Automatic Color Sorting System for Hardwood Edge-Glued Panel Parts

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Abstract

The color sorting of edge-glued panel parts is becoming more important in the manufacture of hardwood products. Consumers, while admiring the natural appearance of hardwoods, do not like excessive color variation across product surfaces. Color uniformity is particularly important today because of the popularity of lightly stained products. Unfortunately, color sorting of edge-glued panel parts is labor intensive and it is very difficult to obtain consistent sorts given the fact that different people have different perceptions of color. This paper describes an automatic color and grain sorting system that has been developed at Virginia Tech working in cooperation with NOVA Technologies. In its current configuration, the system examines both faces of a panel part and then determines which face has the “best” color given specified color priorities defined by management. The resulting system has undergone extensive plant testing capable of sorting red oak panel parts into a number of part classes. The system is currently being marketed by Sutton Woodworking Machinery Company.

Introduction

Color sorting of edge-glued panel parts is an important manufacturing step where color uniformity has an impact on the value of the final products. Consumers, while admiring the natural appearance of hardwood, prefer color uniformity in hardwood products. This preference is particularly true today because of the popularity of products with natural finishes or very light stains. Unfortunately, color sorting of edge-glued panel parts is very labor intensive and it is very difficult for management to obtain consistent sorts across the spectrum of individuals who do the sorts. Clearly, different people have different perceptions about color uniformity in hardwood panel products.

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Because a distinct market preference for color uniformity exists, a number of researchers have examined the color characteristics of wood [Con85], [Ard91], [Yoo92], [Han94], [Pug95]. These researchers have studied color measurement systems and how they can be applied to better control the color sorting process in the manufacture of hardwood products. Unfortunately, these studies have not lead to commercially available systems that can meet the demands of the furniture and cabinet industry. The primary difficulties that must be overcome to create a robust color sorting system include controlling the stability of the illumination source, defining a measurement vector that can characterize colors, defining a statistical pattern recognition procedure that can accurately classify the measurement vectors, and achieving real-time operation.

This paper describes a color sorting system for red oak panel parts that was developed at Virginia Tech in cooperation with NOVA Technologies of Charlotte, North Carolina. This system has a throughput of approximately 61 cm (2 feet) per second. The parts can have random lengths. A spacing of no less than 11 cm (4 inches) between parts can be handled. This spacing is the amount of time it takes the system to process both faces of a part and determine its color class. A *best* face algorithm is employed to determine which of the two faces is the better for putting in a panel. This algorithm allows management to prioritize the colors most desired. The parts to be sorted can have mineral streak on one or both faces. If desired, the amount of mineral streak present can be used in making the best face determination. A large number of color classes can be handled. The system can also be employed on other wood species used in edge-glued panel parts.

Virginia Tech was responsible for the development of both the color sorting algorithms and the special purpose hardware. The special purpose hardware provided the means for real-time implementation. NOVA Technologies was responsible for the integration of the overall color sorting system onto a material handling system and the development of the computer user interface. The system is currently being marketed by Sutton Woodworking Machinery Company.

System Hardware Description

The system uses two Pulnix color line scan cameras to image the parts, one to image each part face. Each color camera is positioned so that its optical axis is perpendicular to the part face it is imaging. The materials handling system is tilted from true vertical by approximately 30 degrees. The parts run through the system on an edge driven by a belt that touches the edge. The optical axis is located 2.5 cm (1 inch) from this belt. Using this imaging geometry means the system never images a part edge but only a complete part face. The field of view of each camera is such that it not only images a part face but a white target as well. The white target is used to check for variations in lighting. The cameras run continuously.

Each color camera is connected to art especially designed color camera controller. This controller provides timing signals to the camera. These signals control the frame rate and integration time for collecting the imagery. This controller has three analog-to-digital converters, one for each color channel, that can be used to equalize the response of the red, green, and blue color channels. The controller also performs a rough shading correction to the color imagery as it is collected. The need for shading correction will be described in the section on system software.

The digital data coming out of each color camera controller is input to a special purpose image processing board, a board that was designed and built at Virginia Tech. This board is called the MOdular Reprogrammable Real-time Processing Hardware, or MORRPH [Dra95]. It performs most of the processing on the collected image data including shading correction on the incoming data, removing background pixels, computing the measurement vector used to do the sorting, and continuously monitor the output of the light sources. Since the cameras are running continuously, color image data is continually collected by the MORRPH. The MORRPH ignores this data until it senses a part is entering the field of view at which time it begins computing the measurement vector. The MORRPH stops computing the measurement vector when it senses the part is leaving the field of view. The MORRPH continuously monitors the lighting, even when a part is not in the field of view. If the lighting changes beyond a defined tolerance, it interrupts the image processing computer so that this computer can signal the light source power supply to increase or decrease the voltage supplied to the bulbs until the defined tolerance is regained. The MORRPH is the processing heart of the system. Without it, real-time processing would not be possible.

A key element in the design of the MORRPH is its reprogrammability. To achieve this reprogrammability, the MORRPH uses Xilinx field programmable gate arrays (FPGAs). This reprogrammability is used extensively on the color sorting system. The color sorting system has three modes of operation, real-time processing, system training, and system setup. When entering any of these three modes, the MORRPH is reprogrammed to perform the special task needed only for that mode. This reprogramming is necessary since all of the needed processing logic for the three modes of operation will not fit into the six available FPGAs at one given time. The specific details on the different modes of operation will be described in the System Software section.

After the MORRPH senses a part is leaving the field of view of the camera to which it is attached, it immediately sends the measurement vector of the part face its camera has imaged to the image processing computer. This transfer occurs over the ISA bus. The image processing computer performs the pattern recognition algorithm used to classify each part face. Once a color class has been assigned, this computer also does the best face analysis. This computer also performs all the processing needed to handle mineral streak. Note that mineral streak areas of a part face are removed from consideration when assigning a color class to a face.

The light sources used on the system employ tungsten halogen bulbs. These bulbs are used because the light intensity they emit does not vary much across bulb lifetime. Also, the color temperature of these bulbs do not vary much across a bulb lifetime. Switching power supplies are used to provide power to the bulbs. Each switching power supply has an input that allows the power supply output voltage to vary depending on the input signal. This input allows the MORRPH to adjust the power supply voltage when lighting intensity falls outside a specified tolerance.

System Software--The Analysis Algorithms

The color sorting of edge-glued panel parts can be a demanding application. There is typically a low frequency variation in color both along the length and across the width of a part face. There is also a high frequency variation caused by the grain pattern that occurs in wood. The key to sorting panel parts is defining a measurement vector that accurately gauges all these characteristics.

It is well believed by many, including the authors, that a three-dimensional (3-D) color histogram of a part's face contains all the needed color information. Unfortunately, a 3-D color histogram contains many tens of thousand components, many more than one would like to handle to achieve real-time processing. Hence, researchers and system developers have looked for ways to reduce the dimensionality of this color histogram. One approach has been to compute only the mean value of the histogram, i.e., computing an average red response for the part, the average green response, and the average blue response. Experiments conducted by the authors suggest that using the average response of each color channel does not adequately characterize the color of part faces. For example, a part with little or no grain pattern can have the same average color as a part with a prevalent grain pattern. In some applications purring two such parts together in the same panel would not meet the quality requirements for a product. Hence, this averaging approach will not work.

Another approach to the problem [Ard91] is to project the full 3-D color histogram onto each of the red, green and blue axes creating three one-dimensional histograms. Unfortunately, experiments conducted by the authors suggest that this reduction method does not preserve all of the necessary color information. The problem with this reduction method is that it is very sensitive to color intensity, i.e., it cannot separate a light red from a light brown or a dark red from a dark brown. Since such distinctions are needed in many color sorting applications, this approach will not work on a color sorter for edge-glued panel parts.

The techniques used on this color sorting system employ a color mapping algorithm, in particular a variant of [Hec82], to reduce the size of the measurement vector while preserving the necessary 3-D color information. Hence, a 64x64x64 3-D color histogram with over 260,000 elements is reduced to a measurement vector that is only 2000 elements long.

The pattern recognition method used is the k-nearest neighbor approach [Dud73]. The distance measure used is the l_1 norm. Using this algorithm, a part face will be assigned the color class to that which is closest on the k-nearest training samples. Note that if a part face is too far away from any of the training data, it will be placed in an *out* class. The distance threshold used to make this determination is a program input variable. Hence, in those applications where near perfect color sorts are required, this distance can be made small. If, on the other hand, a good deal of color variation is going to be allowed in the panels this distance can be large. For instances where parts are designated as an *out* class, plant operators can be used to manually determine a part classification.

Using the above color sorting methods requires that the lighting conditions remain reasonably uniform over time. Hence, their is a need for continually monitoring lighting variations so that these variations can be minimized. It also requires that the lighting and the sensitivity of the CCD imaging elements be perfectly uniform across the field of view. One can never physically achieve absolute uniformity, but an algorithm [Saw77] can be used to reduce the effects of inevitable variations. This algorithm is called the shading correction algorithm.

The software system provides for three modes of operation: 1) real-time operation, 2) system training, and 3) system setup. Real-time operation involves those function used in the actual sorting of parts and continually monitoring lighting variations. These functions have been described above. System training involves those functions involved in specifying different color classes. System training is based on showing the system a number of part faces that span the range of colors management allow in a given color class. Because the k-nearest neighbor pattern recognition method is used, a color class can have a wide color variation in it. Any number of classes can be used. However, the computational complexity goes up as the number of classes is increased. The previously mentioned throughput of the existing system is based on seven color classes. Finally, system setup involves specifying different parameters and tolerances that an operator can use to control and fine tune the operation of the system.

Summary

This paper has described a color sorting system for use in sorting edge-glued panel parts. Operational in-plant tests indicate that the system performs very well for color sorting red oak panel parts. The system can be trained for other wood species as well. The introduction of the system into the plant environment was well received by plant employees. The manual color sorting of panel parts is difficult and is a job many employees do not like to perform.

It is believed that the patent pending technology of this device will have a relatively broad range of application not only in the forest products industry but in other industries as well.

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