Grading Pine Seedlings with Machine Vision[1]

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Kranzler, Glenn A.; Rigney, Michael P. 1987. Grading Pine Seedlings with Machine Vision. In: Landis, T.D., technical coordinator. Proceedings, Intermountain Forest Nursery Association; 1987 August 10-14; Oklahoma City, OK. General Technical Report RM-151. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 100-104. Available at: http://www.fcnanet.org/proceedings/1987/kranzler.pdf

A machine vision technique for grading pine seedlings at production line rates was developed. Singulated seedlings were inspected on a moving belt. Classification as acceptable or cull was based on minimum criteria for stem diameter, shoot height, and projected root area. Individual seedlings were graded in approximately 0.25 seconds. Average classification error rate was 5.7 percent.

INTRODUCTION

Hundreds of millions of tree seedlings are grown each year in commercial, federal, and state nurseries. At harvest, these bare-root seedlings are graded to remove inferior stock and improve productive potential.

Grading is typically performed manually by grasping individual seedlings from a conveyor belt and applying a number of visual quality criteria. Manual inspection tends to be labor-intensive and costly.
Seedling classification is subjective and susceptible to human error. Grading into more than two classes is not feasible. Valuable production data such as seedling count and classification statistics are difficult to obtain. Disadvantages of manual grading have spurred growing interest in automated alternatives.

A seedling grading machine was commercially tested by Lawyer (1981). This mechanical system measured stem diameter, shoot height, count, and classified seedlings into three grades. However, productivity was only 1000 seedlings per hour, a rate approximately three times slower than manual grading.

A digital electronic system for measuring and recording seedling diameter, height, root area index (silhouette area), and sample number was described by Buckley et al. (1978). Potentiometric transducers and a linear 1024 element photodetector were employed. Although measurements were accurate, the apparatus was much too slow to grade large quantities of seedlings at production line rates.

Digital image processing has been successfully implemented in many industrial and agricultural inspection processes. It has demonstrated high accuracy and throughput and has permitted 100% inspection in applications which were previously not feasible (Kranzler 1985). Machine vision inspection would appear to be an ideal tool for addressing the tree seedling grading problem.

OBJECTIVES

This study was initiated to investigate the ability of machine vision to grade bare-root pine seedlings under nursery roduction conditions. Specific objectives included:

1. Develop and implement a machine vision algorithm for obtaining grade classification measurements at production line rates,
2. Evaluate performance in terms of measurement speed, precision, and accuracy of classification.

METHODS AND MATERIALS

Assumptions

Several assumptions were adopted concerning the environment in which the grading would be performed. First, seedlings would be singulated, permitting only one seedling to appear within the camera field-of-view at a given time. Second, shoot orientation and lateral position would be loosely constrained. Finally, it was assumed that a black conveyor belt would be used to transport seedlings beneath the cameras.

Equipment

Equipment included a conveyor belt, machine vision computer, cameras, lenses, and lights. To simulate production grading operations, a variable-speed belt conveyor was constructed to transport seedlings for inspection. The black belt shiny surface was dulled by sanding to minimize specular reflection.

An International Robomation/Intelligence (IRI) D256 machine vision development system was used. Images were digitized into an array of 256 X 240 picture elements (pixels) with 256 grey levels. A high-speed hardware coprocessor performed computationally intensive operations such as image filtering and edge

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1 Paper presented at the Intermountain Forest Nursery Association Meeting. [Oklahoma City, OK, Augus; 10-14, 1987]

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detection, runlength-encoding, and moments calculations. Software was developed in the C programming language.

Two Hitachi KP-120U solid-state black-and-white television cameras were employed for image acquisition. Camera 1 was used to obtain a close-up image of the seedling root collar zone. A field-of-view (FOV) approximately 12.8 cm (5 in) square provided a 0.5 mm (0.20 in) pixel resolution (fig. l). Camera 2, with a FOV approximately 51 cm (20 in) square and resolution of 2.2 mm, acquired an image of the entire seedling.

Illumination was provided by fluorescent room lighting and strobed xenon flash. Relatively low-level room lighting was adequate for detection of the moving seedlings in the FOV of camera 2. When a seedling was detected, synchronized strobe lamps were triggered to obtain a "frozen" image with each camera.

Grading Scheme

Morphological characteristics are used in the grading of most nursery stock. These characteristics include stem diameter at the root collar, shoot height and weight, root weight or volume, root fibrosity, foliage color, presence of terminal buds, root/shoot volume ratio, and ratio of top height to stem diameter (sturdiness ratio) (Forward 1982, May et al. 1982). Stem diameter, shoot height, and root volume are generally given priority and were adopted as the grading criteria for this study. Of these three, stem diameter is typically considered most important.

To meet image processing time constraints, we decided to emphasize stem diameter measurement accuracy and obtain close approximations of shoot height and of root volume as indicated by projected root area (root area index). A classification scheme based on minimum acceptable values of these three parameters (May et al. 1982) is given in table 1. Seedlings were graded into two classes; acceptable and cull.

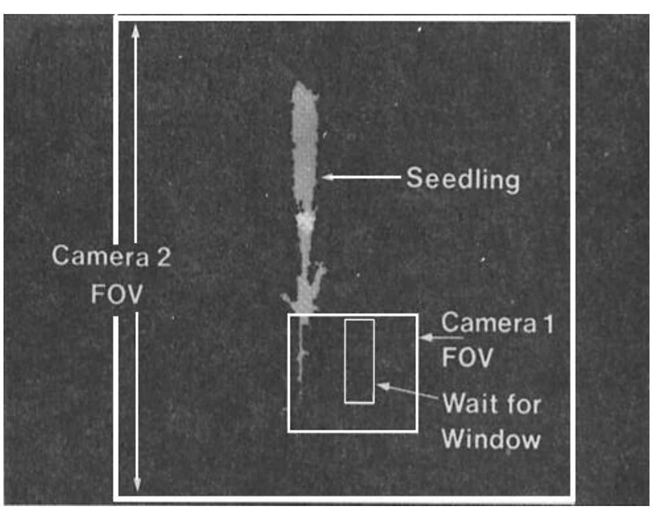

Figure 1. Field-of-view for cameras 1 and 2. Note Waitfor window.

ALGORITHM

The gradingg algorithm is composed of several separate tasks. These operations are: calibration, seedling detection, measurement of orientation, location of the root collar, diameter measurement, root area measurement, shoot height measurement, grade classification, and recording of seedling statistics. A detailed description of the algorithm is presented by Rigney (1986).

Accuracy of diameter measurement and the probability of the root collar appearingg within the camera view influenced the choice of FOV for camera 1. Because the position of the root collar cannot be closely constrained, a relatively wide FOV is necessary. We decided to make the FOV as large as possible, while maintaining a measurement precision of at least 0.5 mm (0.20 in).

Seedling Detection

A program loop is entered in which successive images are acquired with camera 2 (wide FOV). Each image is multiplied by a template which defines a window in which seedling detection will trigger subsequent operations (Waitfor window, fig. 1). After grey-level thresholding, the area occupied inside the window is calculated. When the area exceeds a programmed number of pixels, the presence of a seedling is assumed, and an image is automatically acquired from each camera with strobe illumination.

Seedling Orientation

The image from camera 2 is next processed to determine shoot orientation on the conveyor belt. Coprocessor moments calculations provide the angle between the seedling major axis and a line perpendicular to the direction of travel. This angle is used as a correction factor in subsequent calculations of stem diameter and shoot height. Because measurement error becomes excessive at large angles, seedlings are not graded if the orientation angle is greater than thirty degrees.

Location of the Root Collar

Accurate location of the root collar is crucial for subsequent measurement of stem diameter, shoot height, and root area index. The image from camera 1 is thresholded, yielding a binary image showing the stem, roots, branches, and needles (fig. 2). This image is then runlength-encoded and processed line-by-line. The runlength code is an array of column numbers of the transitions from black,-to-white and white-to-black on each line of a binary image.

If the number of transitions on a line is less than or equal to a selected variable (initially two), that line is a candidate for the root collar location. Additionally, from a priori knowledge about stem diameters, the maximum distance between paired transitions must be between 5 and 18 pixels (2.5 to 9 mm) for a line to be a root collar candidate. The root collar is located at the average of

Table 1.--Grading scheme for loblolly pine seedlings

Stem Diameter (mm)	Root Area Index (pixels)	Shoot Height (cm)	Grade
3.0 - 8.0	> 200	> 16	Acceptable
< 3.0 or > 8.0	any	any	cull
3.0 - 8.0	< 200 or	< 16	cull

the largest set of adjacent candidate lines, if that set contains at least six members. If the collar is not found using the initial value for number of transitions, the procedure is repeated for values of four and then six. When the root collar (line number is found (fig. 3), it is stored along with the collar midpoint (column number) and number of adjacent candidate lines about the collar line.

If the root collar is still not located, the procedure is repeated after thresholding at a higher grey level. At this increased threshold, only the stem, major branches, and roots are visible (fig. 3). The use of two grey-level thresholds for collar location improves overall algorithm performance. A low threshold limits the number of candidate root collar lines for typical seedlings, reducing image processing time. A high threshold may be required to minimize the effect of needles, branches, and roots which are sometimes present in the root collar zone (figs. 2 & 3).

Measurement of Stem Diameter

Diameter measurement is performed inside a hardware window implemented about the root collar in the image from camera 1. Window size is defined by the set of candidate collar lines found in the collar location subroutine. The windowed zone is processed with an edge detector favoring vertical edges and thresholded, resulting in a binary image of the strongest stem edges (fig. 4).

The image is then runlength-encoded. For lines which contain four or more transitions (two transitions occur at each stem edge), the two consecutive odd transitions which bracket the collar midpoint are found. If these transitions are within ten pixels (5 mm, horizontally) of the collar midpoint, the distance between the transitions is assumed to be the stem diameter on that line. When the processing of candidate lines is complete, and at least one line has provided a distance measure, the stem diameter is calculated as the average of the diameters on candidate lines.

Measurement of Root Area Index

The image from camera 2 is initially windowed from the root collar to the bottom of the image and processed with a specialized edge detector. The image is then thresholded, yielding a binary image with a maximum number of root pixels and minimum background noise (fig. 5). The number of pixels inside the hardware window is defined as the root area index.

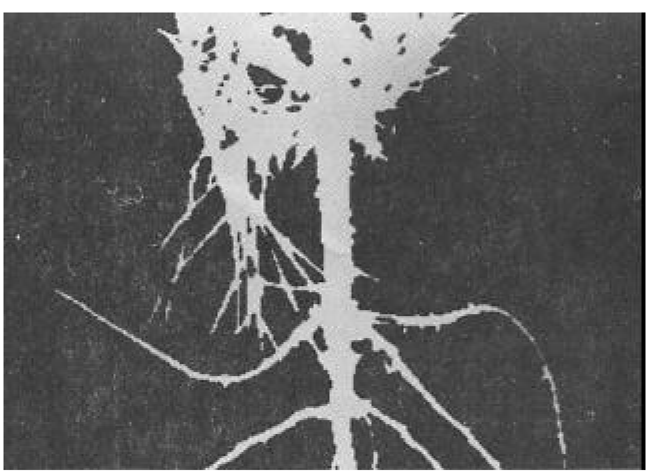

Figure 2. Camera 1 close-up image details root collar region.

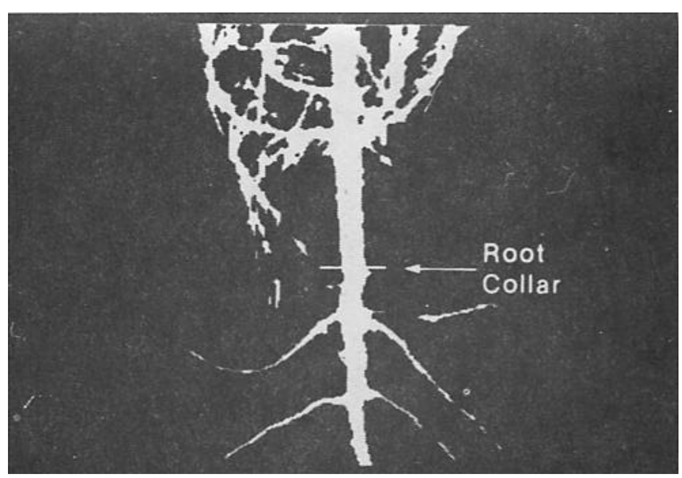

Figure 3. Algorithm locates root collar.

Measurement of Shoot Height

The image from camera 2 is thresholded and runlength-encoded. Starting at the top of the image, each line is checked to determine if the maximum distance between paired transitions exceeds five pixels. The seedling top is assumed to be located when four consecutive lines meet this criterion. Shoot height is defined as the distance between the seedling top and root collar.

Main Program

Inside the main program loop, values returned by subroutines are tested to control program flow. If all grading subroutines are successful in their respective tasks, a series of if-else statements is used to assign a grade to the seedling. Whenever a subroutine fails its task, the seedling is recorded as not gradable. Finally, measured seedling parameters, grade, and count, are written to a statistics file.

Calibration

Proper calibration of threshold values and scale factors is essential for optimum algorithm performance. The calibration subroutine initializes sixteen parameters with default values. The user is then provided an opportunity to alter the default values interactively. A wooden dowel of known diameter and length is used to calibrate scale factors. Grey level thresholds are set using a representative seedling.

EVALUATION

A reference set of 100 loblolly pine (Pinus tacda L.) seedlings was manually measured and graded. Stem diameters ranged from 2.3 to 6.0 mm. Performance of the machine vision system was then evaluated by grading each of the seedlings twenty times. Shoot orientation was limited to plus-or-minus thirty degrees from vertical,

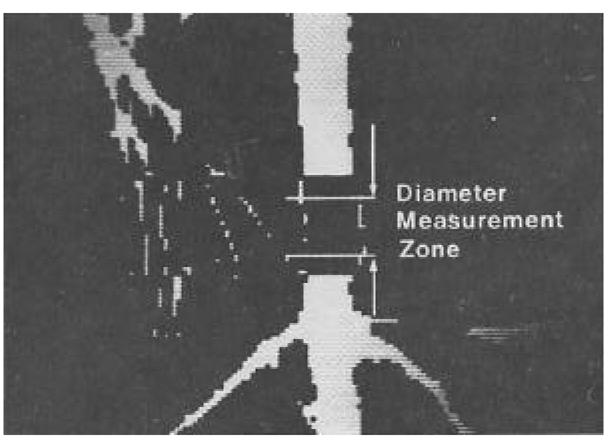

Figure 4. Image is processed to define stem edges in root collar zone.

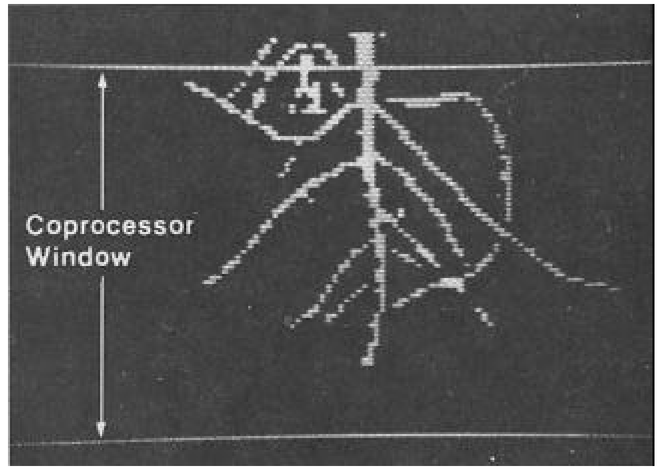

Figure 5. Image is processed to highlight seedling roots.

and root collar location was constrained to the FOV of camera 1.

Time required for the algorithm to grade a seedling averaged approximately 0.25 seconds. Strobe illumination provided reliable image capture at conveyor speeds of up to 1.0 m/s (3.28 ft/s), corresponding to a grading rate exceeding three seedlings per second. To facilitate manual placement of the seedlings on the grading belt, tests were conducted at a velocity of 0.46 m/s (1.5 ft/s).

The classification error rate averaged 5.7 percent for the set of 100 seedlings (table 2). This is very acceptable performance, bettering manual grading operations which have an average misclassification rate of seven to ten percent (Boeckman, 1986). As expected, a large part of the classification error was attributable to seedlings which straddled the borderline between acceptable and cull with respect to diameter and root area. Such seedlings comprised 17 percent of the grading test set and had an average misclassification rate of 23.2 percent. The remaining 83 seedlings had an average misclassification rate of 2.2 percent (table 2). Since there is no significant penalty for misclassification of borderline seedlings, 2.2 percent misclassification may be a better indicator of algorithm performance.

Measurement precision was excellent, considering the spatial resolutions of cameras 1 and 2, which were 0.5 mm/pixel and 2.2 mm/pixel respectively. The coefficient of variation of 20 measurement repetitions averaged 7.6, 12.2, and 4.1 percent fof'stem diameter, root area, and shoot height, respectively.

The few seedlings which showed the largest deviations in measured parameters were characterized either by needles extending down past the root collar, or by roots bent upward past the root collar, or both. The subroutine which located the root collar performed inconsistently on such seedlings. A few such seedlings could not be graded.

Table 2.--Percent misclassification of 100 seedlings, 20 reps

Manual Grade	Acceptable		Cull		Total		
	#	mis.	#	mis.	#	mis.	n.g.
Borderline	6	31.7%	11	18.6%	17	23.2%	2.6%
Easily Classified	63	2.2%	20	2.0%	83	2.2%	2.3%
All	69	4.7%	31	7.9%	100	5.7%	2.3

n.g. = not gradable mis. = misclassified

We anticipate that algorithm performance could be enhanced with minor modifications. First, the shoot area could easily be measured, allowing calculation of a root/shoot ratio. Calculation of the sturdiness ratio (diameter/height) would also be straightforward. Collection of a data base with the machine vision system would allow implementation of a statistical classification scheme, leading to improved grading performance.

The measurement precision demonstrated by the algorithm suggests use for classification of seedlings into several acceptable grades. Additional grade definitions could be optimized for specific planting sites. Finally, we expect that the comprehensive statistics collected in a commercial implementation would make machine vision grading a valuable nursery management and research tool.

SUMMARY AND CONCLUSIONS

This study has demonstrated that machine vision can provide accurate production rate grading of harvested pine seedlings. Singulated seedlings were transported on a conveyor belt, with shoot orientation and root collar position loosely constrained. Seedlings were classified as acceptable or cull on the basis of stem diameter, shoot height, and projected root area.

Tests with loblolly pine seedlings revealed excellent system performance. Seedlings were graded in approximately 0.25 seconds, with an average classification error rate of 5.7 percent. These results exceed manual grading performance, which typically requires one second per seedling with an error rate of seven to ten percent. Misclassification was largely due to seedlings with borderline diameter and/or root area, and the occurrence of branches or roots in the root collar zone. Measurement precision was adequate for seedling classification into several grades, suitable for specific planting sites.

DISCLAIMER

REFERENCES CITED

Boeckman, W. 1986. Personal contact. Weyerhaeuser Nursery, Fort Towson, OK.

Buckley, D. J., W. S. Reid and K. A. Armson. 1978. A digital recording system for measuring root area and dimensions of tree seedlings. Transactions of the ASAE. 21(2):222-226.

Forward, P. W. 1982. Stock production specifications – bare root stock. Artificial Regeneration of Conifers in the Upper Great Lakes Region. Michigan Technological University, Houghton, MI. pp. 260-268.

Kranzler, G. A. 1985. Apply' digital image processing in agriculture. Agricultural Engineering. 66(3):11-13.

Lawyer, J. N. 1981. Mechanization of nursery production of bare root deciduous planting stock. Forest Regeneration. ASAE Publication 10-81, pp. 30-37. ASAE. St. Joseph, MI.

May, J. T., E. W. Belcher, Jr., C. E. Cordell, T. H. Filer, Jr., and D. South. 1982. Southern Pine Nursery Handbook. Forest Service, USDA.

Rigney, M. P. 1986. Machine vision for the grading of pine seedlings. Unpublished MS Thesis. Agricultural Engineering Department, Oklahoma State University, Stillwater, OK.