Chapter 6

Summary and Conclusions

6.1 Summary

Automated defect detection in the forest products industry is capable of providing better utilization of resources by improving yield, reducing labor costs, allowing minimum lumber grades to be utilized, and providing the technology required for new processing methods. While many sensor types and processing methods have been proposed for the detection and classification of wood features, there exists a lack of understanding how wood features are represented in relation to one another and what measures would provide the best differentiation between features. The goal of this dissertation was to develop knowledge of how wood features are represented by color, shape, and density parameters, to determine how these parameters were related within and between features, and to demonstrate that the improved knowledge benefits the classification of wood features. To achieve this goal color, shape, and density parameters were measured for knots, bark pockets, stain/mineral streak, and clearwood for red oak, hard maple, and white pine. These parameters were measured from regions manually segmented from color and x-ray images.

The relationships of the parameters between feature types were then determined based on significant differences of parameters between feature types. By characterizing parameter differences between features using statistically significant differences, those parameters that can be used to differentiate features were determined. Analysis of variance and multiple comparison methods were used to determine significant differences. This method of gaining knowledge of what parameters would provide good classifiers using statistical was suggested by Huberty (1994).

It was discovered that the color parameters, which would provide good differentiation between features, varied between species with the exception of R_m, G_m, B_m, and I_m. Color was found to be an important parameter in classification of difficult features and species. At least two color parameters were determined to be required in hardwood feature type classification, where the differences between parameter measures were small in relation to the variation between measures. The importance of two color parameters in classification has also been discussed by Conners et al (1985), Maristany et al. (1991). Density and shape parameters were suggested to provide benefit to feature differentiation when a multi-parameter method is used.

The effect of resolution on the parameter relationships was determined by comparing two different spatial resolutions for each parameter and feature type. No significant differences were found between the resolutions of parameters in any of the feature types; therefore, it was concluded that halving the resolution for the wood features compared does not affect their variability or relationships. This conclusion is conditional to the method applied to segmenting the features in this research. Resolution has a greater effect on the segmentation of features. Since the measures used in classification are generated from segmented features, poor segmentation can affect the classification results.

The effect of species on the relationships of parameters was determined by comparing values for each species using analysis of variance. It was discovered that bark pockets are the only feature type for which a parameter was not significantly different between the three species. All other parameters where significantly different for at least one of the species. A relationship was discovered to exist between the I_m of clearwood and the I_m of the other feature types for each species. The density of knots was found to be greater in relation to clearwood density for white pine. The clearwood to knot density ratio is smaller for hardwoods than in white pine. This result helps to explain why the density parameters for white pine outperform the hardwood density parameters in the classification of knots.

Discriminant classifiers were used to demonstrate that an in-depth knowledge of how parameters are related between features could be used to develop the best possible classification functions. Classifiers developed based on the knowledge of parameter relationships were found to provide higher classification accuracies for all features and species than those which used all parameters and variable selection procedures. This result demonstrates that by understanding how wood features are represented by color, shape, and density parameters, the best possible classification can be achieved. Also, fewer parameters were required for classification when information is known about how parameters relate between feature types. The methods for determining the best classification variables for features presented in this dissertation can be used for other species and classification methods.

The knowledge gained about feature parameter relationships was also valuable in explaining classification errors. By understanding how parameters contribute to classification errors, future classification errors may be avoided. It was found that most classification errors were based on confusion with stain/mineral streak. Most single parameter classifiers performed 60% or lower in classification accuracy for stain/mineral streak. The ability to classify stain/mineral streak in multiple parameter classifiers was 90% or better for all species, proving that combining parameters from multiple sensors increases classification accuracy of wood features.

Shape and density parameters were found not to provide good classification variables for features when used separately, but both contributed to the classification accuracy of features when used in combination with other parameters. It is likely that as variation increases in all parameters, due to different segmentation methods or increasing the different types of features, that density and shape parameters will become more important for classification. The importance of multi-sensor information increases with the variability in parameter measure as demonstrated in red oak.

Many color spaces have been used to classify wood features. The most common are the RGB (red, green, and blue) color space and the HSI (hue, saturation, and intensity) color space. The two color spaces were compared for each species and it was concluded that for the classification of ingrown knots, bark pockets, stain, and clearwood there is no significant difference in discriminant classification using either RGB or HSI color parameters for red oak, hard maple, and pine.

6.2 Conclusions

- Analysis of variance and multiple comparisons can be used to characterize the differences of color, shape, and density measures between wood features. Statistical analysis of color, shape, and density measures for feature types suggest that certain measured values have more significant differences between features than others, indicating that these measures do vary between feature types. It is this variability in measures that allow the feature types to be differentiated.

- For red oak it was determined that mean color values alone do not provide enough information to accurately differentiate between knots, bark pockets, stain/mineral streak, and clearwood in red oak, hard maple, and white pine.

- Analysis of variance, multiple comparisons, and discriminant classification accuracies were used to demonstrate that knots, bark pockets, stain/mineral streak, and clearwood vary greatly in intensity. It was determined that the intensity mean should be included whenever using a HSI color based classifier.

- By comparing normalized feature color values to clearwood color values, it was determined that the mean intensity value for knots, bark pockets, and stain/mineral streak is related to the clearwood mean intensity value for the species they reside in.

- For bark pockets, none of the color parameters varies significantly across the species. Bark pocket color is uniform regardless of the species.

- The RGB mean color values and intensity mean value provide the same information for certain feature types for red oak, hard maple, and white pine. This similarity was noted by analysis of variance where these measures were found to exhibit significant differences between the same feature types for all three species and by the discriminant classification accuracy results for each measure.

- Based on the number of significant differences between feature types and discriminant classifier accuracies, it was concluded that wood features vary more between species in hue mean values and saturation mean values than intensity mean values for the HSI color space. The hue mean value should be used for classification of wood features in hard maple and the saturation mean value in white pine.

- Halving the image resolution does not effect the relationships of color, shape, and density measured values between feature types for bark pockets, knots, stain/mineral streak, and clearwood in red oak, hard maple, and white pine. This conclusion is contingent upon using manual segmentation methods.

- A multi-species classifier developed using an in-depth knowledge of the relationships of color, shape, and density measures for wood features, will provide higher classification accuracies than a classifier with all or randomly selected measures. A multi-species classifier will provide the greatest accuracy when two color mean value, one color standard variation value, one shape, and two density measures were used.

- By understanding the statistical differences of color, shape, and density measures between feature types, classification errors in feature differentiation can be explained. Those feature types that are confused in classification do not have many significant p-values in statistical comparisons of color, shape, and density measures.

• Feature aspect, roundness, density mean, and density standard deviation values provide poor classification variables when used alone in discriminant classification of wood features. However, they increase the classification accuracy of knots, bark pockets, and stain/mineral streak, and clearwood by 5-10% when combined with color measures in red oak, hard maple, and white pine.

• For the classification of ingrown knots, bark pockets, stain, and clearwood there is no significant difference in discriminant classification using either RGB or HSI mean and standard deviation color values for red oak, hard maple, and white pine.

6.3 Recommendations for Future Research

In this dissertation wood features were represented by color, shape, and density parameters. One of the main limitations of the findings of this research is that the features were segmented from clearwood manually and that features were grouped with relatively homogenous parameters. The focus of this research was to determine the relative parameter relationships between features, which required data with low variability. Improvements to the proposed method of determining classification parameters can be made by using automated segmentation methods and by increasing the number of features classified to determine the affect of larger variability on the parameter relationships. Weights could be applied to parameters for differentiating between specific features in classification. Also, classification could be broken in to different segments where the parameter weights changed with the expected feature class outcome.

This research has focused on the characterization of wood features for classification purposes. It is a reasonable assumption that the same parameters selected for classification of features could be used to improve the segmentation of wood features. Currently, the majority of segmentation methods use black and white (intensity) information only. It is proposed that color information would be beneficial for those species and features, which prove difficult to segment. The segmentation of different features could be based on knowledge of the parameters that best separate particular features. This would require the segmentation to be done in several steps, but could possibly provide better-segmented feature regions. It has been shown in this dissertation that when regions are well segmented, classification accuracy is high.

The conclusions of this dissertation are based on regional measures. The same feature relationships, with the exception of shape, could be used in classification of features at the pixel level. The color parameters used for classification may have to be re-determined for pixel level classification; however, the same statistical analysis could be used for classification variable selection. Once the classification parameters have been determined, pixel neighborhoods or windows could be used to classify pixels into feature classes.

While the importance of density information for classification was demonstrated, the density parameter did not perform as well as expected. The down-board resolution used likely contributed to the lack of classification using density. However, it is also likely that there was a loss of true regional density information caused by the angle of defects in the image as discussed in Chapter 3. The limitation is caused by collecting data on a three dimensional object from a one-dimensional image. It is possible that by determining the density of the feature in two dimensions that the angle of the feature through the material can be determined and the location mapped. This information could then be used to calculate the density of the entire feature relative to the density of the surrounding material, and improve the ability of the density parameter for differentiating between features.