Machine Vision Development and Use in Seedling Quality Monitoring Inspection

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Abstract- Seedling processing costs have increased in proportion to overall seedling costs in part because of lack of automation. A PC-based machine vision seedling inspection station has been developed for packinghouse quality monitoring as part of a program to develop an automated seedling grading and packing system. This inspection station is being evaluated for incorporation into the quality monitoring inspection program at J. Herbert Stone Nursery. The station has been evaluated for accuracy of measurements of seedling morphological features with favorable results. Machine vision grading criteria are being developed from comparisons of machine vision with current manual methods of measurement. Further studies will be made into developing grading criteria using features measured by machine vision which were not obtainable with manual methods. A fully functional machine vision based seedling grading and packing system remains the goal of the program.

INTRODUCTION

J. Herbert Stone Nursery is in Southwestern Oregon near the city of Medford. It is a USDA Forest Service nursery and produces conifer seedlings and other plant materials for publicly owned lands only. The major clients are the USDA Forest Service and the USDI's Bureau of Land Management and Bureau of Indian affairs. The capacity is approximately 24 million seedlings per year. More than 275 million seedlings have been shipped since 1979 to planting sites throughout Oregon, Washington, Northern California, Northern Idaho, and Western Montana.

LIFTING AND PROCESSING

One and two-year-old seedlings are lifted from seedling beds during the dormant season. The lifting window established for the J. Herbert Stone Nursery is between December I and March 1. Lifting begins with undercutting with a blade spanning the 4-ft wide seedling bed. Shaker tines attached behind the blade shake the seedlings and soil up and down, loosening the soil from the seedlings.

Seedlings are hand lifted out of the loosened soil with any soil remaining removed from the roots by a gentle shaking motion. The bareroot seedlings are packed into field containers and loaded onto specially designed field trailers. Seedlings are then taken to storage facilities to await processing.

Seedlings are transported from storage to the processing shed using a forklift. The seedlings are placed on a moving conveyor that delivers them to the grading stations. Grading is accomplished by individuals taking a hand-full of seedlings and visually inspecting them by passing the seedlings from one hand to the other. Groups of five or 10 shippable seedlings are placed back onto the same moving conveyor. This conveyor moves the shippable seedlings to where the seedlings are gathered, root pruned, and placed into their final storage and shipping containers. We have five of these grading conveyors with the potential of processing up to five different lots simultaneously.

Inspections for quality are made throughout the process. As a minimum, 1% of all seedlings are inspected for sorting, root trimming, accuracy of count, etc. Samples of culls are also inspected for shippable seedlings before disposal.

THE CASE FOR MACHINE VISION

Unlike advances made in seed handling and seedling culturing, very little has changed in the lifting and processing of tree seedlings for decades.

Ten years ago, the cost of seedling production was two-thirds of the total direct cost of our program. Today, two-thirds of our direct cost is in lifting and processing. Most of this change is our lack of mechanization while facing steadily rising labor costs. Quality monitoring also requires heavy use of labor while yielding only pass/fall information. Our personnel only have time to determine if grading, pruning, etc. meets our standards.

Our clients have expressed interest in having actual data on various attributes for each seedling lot they receive. They would use this information in making final plans for the seedling use such as reserving lots with heavier root systems and/or larger calipers for the more harsh sites. Having nearly 100 clients and more than 650 individual seeding lots each year would require an automated data processing system.

MACHINE VISION DEVELOPMENT

Machine Vision has progressed through several stages of development beginning with discussions about grading criteria and various technologies available for sensing seedling attributes and computing data. One major decision was to use a line scan instead of an area scan system. The project developed along with new technologies including faster computer CPU speeds, larger memory, and more accurate camera devices. At times, the project was slowed awaiting availability of new equipment developed, but not manufactured and released on the market.

THE CURRENT MACHINE

In Feb. 1994, the Machine Vision Seedling Inspection Station was delivered to J. Herbert Stone Nursery. This station has been described in detail by Rigney and Kranzler (1994). The station consists of two 18-inch-wide conveyors mounted end-to-end on a single frame. The first (inspection) conveyor is 74.5 inches long and the second (sorting) conveyor is 39 inches long. These conveyors operate at the same speed and have a variable speed control that allows operating at speeds of one to three m/sec. The distance between the inspection conveyor and the sorting conveyor is 1.5 inches. This allows for the high-intensity fluorescent back-light mounted below the conveyors to shine up between them. A line scan camera is mounted above the conveyors directly above the light.

No supporting equipment to feed seedlings onto the inspection conveyor or to process the seedlings from the sorting conveyor has been developed. Seedlings are placed on the inspection conveyor top first with their long axis running parallel with the direction of conveyor travel. As they cross the gap between the conveyors, the camera "sees the shadow cast by the seedling against the very bright back-light. This camera image is then digitized by a line-scan digitizer and sent to a 50-MHz 486 computer.

The computer uses the OS-9000 operating system (Microware Systems Corp., Des Moines, Iowa). A combination of commercial and custom software is required to run the station. Oklahoma State University holds the copyright to the custom software written in the C programming language. Algorithms developed for inspecting the seedlings are the intellectual property of Oklahoma State University and are considered a trade secret.

Operational speeds vary depending upon the average total length of the seedlings. The station is designed to handle seedlings with tops ranging from seven to 91 cm and with roots up to 36 cm.

The seedling features measured include stem diameter, top height, maximum root length, root mass length, percentage of root area outside the user defined root zone, percentage of fine roots, projected root area, and projected shoot area. From these measurements are calculated the sturdiness (top height/stem diameter) and shoot to root ratios.

SEEDLING FEATURES MEASUREMENT

Initial testing showed the station had some difficulty in finding the exact location of the root collar. It also had difficulty finding the terminal bud on species such as ponderosa pine where the terminal bud may be obscured by needles. Because of these difficulties, the calculated top heights and root lengths varied from actual measurements. Modifications were made to the software to allow user defined adjustments on bow the root collar and terminal bud are found and to allow for adjustments as needed. These adjustments have allowed for top height and root length measurements to compare more favorably with manual measurements of Douglas-fir and ponderosa pine. Machine vision measurements comparable with manual measurements have been made on stem diameter of Douglas-fir and ponderosa pine.

The fine root percent measurements appear accurate when the root mass is not so heavy that it appears as a large solid mass to the camera. When the root mass appears solid to the camera, a low percent of fine roots is recorded. This might make it difficult to use this measurement on some species and age classes.

Root area comparison with root volume measured using the water displacement method shows a general correlation with 2-0 Douglas-fir (fig. 1). This suggests that shoot to root ratio based on the shoot and root area has a tendency to be comparable to the volume method. Further investigation is needed to clarify this relationship with other species and age classes.

Root zone percentages as measured by machine vision appear from observations to correspond to the percent of roots outside the user defined root zone.

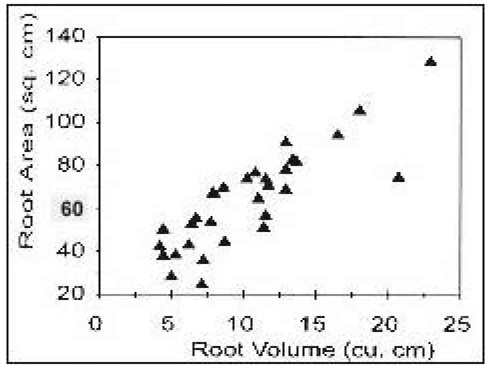

Table 1. Comparison of root volume and root area in 2-0 Douglas-fir.

GRADING CRITERIA

The machine vision seedling inspection station produces classification reports based on up to eight user defined grading criteria classes using the seedling features it can measure. Stem diameter, top height and root length grading criteria correspond closely with the same measurements manually. These criteria need modification to compensate for the discretion allowed by manual observation where looking at the seedling in a three dimensional perspective is possible.

Grading criteria for the other features measured will be developed as more experience allows us to translate visual evaluation of these features to a form usable by the station.

ALGORITHM PARAMETERS

The machine vision inspection station uses various parameters in the algorithms to distinguish seedling features. These parameters must be modified depending on the morphology of the seedling being inspected. Currently parameters have been developed for 1-0 and 2-0 ponderosa pine and 1-0 and 2-0 Douglas-fir. Due to variations within species and age classes these become default settings which may require modifications for a given lot.

SUMMARY AND DATA REPORTS

Summary and seedling measurement data reports may be created by the inspection station at the users request (Table 1). The summary report displays the measurement statistics and the data report displays the measurement data for each seedling graded. The data summary is stored as ASCII text in a DOS partition on the hard disk and is easily used by many commercial software packages for further analysis.

Table 1. Sample Summary and Data Reports produced by the Machine Vision Seedling Inspection Station.

Summary Report-Measurement Statistics

Feature	Mean	STDEV	Min	Max	Units
Diameter	6.59	0.05	6.51	6.75	mm

Height	33.1	0.1	32.7	33.5	cm
Shoot/Root	4.3	0.1	4.1	4.5	ratio
Sturdiness	5.0	0.06	4.8	5.1	ratio
Rt Max Length	19.4	0.2	19.1	20.0	cm
Rt Mass Len	19.4	0.1	19.1	19.7	cm
Out Root Zone	7.0	2.3	4.7	14.6	%
Fine Roots	11.2	0.4	10.7	12.2	%
Root Area	46.7	1.0	44.9	48.1	sq cm
Shoot Area	201.4	2.6	194.5	204.6	sq cm

Seedling Measurement Data

Diameter (mm)	Height (cm)	Shoot/root ratio	Sturdiness ratio	Root Max (cm)	Root Mass (cm)	Root Zone %	Fine Root %	Root Area (sq cm)	Shoot Area (sq cm)
6.61	33.0	4.1	5.0	19.6	19.6	5.3	11.5	47	197
6.51	33.2	4.5	5.1	19.2	19.2	4.8	11.7	44	200
6.56	33.0	4.4	5.0	19.1	19.1	5.8	11.5	45	202
6.54	33.2	4.3	5.1	19.5	19.4	7.0	10.9	47	201
6.61	33.3	4.3	5.0	19.6	19.6	7.1	11.3	47	202
6.54	33.1	4.4	5.1	19.3	19.3	6.8	12.2	46	202
6.60	33.2	4.4	5.0	19.2	19.2	5.3	11.0	46	204
6.59	33.2	4.3	5.0	19.4	19.4	5.4	11.0	46	201
6.54	33.1	4.3	5.1	19.7	19.7	5.2	11.7	46	201
6.59	32.8	4.4	5.0	19.7	19.7	8.7	11.2	46	202
6.61	33.3	4.4	5.0	19.5	19.5	7.7	11.1	46	204
6.55	33.2	4.5	5.1	19.4	19.4	6.0	10.9	45	203
6.75	32.7	4.4	4.8	19.5	19.5	14.6	11.2	46	204
6.62	33.1	4.3	5.0	19.4	19.4	8.3	11.1	47	201
6.52	33.4	4.3	5.1	19.5	19.5	5.7	10.9	46	202
6.64	33.3	4.2	5.0	20.0	19.7	6.9	11.0	48	200
6.64	32.9	4.1	5.0	19.7	19.7	10.9	11.1	47	194
6.60	33.2	4.3	5.0	19.2	19.2	7.8	10.7	46	201
6.52	33.3	4.3	5.1	19.3	19.3	4.7	10.9	46	198

6.57	33.5	4.2	5.1	19.6	19.6	5.3	10.9	47	197

FUTURE DEVELOPMENT

Further refinement of the algorithm parameters and grading criteria for various combinations of species and age class is the next step. New grading criteria will be analyzed and outplanting survival checked. Current grading processes depend entirely upon human ability to judge sizes and amounts. This places a significant part of the decision as to the plant being acceptable upon the easier to visualize and describe attributes such as top height, root length, and stem diameter. The current equipment will gather more dependable information on other attributes such as shoot to root ratio, percentage of fine roots and shoot and root areas. The use of new combinations of grading rules such as stem diameter and total root mass may be better indicators of survival and initial growth than those currently in use.

Evaluation will be made of the use of color and shades of grey in detecting off-color foliage and recognizing damage such as stripped roots or other wounds.

Development of a complete system is the final goal. This will include equipment capable of singulating and feeding seedlings to the station, separating out two, three, or more grades of seedlings, performing root trimming and other final preparation of the seedlings, and packaging the seedlings.

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LITERATURE CITED

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