PARTS COLOR MATCHING SCANNER FOR EDGE GLUING —RESEARCH THAT WORKS

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ABSTRACT

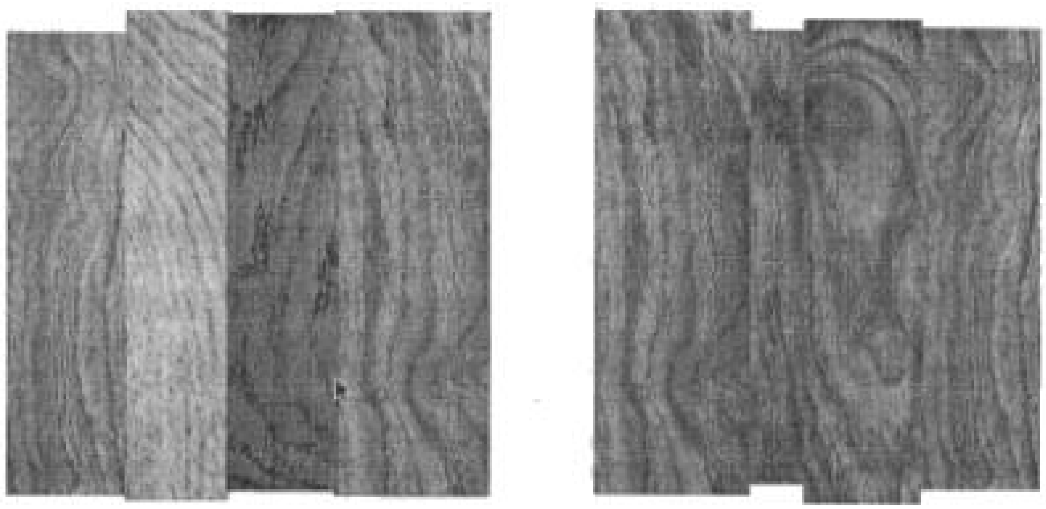
This paper presents an automatic color sorting system for hardwood edge-glued panel parts. The color sorting system simultaneously examines both faces of a panel part and then determines which face has the "best" color given specified color uniformity and priority defined by management. The real-time color sorting system hardware and color matching hardware is briefly described. An actual working system has undergone extensive plant testing capable of sorting red oak panel parts into a number of color classes at plant production speeds. The system has been developed by Virginia Tech in cooperation with NOVA Technologies and 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. Figure 1 illustrates how color uniformity can affect the look of the panel product that is produced. If performed manually, proper color sorting of edge-glued panel parts is very labor intensive and different people have different perceptions about color uniformity in hardwood panel products. Therefore, uniformity and consistency in edge-glued panel color is very difficult to achieve through manual color sorting.

Because a distinct market preference for color uniformity exists, a number of researchers have examined the color characteristics of wood (Conners et al., 1985; Brunner et al., 1990; Yoo et al., 1992; Haney et al., 1994; and Pugel et al., 1995). 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 led directly to commercially available systems that can meet the demands of the wood processing industry. In creating a color sorting system that will work in the industry, it must be (1) able to accurately and consistently separate parts into appropriate color classes, (2) able to keep up with the production requirements of the plant, and (3) easy to operate by plant production personnel.

The purpose of this paper is to describe a color sorting system for panel parts. The system was developed at Virginia Tech in cooperation with NOVA Technologies of Charlotte, North Carolina. The commercial system is



(a) (b)

Figure 1. Red oak panel color (brightness) variation for (a) improperly sorted panel parts and (b) properly sorted panel parts.

currently being marketed by Sutton Woodworking Machinery Company. This system has a throughput of approximately 61 cm. (2 feet) per second. The parts can have random lengths. 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. A large number of color classes can be handled. The system has been extensively tested on red oak parts but can also be employed on other wood species used in edge-glued panel parts.

SYSTEM HARDWARE DESCRIPTION

Figure 2 shows the system hardware used to perform real-time color sorting operations. The system uses two Pulnix color line scan cameras to image the parts, one to image each part face. Each color camera is connected to a specially designed color camera controller. The controllers control the speed of the cameras, equalize the color response of the cameras, and shade corrects for lighting variations in the cameras' field of view. The digital data coming out of each color camera controller is input to a special purpose image processing board that was designed and built at Virginia Tech. This board is called the MOdular Reprogrammable Real-time Processing Hardware, or MORRPH (Drayer et al., 1995). The MORRPH boards then provide color measurement information which is processed by the computer to sort parts into appropriate color classes. The computer also is able to control the illumination level within certain defined tolerances. Consistent illumination is critical to the performance of the color sorting system.

Each color camera is positioned so that its optical axis is perpendicular to the part face it is imaging (see Figure 3). 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 apart 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.

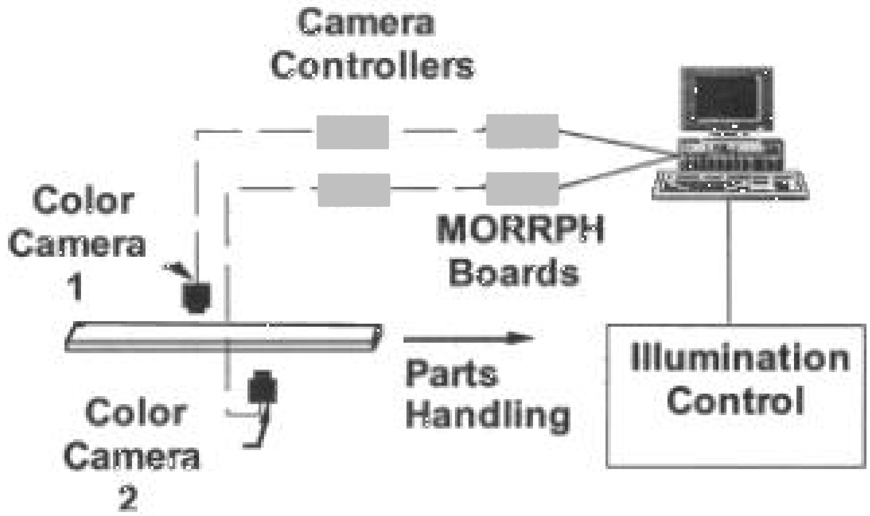


Figure 2. System hardware for the color sorting system.

The illumination system (see Figure 4) for the color sorting system must be as consistent and uniform as possible. The light sources used on the system employ tungsten halogen bulbs. These bulbs are used because the color temperature and light intensity does not vary much across 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 illumination control system to adjust the power supply voltage when lighting intensity falls outside a specified tolerance.

The MORRPH boards are the heart of the color sorting system. The MORRPHs perform most of the processing on the collected image data including shading correction on the incoming data, removing background pixels, computing the color measurement vector used to do the sorting, and continuously monitor the output of the light sources. The MORRPH ignores color camera data until it senses a part is entering the field of view at which time it begins computing color measurement data. The MORRPH stops computing color data 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

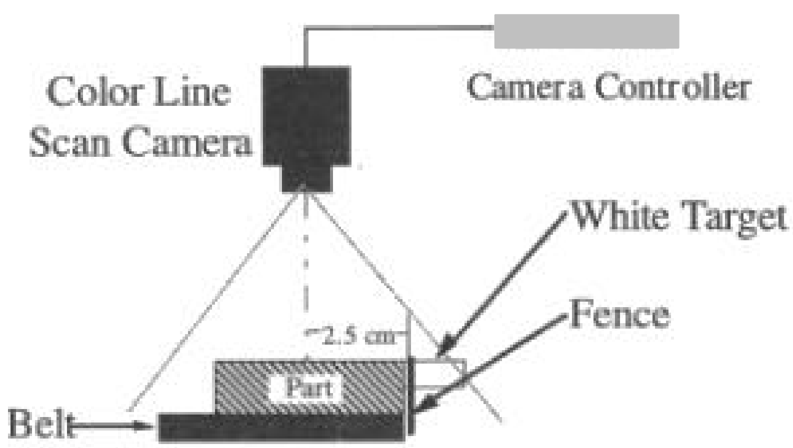


Figure 3. Color imaging geometry.

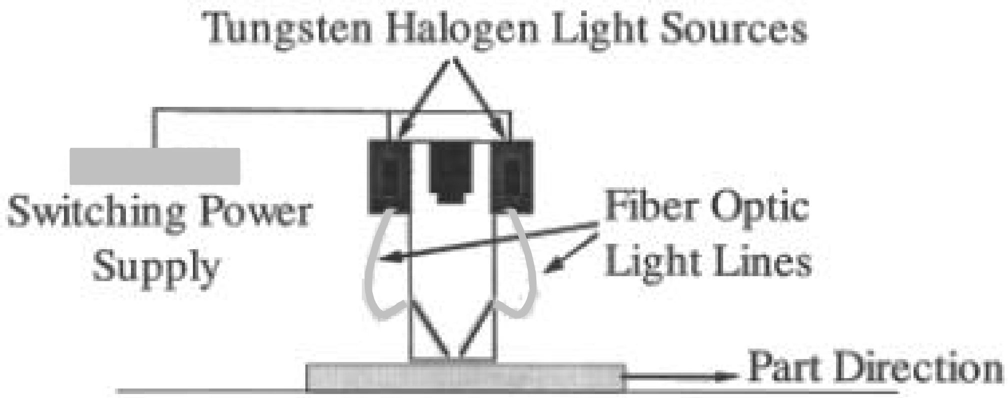


Figure 4. Illumination system.

that the computer can signal the light source power supply to increase or decrease the voltage supplied to the bulbs until the defined tolerance is regained.

After the MORRPH senses apart is leaving the field of view of the camera to which it is attached, it immediately sends the color measurement data 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 the color of each part face and perform a best face analysis.

SYSTEM SOFTWARE DESCRIPTION

The key to color sorting panel parts is defining a measurement vector that accurately gauges all the natural color variations in wood. A three-dimensional (3-D) color histogram is used as the measurement vector for the color characteristics of a part face. 3-D color histograms are needed to overcome color separation problems found with simpler methods of color measurement vectors (Yoo et al., 1992). Unfortunately, 3-D color histograms are very large (tens of thousand color components) and substantially increase the computational complexity needed. To reduce computational complexity, the techniques used on this color sorting system employ a color mapping algorithm (Heckbert, 1982) to reduce the size of the measurement vector while preserving the necessary 3-D color information. It was determined experimentally that a 3-D color histogram for red oak panel parts can be accurately represented using 2000 color elements. 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 for assigning apart face to a color class is the k-nearest neighbor approach (Duda and Hart, 1973). The k-nearest neighbor approach is illustrated in Table 1 for three different color classes: (1) Red, (2) Brown, and (3) White. Each color class is defined with 5 different training samples. A training sample is a reference part used to define the color within a class. The more training samples used to define a color class, the more adequate representation of the total variability in color that is allowed for parts that are acceptable within a panel. To classify a new part into one of the color classes using the k-nearest neighbor classifier first involves measuring the color difference of the part from the 15 training samples used to define the color classes. The difference measure used is the l_1 -norm. The l_1-norm is the sum of the absolute values of the difference between each element in the color measurement vector. Table 1 shows the difference of the new part from each of the training samples. By employing the k-nearest neighbor method with k=3, the 3-nearest neighbors are B2, B3, and R4. More samples from the Brown Class are closer to the part than any other class. Therefore, the part would be classified as Brown.

Table 1. Color difference (l_1-norm) of a part from training samples used to define color classes. The 3-nearest neighbors are underlined.

Training Samples	l_1-norm
Red Class:	
Sample R1	0.025
Sample R2	0.021
Sample R3	0.031
<u>Sample R4</u>	<u>0.017</u>
Sample R5	0.022
Brown Class	
Sample B1	0.018
<u>Sample B2</u>	<u>0.015</u>
<u>Sample B3</u>	<u>0.013</u>
Sample B4	0.020
Sample B5	0.021
White Class	
Sample W1	0.043
Sample W2	0.053
Sample W3	0.049
Sample W4	0.055
Sample W5	0.048

In general, 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. For example, a distance of 0.01 is specified as the distance threshold in which if the threshold is exceeded, then the part would be classified as *out*. In the example illustrated by Table 1, then, the part would be classified as *out* since no distance is less than 0.01. 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.

Once a color class has been assigned, the computer performs a best face analysis. If the color of each face is of equal priority, then the best face is assigned to that which is closest to the training samples. If the color of each face is of different priority, then the best face is assigned to that which is of the highest priority.

The color sorting software also performs all the processing needed to handle features that may be allowed in panel parts such as small knots and mineral streaks. While these features maybe allowable on a part face, they can alter or bias the color data collected such that the part can be mis-classified into a different color class. The software has provision to segment out these features, determine if they are within acceptable limits, and exclude feature regions from the color measurement vector.

Using the above color sorting methods requires that the lighting conditions remain reasonably uniform over time. Hence, there 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 a shading correction algorithm (Sawchuk, 1977) can be used to reduce the effects of inevitable variations.

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. Finally, system setup involves specifying different parameters and tolerances that an operator can use to control and fine tune the operation of the system.

IN PLANT TESTING

Figure 5 shows the color sorting system in operation in the plant. Parts are fed into the system from right to left at speeds of 61 cm./s (2 ft./s). The system inspects both faces of a part, sorts it into a color class and uses a printing device to code the part for it color class and best face. As an alternative to printing a code, the system can drive an automatic part sorting system (not shown here). In plant testing has shown the system to be very accurate in sorting red-oak panel parts and generating uniform color matched panels. The system has demonstrated reasonable service maintenance requirements and was well received by plant personnel.

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 system is now commercially available and is currently being marketed by Sutton Woodworking Machinery Company.

REFERENCES

Conners, R., C. McMillin, and C. Ng. 1985. The utility of color information in the location and identification of defects in surfaced hardwood lumber. Proceedings of the First International Conference on Scanning Technology in Sawmilling, San Francisco, California, October 10-11.

Brunner, C. C., B. Shaw, D. A. Butler, and J. W. Funck. 1990. Using color in machine vision systems for wood processing. Wood and Fiber Science 22(4);413-428.

Drayer, T., W. King IV, J. Tront, and R. Conners. 1995. A modular and reprogrammable real-time processing hardware, MORRPH. Proceedings of the IEEE Symposium on FPGAs for Custom Computing Machines, Napa Valley, California, April 19-21.

Duda, R. and P. Hart. 1973. Pattern Classification and Scene Analysis. John Wiley and Sons, New York.

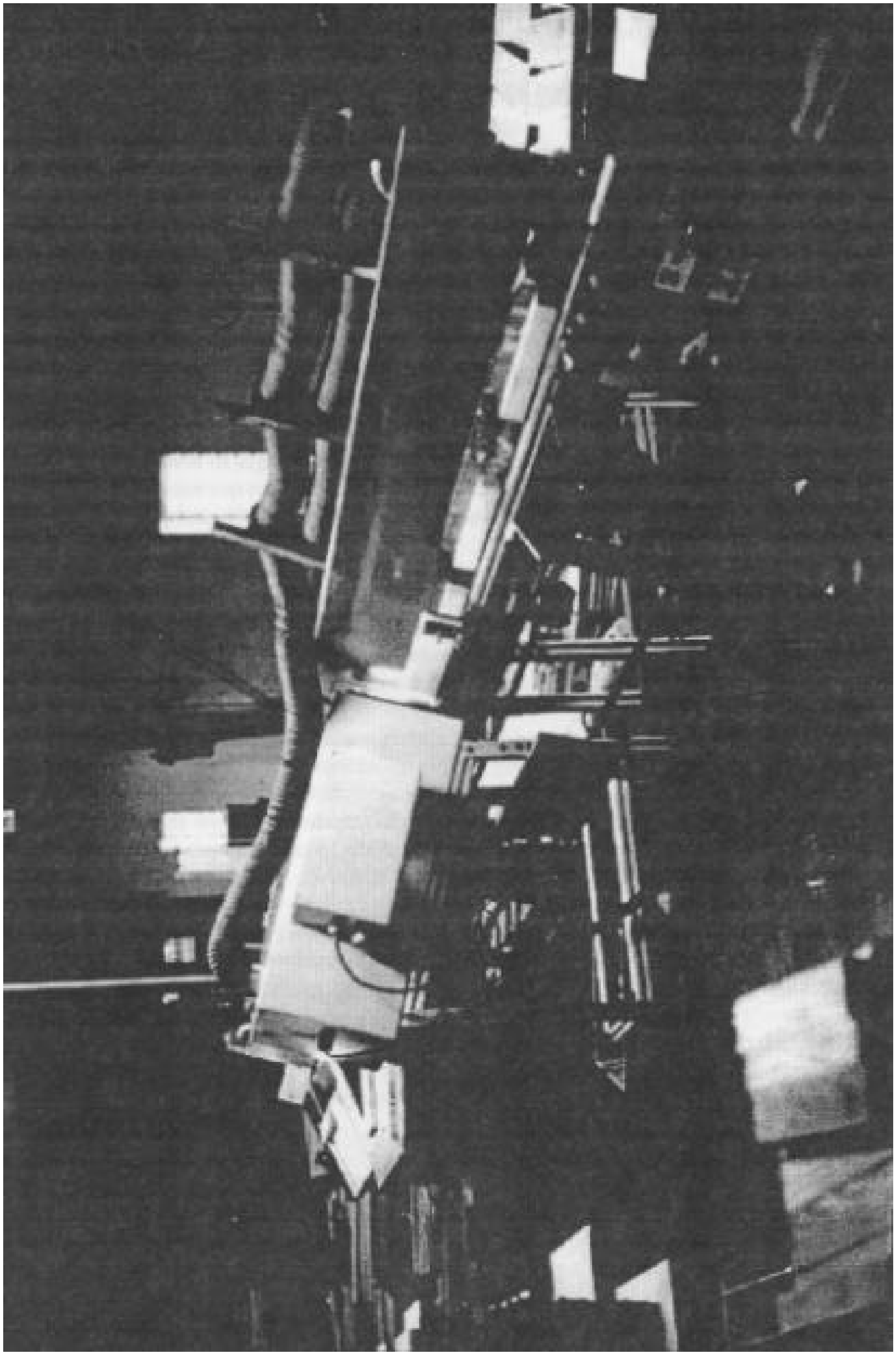


Figure 5. In-plant operation of the color sorting system.

Haney, L., C. Precetti, H. Gibson, G. Krutz, and D. Cassens. 1994. Color matching of wood with a real-time machine vision system. American Society of Agricultural Engineers, Atlanta, Georgia, December 13-16.

Heckbert, P. 1982. Color image quantitization for frame buffer display. Computer Graphics, Vol. 16, No. 3, pp. 297-307.

Pugel, A. D., J. E. Phelps, and D. D. Stokke. 1995. Improving visual color sorting of dimension stock. Forest Products Journal, Vol. 45 No. 11/12, pp. 57-60.

Sawchuk, A. 1977. Real-time correction of intensity nonlinearities in imaging system. IEEE Transactions on Computers, Vol. 26, No. 1, pp. 34-39.

Yoo, S., C. Precetti, and D. Cassens. 1992. Color machine vision used to establish color grading standards for hardwood dimension parts. American Society of Agricultural Engineers, Nashville, TN, December 15-18.

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