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## 学位論文の内容の要旨

A large proportion of Sugi forest is approaching economic maturity aging around 50 years old. The green under Sugi forest is gradually degrading due to Sugi crown shadow so that the earth and sands are being washed away according to an investigation carried by Sanyiin Newspaper. The wood industry is important for the economy of many small communities in the rural areas and to maintain and improve the recycled ecology system. However, many companies prefer to import wood resource from foreign countries because the labor cost is too high to develop domestic wood resource in Japan. Therefore, how to increase the competitive ability of domestic wood species is a hot research topic in Japan. Various automatic technologies, such as automatic wood lumber grading technology and automatic wood machining, are focused to reduce the product cost and to increase the productivity in the wood industry. Ultrasound, Microwave, X-ray, cutting force, thermograph, optical method were proposed to automate the wood utilization process. Among all the above mentioned automatic technologies, machine vision is very potential in wood utilization.

Most research has gone into optical sensing methods, including cameras and spectrometers, which measure the intensity and color reflected. These devices detect surface features and can be readily automated, but they will miss knots that have the color identical to clear wood. They can also be confused by variations between species and by the roughness and moistness of the wood. Generally, machine vision system is question-oriented and wood specie-oriented in wood industry. For example, in the case of Sugi, the holes are difficult to classify from the other defects with traditional color CCD-camera because holes have color and shape features identical to sound knots; splits are difficult to detect because they have color and shape features identical to the growth ring in the captured image. Furthermore, to identify the splits, what is needed is a high resolution image, which will increase the storing data and computing time of the machine vision system. Also the appearance of wood varies greatly and there are no two boards or defects that have the same properties of color or texture. So there are still some problems and it is necessary to develop the new detecting system for automatic Sugi utilization. All literatures about application of machine vision technology in wood utilization found at present are centered on the problems that occurred when sawing lumber from log. No work has been reported on the application of machine vision technology for the control of wood machining after sawing lumber.

The split and the hole are two kinds of common defects on Sugi (Cryptomeria japonica D.Don). They have a common feature, that is, they are associated with surface irregularities. In the first chapter, I developed a laser scanning system to detect the splits and the holes according to their thickness that is exactly correlated spatially with the profile information. The displacements measured by the laser sensor were converted to the pixel values to generate the displacement profile image. Both the splits and the holes manifested well in the image. A dedicated image processing program written in Visual Basic has been developed. The defects regions were located by the image processing accurately. To identify the defects, 8 recognition rules based on the four features has been utilized. Furthermore, a method based on the pixel model was proposed to compute the area of the defect. The results indicated that the defects could be identified correctly and the areas could be computed by the pixels model accurately.

The knowledge of the sound and dead knot on the surface is important for application of Sugi. The research reported in chapter two explored a sound and dead knot detecting color vision system. This system can conceptually be divided into three components: a CCD-camera scanning system, an image segmenting module, and a rule-based defect identifying module. The results showed that the potential defect regions could be located by the Otsu's threshold algorithm in conjunction with T-test analysis. The accuracies of locating sound knots and dead knots are 92.6% and 97.1%, respectively. The rule based approach was used to identify sound and dead knots and the identifying accuracies of sound knots and dead knots are 92.0% and 94.1%, respectively. The total detecting accuracy of the system was 87.6%. The results indicated that the rule-based color vision system was an efficient way to detect the surface defects of the sound knot and the dead knot associated with the color information on Sugi.

Under fixed cutting conditions, the surface finish roughness is correlated to the grain angle. However, how to determine the grain angle automatically and accurately is still a problem in the on-line control system of the router. It is therefore necessary to develop a new technology in order to determine the grain angle accurately and automatically. In the third chapter, a laser light scattering pattern was used to determine accurately and effectively the grain angle on-line. The light scattering pattern image was a quasi-ellipse caused by the grain direction and tracheid effects. A new modified Hough transform ellipse analysis technology was adopted to determine the ellipse parameters that could be used to determine the grain angle. The results indicated that the measured grain angle by the method proposed here was accurate and effective. The measured grain angle coincided with the real grain angle. There was an insignificant difference between the measured grain angle of Japanese beech (Fagus crenata blume) and that of Sugi (Cryptomeria japonica D.Don) under two machining conditions of planned and sawn finishes. However, the measured grain angle of Sugi was better than that of Japanese beech under planned finish; the measured grain angle of Japanese beech was better than that of Sugi under sawn finish; the measured grain angle under planned condition was better than that under sawn condition for both Sugi and Japanese beech.

Under fixed cutting conditions, the surface finish roughness is correlated to the grain angle. The cutting force and acoustic emission (AE) are used to evaluate the grain angle that is used to control the feed rate to achieve the maximum cutting efficiency and finished surface quality in the on-line control system of the router. However, the cutting force is affected by its additional inertia and the difference between the latewood and early wood. Besides, the linear relationship between AE count rate and surface roughness under every discrete grain angle is complex and how to determine the grain angle automatically and accurately is still a problem. It is therefore necessary to develop a new technology in order to determine the grain angle accurately and automatically in the control system of the router. In the fourth chapter, a laser light scattering pattern was used to determine the grain angle directly. The light scattering pattern image was a quasi-ellipse caused by the grain direction and tracheid effects. A modified Hough transform ellipse analysis technology was adopted to determine the ellipse parameters, which were used to determine the grain angle. The results indicated that the measured grain angle by the method proposed here was accurate and effective. Then an improved automatic control of wood routing operation using the measured grain angle was developed. The experimental results are expected to improve the routing efficiency and the finished surface quality.

Some wood species have received little attention in terms of usage because of their perceived poor physical and mechanical properties. The use of an engineered wood is a solution to the variation in the properties of conventional wood. The use of Oriented Strands Board (OSB) is gaining increasing popularity in Europe, North America and Asia. OSB is manufactured from species with low mechanical properties. Besides, OSB comprises large size element which are wood strand, and its mechanical properties depend on the fiber orientation of the strands. The modulus of rupture (MOR) which is the key to the strength of OSB in bending depends on the fiber orientation. In order to improve the quality of OSB products, it is essential to optimize the flake alignments of the wood strands. The objective of the fifth chapter is to develop an automatic method to determine fiber orientation in oriented strand board (OSB) with the ultimate aim of optimizing the fiber orientation and quality of the manufactured product. A line detector based on small eigenvalue in conjunction with Canny edge detector was adopted to simulate the fiber strands. Then ellipse fitting analysis using the modified Hough transform technology and/or the least square line fitting analysis were used to determine the fiber orientation for all line or ellipse connectedness labeling, which expresses the fiber strands. The fiber orientation measured automatically was compared to that measured manually. It was observed that two fiber orientations measured manually and automatically were very close to each other. The results indicated that the method developed in this study when used to determine fiber orientation of the face surface in OSB was effective. However, the method developed in this study was not effective for the under surface because small strands tend to fall when the face and middle layer were distributed, on the edge formation of fiber strands.

## 論 文 審 査 の 結 果 の 要 旨

自動グレーディングマシン、自動切削加工機械を始めとする様々な自動化技術が導入され、木材産業の製造経費削減、生産性の向上が図られている。超音波、マイクロ波、X線等を利用する方法が提案され、木材加工の自動化が可能となっている。これらの方法の中でも特に、マシンビジョンシステムは有効な方法である。カメラを始めとする光学的計測器を用いて加工面の色とその強度を測定する研究が多く行われている。この方法で、加工面状態を自動的にそして容易に識別できるが、正常部と同じ色の節を識別することは困難である。更に、樹種、加工面粗さ、含水率の違いによっても識別が困難となる。マシンビジョンシステムは、普遍性がない計測システムであり、識別項目、樹種等を限定した計測システムである。

スギ材の場合、旧来の CCD-カメラでは、穴と生節とを区別することは、両者ともに形も色も類似しているので困難である。割れと年輪は共に、類似し形状と色を持つので、両者を識別する

ことは困難である。更に裂け目を識別するには画像の解像度を高める必要がある。このことは、多量のデータ量と、解析に長時間を必要とすることを意味する。また、色や形状で同じ特質、欠陥を持つスギ材は2本とない。従って、スギ材に対する識別システムを提案する必要がある。文献によると、従来のマシンビジョンシステムを利用した欠陥識別研究は、1 次加工の製材にのみ限定し、2次加工については未だ着手されていない。

スギ材の穴と割れは、よくある欠点で、両者ともに形状は類似し、共に材面の凹凸に関連する。第一章では、穴と割れ部では厚みが薄いという特性をレーザセンサで測定し,スギ材表面の穴と割れの識別方法を検討した。センサーからの距離信号を画像ピクセル値に変えて、変位のプロフィール画像を生成した。穴と割れ部では、レーザセンサから木材表面までの距離が正常部より長く,レーザセンサで測定した距離データが大きい。距離データを基にした距離画像で示された穴と割れ部は実物によく対応する。欠陥を検出するためのアルゴリズムを考案した。考案したアルゴリズムにより、材面上の割れと穴を正しく検出できた。欠陥を識別するため、 4 つの特徴に基づく8 つの認識の規則を利用した。考案した識別ルールにより、割れ、穴を正しく識別できた。提案したシステムで複数の実験材を検出・識別できる確率は 97.4%である。また、 ピクセルモデルに基づいて欠陥位置を同定し、その面積を計算する方法を検討した。欠陥位置を同定するだけでなく、計算値と実測地は近似することができた。

第二章では、材面上の生節と死節を検出・識別できるカラービジョンシステムを提案した。このシステムは、三つのモジュールで構成されている: すなわち、CCD カメラによる撮像部、生節と死節を検出する画像処理部、生節と死節を識別する認識部である。T-テスト分析と大津による自動閾値アルゴリズムによって欠陥部の検出ができる。生節と死節の検出率はそれぞれ 92.6% 及び 97.1% であった。生節と死節を識別するモジュールによる生節と死節の識別率はそれぞれ 92.0% 及び 94.1% であった。 システム全体の精度は 87.6% である。提案したカラービジョンシステムは、スギ材面上の色彩情報から生節と死節を検出・識別することができる。

第三章では、 レーザー光線を利用して、被削材の繊維傾斜角をオンラインで正確に測定する方法を検討した。切削条件を同一にすると、加工面の粗さは、被削材の繊維傾斜角の影響を受ける。ルーター加工のオンライン制御において、繊維傾斜角を自動認識する適切な方法は、未だ見当たらない。従って、被削材の繊維角度を高精度でそして自動的に認識する新技術を開発することは必要である。被削材面にレーザー光線を照射した場合、繊維走行及び仮導管の影響を受けて、その反射光のパターンイメージは楕円形状を示す。MTH(Modified Hough Transform)方法を利用して、分散パターンイメージを分析し、楕円パラメータを決めた。楕円パラメータを通して繊維傾斜角を計測できる。提案した方法により求めた繊維傾斜角は実物の繊維傾斜角と一致した。広葉樹のブナ材(Fagus crenata blume)と針葉樹のスギ材(Cryptomeria japonica D)を用いて、開発したシステムの精度を検討した。プレナー加工と鋸挽加工を施した材面を検討した。プレナー加工の方が鋸挽加工より繊維傾斜角の読み取り精度が高い。プレナー加工材面では、スギ材の方がブナ材より精度が高いが、鋸挽加工材面では逆の結果となった。

第四章では、第三章の MTH 楕円分析技術によって計測した繊維傾斜角を監視モジュールとし

て、CNC 機械の自動制御切削システムを開発した。加工効率および切削面の粗さを改善できることが分かった。

第五章では自動的に OSB（Oriented Strand Board）面のストランド配向を監視・評価するマシンビジョンシステムを開発した。OSB は低強度の樹種から製造される。OSB の機械特性（MOE と MOR）はストランドの配向に左右される。OSB の 製品品質とその強度特性を増大させるには、適切なストランドの配向を求める必要がある。ビデオカメラにより、OSB 面のストランド配列の画像をパソコンに読み込み、ストランド配列を解析するアルゴリズムを考案した。Canny が考案した方法と Small Eigenvalue 法を組み合わせて、ストランドの両エッジを検出した後、一次回帰、あるいは MTH 楕円分析法を利用して、OSB 面のストランド配列方向を測定することができた。自動測定したストランド配向と手動で測定したストランド配向とは一致した。提案したマシンビジョンシステムは OSB 表面のストランド配列を高精度で読み取るが、OSB 裏面のストランド配列に対しては、検討の必要がある。この結果を実用すると、OS B 生産現場でストランドの適切な配列をオンラインでコントロールできる。