feature detection has been a challenge mainly due to the lack of knowledge about the enormous variability in the nature and condition of the wood materials processed by the industry, and by limitations of the individual sensing technologies.

It has been proposed that the system that will drive new automation technologies will require the use of a multiple sensor scanning system (Kline et al., 1993). Although different types of sensors for automatic feature recognition in wood have been studied, little work has been done to investigate the combination of different sensors in one system (Conners et al., 1992; Åstrand, 1992, Hagman and Grundberg, 1993). The need for a multi-sensor scanning system can be illustrated in the case of hardwood lumber where it is very difficult to accurately locate and identify all critical features using only contrast information from an optical sensor. The unsurfaced and often weathered appearance of hardwood lumber can obscure features making them difficult to detect even with the human eye. The presence of dirt and other applied marks on lumber can give the illusion of a feature that is not present. Even if the lumber is surfaced and cleaned, two predominant hardwood features, knots and wane (where bark has been removed), can sometimes have nearly the same contrast as clear wood. Therefore, it is very difficult to correctly identify all surface features on typical hardwood lumber using only optical image data. With the integration of multiple sensor information, the accuracy of an automatic feature inspection system can be substantially improved.

1.2 Research Needs

Several investigators have demonstrated that color, laser, and x-ray information is useful in separating defects from clear areas in wood. The purpose of these investigations was to simply demonstrate that a technique had the potential to locate defects in wood or to demonstrate that a pattern recognition technique could be used to separate defects from clear wood. The majority of these investigations utilized small sample sizes and softwood species. How to best utilize color information for classification is not understood. For example, while it is known that color information enhances the performance of defect detection algorithms in wood (Conners et al., 1985 and Brunner et al., 1990), it is not understood exactly how color information contributes to increased algorithm performance and if there are defect limitations to this information. Brunner et al. (1990) state that knowledge about the color differences between surface features is of great importance for the separation and classification of wood features using color imaging techniques; however, such information is lacking in literature. Recently investigators have proposed the idea of using shape or morphological features in conjunction with color information to improve wood feature classification (Polzleitner and Schwingshakl, 1990, and Conners et al 1995). While the importance of color information in segmentation and classification are well documented, additional information is required for the correct classification of all defect types.

Current research at Virginia Tech has demonstrated that a combination of color and x-ray attenuation information increases the classification accuracy over single sensors. Color and x-ray attenuation information are assigned weights and are combined to increase classification accuracy. Information from one technology can override the classification information of the other. For example, a dark round spot would be classified as a knot using only color information; however, by combining density information to the classification algorithms it can be determined that the feature is a stain or a handling mark. In any event, there exists a lack of understanding of what sensor parameters should be measured and used to adequately represent and differentiate wood features. An in depth understanding of this parameter information would lead to the correct application of a sensor type for the particular situation, reduced information collected by the sensors, and an increase in the performance of algorithms.

To help guide the development of multi-sensor machine vision systems for detecting features in wood and truly understand the contribution of color and x-ray information for defect detection, a fundamental understanding of the nature of wood characteristics is needed. There are many different features of commercial importance that need to be detected in wood. There are also large variations in appearance within each type of feature. Furthermore, the nature and condition of wood is highly variable both within and across species. Basic research is needed to develop key parameters to characterize wood features and to understand how these parameters may be related. Also, there needs to be an understanding of the relationship of these parameters to various species. The importance of each parameter as a prediction factor for a specific feature type needs to be determined. Specifically, critical barriers need to be addressed concerning the fundamental relationships of intensity, color, shape, density, and other properties in wood to those features that determine the ultimate quality of solid wood products.

1.3 Hypothesis

In this research, color, and x-ray scanning techniques will be used to characterize wood features in terms of color, density, and shape parameters. It is proposed that by having an in depth understanding of the interaction, variability, and knowledge of how well each derived parameter contributes to feature representation, then very accurate and consistent differentiation between feature types can be achieved. It is also proposed or hypothesized that the type of wood species will have a significant influence on the ability of these derived parameters to differentiate feature types.

1.4 Objectives

The purpose of this research is to advance the basic understanding of features in wood by describing them in terms of parameters that can be derived from several different scanning technologies and to demonstrate how these parameters can be used to differentiate wood features. The scanning technologies explored will pertain to those that measure the color, intensity, and density properties of wood features. Measured parameters will be compared to determine their importance for classification and to determine their relationships to one another. The effect of species and resolution on these parameters will be described. This research will be accomplished through the following objectives:

1. Describe wood features using parameters derived from information measured by color and x-ray sensors and characterize the variability and interrelationships of these parameters.

2. Determine the effect of species and resolution on the level, variability, and interrelationships of parameters derived in Objective 1.

3. Determine the importance and contribution of each parameter derived in Objective 1 for differentiating between wood features using a statistical prediction model relating feature types to the parameters. Determine how species influences a particular parameter's ability to differentiate between feature types.

1.5 Significance

This research will result in an improved scientific knowledge base describing how wood features are represented by color, shape, and density parameters. A comprehensive understanding of what parameters are required to differentiate each feature from one another, the importance of each parameter in differentiating features, and an understanding of how resolution and species effect these parameters has been obtained. The knowledge developed can be used for the development of the best possible classification methods, regardless of the particular processing method employed. This information will contribute to better-automated defect detection systems for the forest products industry, which should allow them to successfully and better compete in the ever-changing global economy.