Chapter 6. Results and Evaluation of the Histogram Modeling Technique

The histogram modeling technique was tested using the three different species of wood, namely red oak, southern pine, and yellow poplar. The boards were picked so as to include most of the defects commonly found in those species. Further, color based defects like blue stain were also included since these features are hard to detect using black and white segmentation. The test boards consisted of a set of eight pine boards, five yellow poplar boards and over thirty oak boards. This is not an exhaustive set of data, though the boards had most of the features that can be found in a species. The results can thus be used to make a qualitative rather than a quantitative analysis of the algorithm. The results obtained conclusively show that the model based approach is feasible, and can be used to segment images of wood. However, for obtaining more quantitative results, the algorithm will have to be tested on a much larger set of samples. The guidelines used for testing in the current study can be extended over a much larger data.

6.1 Description of the experiments

For each species, the effect of using 2 and 3 channels of information was first studied, while all the other parameters remained constant. All the possible combinations of 2 channels of information (r-b, r-g, b-g) along with 3 channels were tested using the model based approach. If a particular histogram gave noticeably bad results in all the boards (of a particular species) or falsely classified one particular feature, the other parameters of the algorithm were manually varied to try and obtain a better segmentation result. In determining the value of the other parameters, the color characteristics of the histograms were used to optimize the result for each board. For example, if it was difficult to get heartwood-sapwood separation, the value of p and Th was reduced, and so on. If the same misclassification still persisted in all the boards, then that combination of channels was declared unsuitable for that species.

Observing the histograms for a species gives an insight into the effect of p. The general shape of the histograms of each of the species is described in Section 5.1. Only in Yellow poplar, there exists two distinct regions within clearwood namely the heartwood and sapwood regions. Since there are no such distinct regions in pine and oak, in general, reducing the value of *p* puts tighter constraints on the algorithm. The value of *p* was varied to obtain a range of values for each species. The range of values worked well with all the samples in a species.

A similar study showed that the value of *p* and *Th* are not independent of each other. It was possible to obtain similar segmentation, when *p* is reduced and *Th* is increased within a limited range. However a quantitative relationship between the two will require some further testing with more samples, and is beyond the scope of this study.

In all the samples used for testing, the entire color space was used initially to find the peak using the method explained in Section 5.2. Boards that had defect regions that were much larger than the clearwood regions were isolated manually and the method described in Section 5.3.1.2 was used to detect the clearwood peak. In general, it was found that ignoring the peaks that occur within 3-4 elements from the edge of the histogram was sufficient, to give correct results. Of course, limiting the search for the peak within this region will not affect the results in boards where the majority of the board is clearwood.

The adjustable parameters gives the algorithm the flexibility that is needed in any defect detection system for the wood industry. The parameters described above can be varied to get the desired features from the board that can then be used as an input to the recognition algorithms. Broadly, the algorithm can be so adjusted that either it detects only the dark colored defects like knots, wane, and structural defects like splits or it can also be made to detect the color variations on the board. Effects of applying the algorithm to each of the three species of wood are described in separate sections. This algorithm is then compared to an existing b/w segmentation technique currently in use in the lumber defect detection system at the Brooks Forest Products Research Center at Virginia Tech [KLN93].

6.2 Results of Segmentation

In this section the result of applying the algorithm to each of the three species will be described. The reason for studying each species separately is that, each species was found to have some color specific characteristics that made the segmentation procedure unique for a particular species. The parameters that gave good results for all the boards of a species in the sample set are also listed in the following sections. These values are not meant to be the final range of parameters that will give the best results for a species, rather they are meant to serve as guidelines for performing follow up testing and analysis.

6.2.1 Red Oak

The most common defects found on the red oak boards that were used to test the algorithm had knots, holes, wane etc. The dark colored defects like knots etc., are relatively easy to separate out. The segmentation of a typical oak board was shown in Figure 5.5 (f). The original image is shown in Figure

A few of the samples had small amounts of blue stain. The blue stain area were detected in the segmentation process. However since the quantity of blue stains found on the boards were very small and fragmented, the segmented regions were also fragmented and region merging techniques would have to be used before a decision is made. This is so because the algorithm picks up only those pixels, which have blue stains. For the purpose of demonstration, a very high resolution image is required to observe the segmentation results of blue stain. The parameters used for segmenting the images of oak boards are summarized in Table 6.1.

Table 6.1: Parameters for Red Oak

Parameters	Values
R, G, B channels	R - B Histogram
Percentage of Original Histogra7m used	85%
Threshold Th	60

6.2.2 Southern Yellow Pine

Figures 6.1(a-c) show images of a segmented pine board shown in Figure 4.2a. The original image is described in Section 4.2. Some of the typical results of segmentation using, r-b, b-g and all the three channels are also shown. It was found that the combination of blue and green channels alone gave optimum results with pine boards. Including the red channel resulted in the segmentation of the grain patterns on the boards. Another interesting feature that was observed in all the pine boards examined was that the blue stains on the grain patterns were detected by the algorithm more easily on the latewood rather than on the earlywood areas.

Figure 6.1b shows the segmented image when the r-g histogram is used. While all the other major features are being detected, it can be seen that the grain patterns is also being classified as a defect. In particular the prominent grain pattern in the top of the board is being segmented as a defect region. This segmentation was one of the best that could be obtained with r-g histograms when the parameters when manually adjusted to give the best possible results. Similar results were observed with all the other pine boards that were tested. If the algorithm was made less sensitive with the view of including the grain pattern in the clearwood region, the other defects like pith and blue stains were not detected. The grain pattern continued to be classified as defects even when 3 channels were used (Figure 6.1c). When the b-g histogram was used, all the desired features are detected (Figure 6.1a). In this segmentation, there is a minimal amount of grain pattern that is called defect, while all the other features like pith, knots and blue stains are still being detected. The grain pattern that is detected on the left edges of the board, is where the blue stain is present. This can be verified by comparing it to the original image shown in Figure 4.3a.

The range of parameters, which gave good visual segmentation results, in general for pine boards (in the test data set) are shown in Table 6.2. The value of *offset* was set to 1 in most cases, as it was not found to have any visible effect on the segmentation, unless it's value is comparable to the threshold *Th*. The value of *offset* is hence not mentioned in the table. This is true for the two other species of wood as well.

Table 6.2: Parameters for Southern Yellow Pine

Parameters	Values
R, G, B channels	B - G Histogram
Percentage of Original Histogram used	45% - 60%
Threshold Th	60

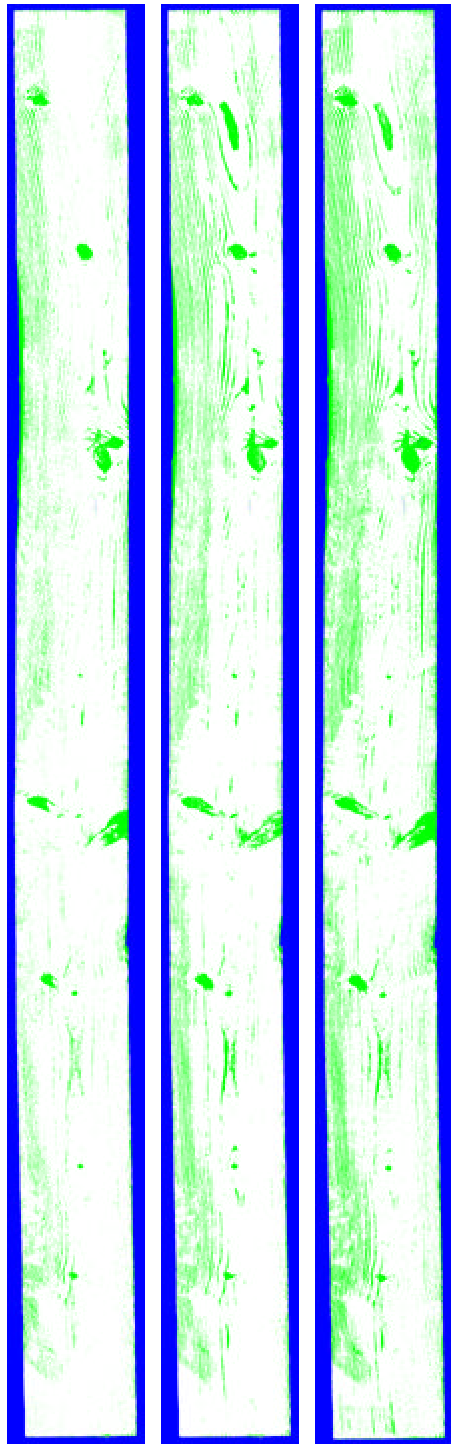

Figure 6.1: Segmented Images of pine board of Figure 4.2a using the model based approach, (a) b-g histogram , (b) using r-g histogram, (c) r-g-b histogram

6.2.3 Yellow Poplar

One of the main characteristic features of Yellow Poplar is the heartwood and sapwood regions that are generally quite distinctive. The segmentation can be performed in two ways. The sap wood region can be treated as the clearwood area. In this case the heartwood region is clustered along with the classic defect areas (like knots, bark, decay etc.). Alternatively the sapwood and heartwood can both be treated as clearwood. In this case the other defects can still be segmented out.

Figures 6.2 shows the segmented images of the yellow poplar board shown in Figure 4.4a. The sapwood region is treated as clearwood, while the greenish heartwood is treated as defect. The two heartwood regions are detected in a much better fashion than what was possible with the multispectral clustering technique (Figures 4.4b-e). Figure 6.2b shows a segmentation when there is no distinction between heartwood an sapwood.

Figure 6.3a shows yet another yellow poplar board that has a region of heartwood in the central and lower portions of the board, some bark at the bottom of the board, and some bark and decay on the top of the board. Figure 6.3b shows the segmented image where the heartwood and sapwood regions are separated, while Figure 6.3c shows the segmented image when there is no such separation. The bark, and decay areas are identified in both the images.

Figure 6.4 shows the segmented image of the yellow poplar board shown in Figure 4.6a. Section 4.4 described how it was not possible to get good heartwood-sapwood separation using the multispectral clustering technique even with multiple iterations. These regions have been clearly identified in Figure 6.4. It is thus clear that this algorithm has the flexibility and accuracy needed to obtain different types of segmentation. Tables 6.3 and 6.4 summarize the parameters which were responsible for these results. Using either the r-g, or r-g histogram did not seem to have any noticeable effect on the segmentation. This is indicated in the first rows of Table 6.3, and 6.4.

Table 6.3: Parameters for Yellow Poplar with Heartwood-Sapwood Separation

Parameters	Values
R, G, B channels	R – B or R – G histogram
Percentage of original histogram used	40% – 45%
Threshold Th	60

Table 6.3: Parameters for Yellow Poplar without Heartwood-Sapwood Separation

Parameters	Values
R, G, B channels	R - B or R - G Histogram
Percentage of Original Histogram used	>60
Threshold Th	40 - 70

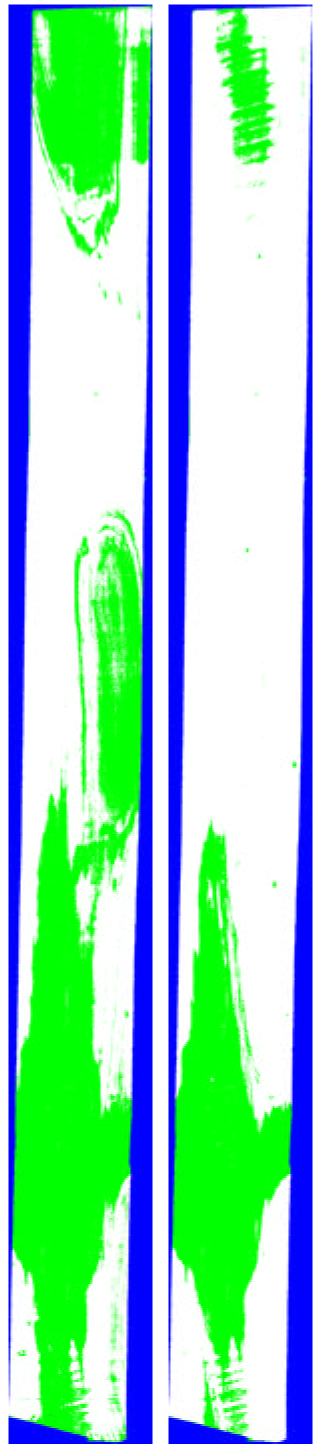

Figure 6.2: (a)Segmented image of yellow poplar board of Figure 4.4 (a), showing heartwood-sapwood separation, (b) no distinction between heartwood-sapwood

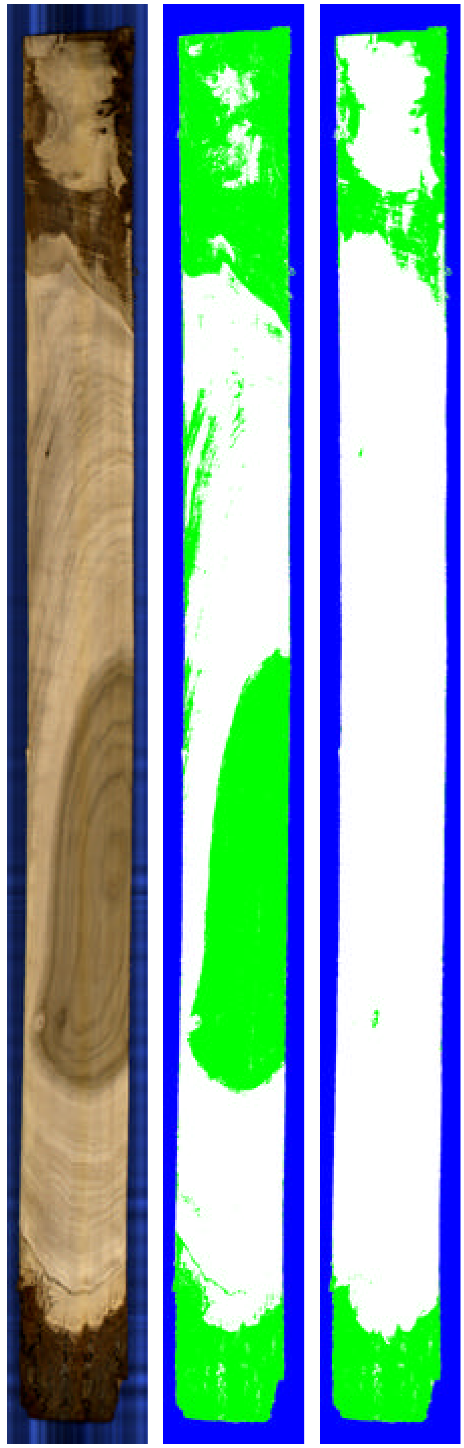

Figure 6.3: (a) Original image of a yellow poplar board y1a.dat, (b) Segmented image with heartwood-sapwood separation, (c) Segmented image without heartwood-sapwood separation

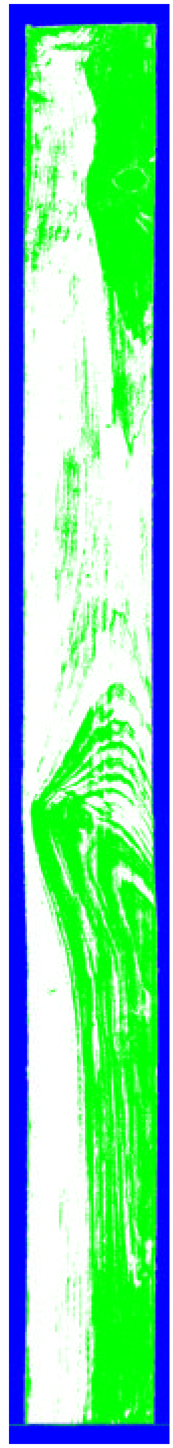

Figure 6.4: Segmented image of yellow poplar board in Figure 4.6 (a)

6.3 Comparison of the Model Based Approach with the B/W Segmentation Algorithm

A B/W segmentation technique is used in the existing lumber defect detection system [CON97] at the Brooks Forest Products Research Center at Virginia Polytechnic Institute and State University, Blacksburg. In this algorithm, a threshold is obtained from the b/w histogram of the image, that is used to segment the image. A connected component labeling is performed on the segmented image to obtain the different regions [XIAO]. Valley and inflection points are used as thresholds for the segmentation.

The b/w algorithm was tested with the same set of samples that were used to test the model based approach. However, due to the nature of the algorithm, it was not possible to execute it on all the samples, used for testing the model based approach. The results of applying the b/w segmentation algorithm and the salient differences in the results as compared to the model based approach are summarized in this section.

Figure 6.5 is the segmented image of the pine board shown in Figure 4.2a. The dark colored knots are being detected, but the entire region of blue stains (which was detected by the model based technique as shown in Figure 6.1a) are not detected. Further, a careful comparison with the original image will show that, in some of the knots the entire area of the knot is not being detected. This is because some of the knots in pine sometimes are brown in color rather than black, which makes them harder to separate on a b/w line.

The segmentation results of using the b/w segmentation on the yellow poplar board of Figure 6.3a, is shown in Figure 6.6. The entire heartwood region is not detected. In the model based approach, this region was detected very clearly. Figure 6.7 shows the segmented image of the board shown in Figure 4.6a. While Figure 6.4 identifies all the features including the heartwood regions, Figure 6.7 has only the prominent knot present in the original image. In yellow poplar boards, the most prominent feature of the b/w algorithm is that it fails to detect the presence of any heartwood regions.

The segmentation results of the oak boards using the b/w algorithm were almost identical to those obtained by the model based approach, the reason being that the oak boards had mostly dark colored defects.

In conclusion it can be stated that the dark colored defects are detected by the model based approach as well as the b/w algorithm. The reason for this is, that the average gray levels of the dark colored defects are much lower than the gray levels of the clearwood regions. Hence it is possible to separate them on the b/w line. However, color based defects like heartwood – sapwood regions on the same board, and blue stain, are not detected by the b/w segmentation process. The b/w segmentation algorithm is unable to identify color based defects simply because it is not possible to separate these defects using only the b/w information. At least one another channel is needed to provide the necessary color separation.

Figure 6.5: Segmented image of Pine board in Figure 4.2 (a), using b/w segmentation

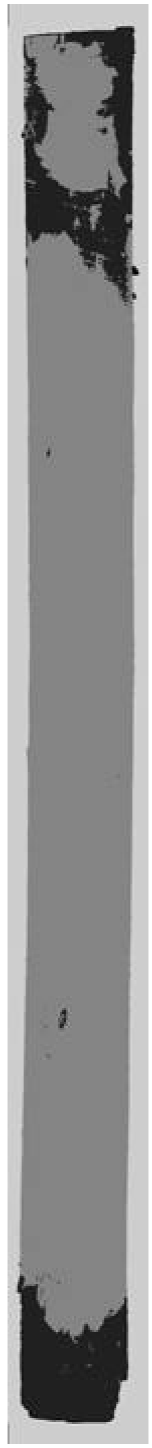

Figure 6.6: Segmented image of Yellow Poplar board in Figure 6.3 (a), using b/w segmentation

Figure 6.7: Segmented Image of Yellow Poplar board in Figure 4.6 (a) using b/w segmentation

6.4 Conclusions

The model based approach, models the histogram of the clearwood regions of a board using a gaussian distribution, and identifies the defects on the board by measuring the deviation of the actual histogram from the model. The results of applying the model based approach to wood images show that such an approach is indeed feasible and using the color information has some definite advantages over b/w segmentation, at the cost of increasing the computational power required to perform the calculations in realtime.

Color based defects are easily identified by the model based approach, while it was not possible to do so with either the b/w algorithm or the conventional clustering techniques, while maintaining reasonable processing speeds. Conventional techniques are found to be suitable for locating only the dark colored defects like knots, bark, wane, etc. The results for pine boards indicated that the b-g histogram is most suitable. Obtaining heartwood-sapwood separation in yellow poplar required the use of a smaller part of the original histogram for developing the model, while a larger part of the original histogram is to be used if the heartwood-sapwood separation is necessary.

Initial experiments have shown that this approach has a lot of potential and flexibility, and can be extended to suit specific needs. The algorithm can be adapted for use in realtime systems after extensive testing for determining the parameters that will give good results for each species of wood.