Machine Vision Inspection System for Packing House Quality Control

Michael P. Rigney and Glenn A. Kranzler [1]

Rigney, Michael P.; Kranzler, Glenn A. 1994. Machine Vision Inspection System for Packing House Quality Control. In Landis, T.D.; Dumroese, R.K., technical coordinators. Proceedings, Forest and Conservation Nursery Associations. 1994, July 11-14; Williamsburg, VA. Gen. Tech. Rep. RM-GTR-257. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 182-191. Available at: http://www.fcnanet.org/proceedings/1994/rigney.pdf

Abstract—A PC-based machine vision system providing high-speed (4/sec) measurement of bare-root seedling morphological features has been developed. Designed for quality control and morphological data acquisition by nursery personnel, the system provides a user-friendly, menu-driven graphical interface. The system automatically locates the root collar, measures root collar diameter, shoot height, sturdiness ratio, root mass length, projected shoot and root area, shoot-root area ratio, and percent fine roots. Sample statistics are computed for each measured feature. Measurements for each seedling may be stored for later analysis. Feature measurements may be compared to multi-class quality criteria to easily determine sample quality. Statistical summary and classification reports may be printed to facilitate the communication of quality concerns with grading personnel. System architecture is described, followed by a discussion of software and morphological measurement capabilities. Results from tests comparing measurement differences and variation among repeated manual and machine vision measurements are summarized.

INTRODUCTION

Over one billion conifer seedlings are produced in the U.S. each year to support reforestation efforts. Most seedlings are graded manually to improve viability after transplanting. Manual grading is labor intensive and subject to human error. The grading task is complicated by the fact that grading criteria change for different species, age classes, seed lots, and customer preferences. Quality control assessments are used to ensure that graded seedlings meet specific grading criteria.

Quality control is performed by sampling seedlings from the grading tables and determining compliance with grading criteria. An accounting system is usually implemented to document deviations, which are then brought to the attention of the grading personnel. The number of specific quality criterion failures per sample might be the full extent of the quality record. Production demands do not allow manual measurement of quality control sample morphology, which may better characterize quality. Morphological statistics from seedling samples could be useful to nursery management as well as customers.

In previous work, we demonstrated the feasibility of using machine vision for tree seedling quality inspection (Rigney and Kranzler, 1988, 1989). Two cameras and a dedicated high-performance machine vision computer were used to automatically locate the seedling root collar and measure stem diameter, shoot height, shoot area, and root area at a rate of 2 seedlings per second. The

[1] Biosystems and Agricultural Engineering Department, Oklahoma State University.

performance of a second prototype was enhanced through the use of backlighting and a single line-scan camera (Rigney and Kranzler, 1992). This system, using a VME bus-based computer and high-performance image processing hardware, achieved increased measurement precision and higher inspection rates (10 seedlings/sec).

An investigation by Hassan et al. (1992) used a machine vision system with 0.5 mm spatial resolution to evaluate manual sorting in three nurseries (one of which did no sorting). Root collar diameter was the primary grading criterion. Results showed that variations in manual sorting had a significant effect on average root collar diameter and number of plantable seedlings. With respect to seedling misclassification, the authors suggested that the nursery which did no sorting had 2.6% greater efficiency.

Kutz et al. (1993) describe two-camera and three-camera machine vision systems developed for seedling quality control and research measurement applications. The two and three camera systems provided inspection rates of 5.8 and 15.8 s per seedling, respectively. Both systems had 0.1-mm resolution for diameter measurement. Root collar location was determined by the operator. Test results showed accurate diameter measurement and high correlation between projected area (root or shoot) measurements made by the vision systems and area meter measurements. Low correlation between machine and manual height (needle tip) measurements was observed, however, low correlation was also observed between repeated manual measurements.

In this paper we describe a PC-based machine vision inspection system which provides high-resolution imaging, automatic measurement, and quality assessment of conifer seedlings at rates of up to four per second. The system measures ten morphological features, stores measurement data to files, and generates statistical and quality reports, all through a menu-driven, user-friendly interface.

SYSTEM DESCRIPTION—HARDWARE

Conveyors

Seedlings are transported through the inspection system on a variable speed conveyor consisting of two sections of conveyor belt aligned end-to-end and powered by a 1-hp motor (Fig. 1). The inspection and sorting conveyors are 46 cm wide and approximately 2 m and 1 m in length, respectively. Singulated seedlings are manually placed on the inspection conveyor, where they accelerate to a belt speed of 1 to 3 m/s. Converging guide plates constrain seedling position and ensure oriented passage through the camera field-of-view (FOV). At the inspection area, seedlings cross the gap between the inspection conveyor and the sorting conveyor as they pass between the overhead camera and an apertured lamphouse beneath the conveyors (Fig. 2). A high-resolution shaft encoder (2540 pulses/rev) measures conveyor displacement, ensuring accurate longitudinal measurements independent of belt speed. Cleaning brushes mounted beneath the conveyors prevent the accumulation of debris on the belts.

Camera

A high-resolution (2048-pixel) line-scan camera is mounted above the conveyors in a protective enclosure. The camera mount provides precise manual adjustment in three axes to simplify alignment of the camera FOV with the center of the lamphouse aperture. A through-the-lens viewer enables the operator to see the line-scan FOV at the camera for adjustment of alignment and focus. Live images may also be displayed to assist with camera aiming, focus, and lens aperture adjustment.

Transverse and longitudinal spatial resolutions are independently adjustable. High transverse spatial resolution is important for precise measurement of

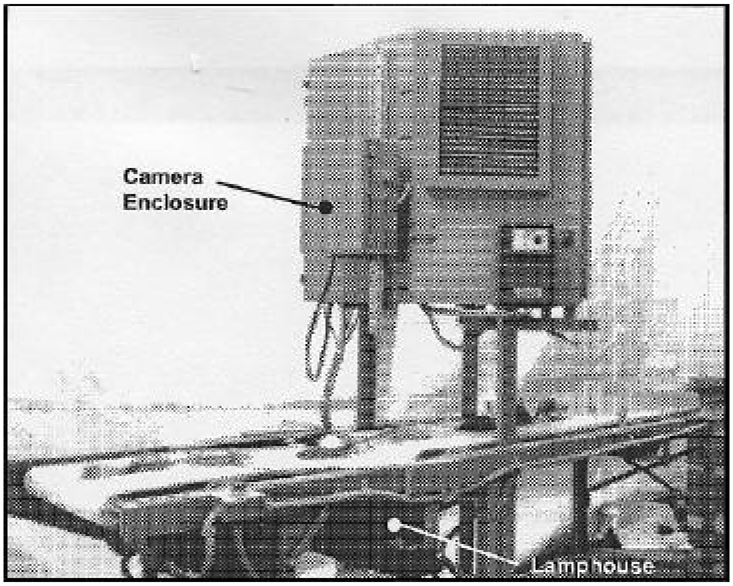

Figure 1. Seedling inspection system.

stem diameter, while much lower longitudinal resolution is sufficient for measurement of seedling height. Transverse resolution is dependent on the camera FOV, which is nominally set to the maximum expected seedling width. The camera FOV is manually adjustable from 10 to 40 cm (0.05 to 0.20-mm spatial resolution) by mov-ing the camera and/or changing the camera lens. The camera enclosure is mounted on a precision linear track with integrated clamp for easy posi-tioning.

Longitudinal resolution is controlled by the rate at which line images are acquired from the camera. Line acquisition is controlled by signals from the shaft encoder, which measures conveyor belt displacement. Longitudinal resolution is software-selectable in the range of 0.5 to 5.0 mm (nominally 1.0 mm).

Lamphouse

A high-intensity, high-fre-Quency fluorescent backlight mounted beneath the conveyors is used to obtain high-contrast seedling images. High lamp brightness is needed due to the short exposure time of each line-scan image . A regulated high-frequency power supply with automatic intensity control provides illumination unifor-mity over the life of the lamp.

An “all’s well” indicator in-forms the operator that the lamp and power supply are operating properly. The lamphouse is protected from water and debris by an updraft airstream exiting the lamphouse aperture. Fil-tered ambient air is provided for lamp cooling and protection.

Computer

The system is controlled by a 50 MHz 486DX PC. The computer is equipped with a high-capacity hard disk, high-density floppy disk drive, and an SVGA color monitor. The computer houses a line-scan digitizer card and a shaft en-coder interface card.

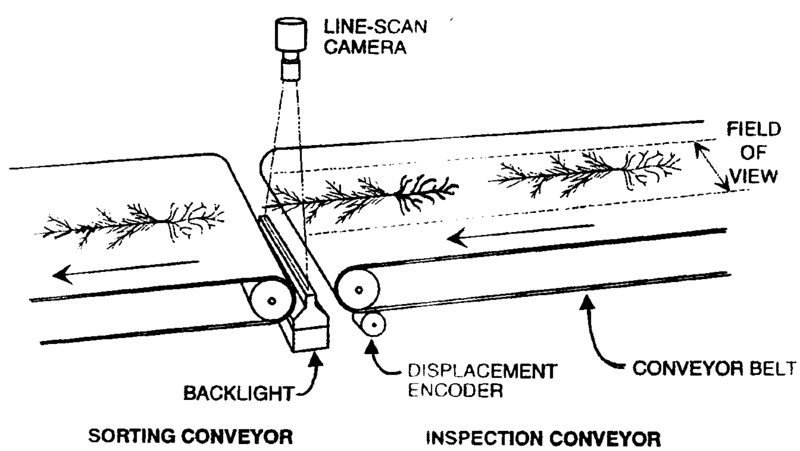

Figure 2. Line-scan inspection configuration.

The computer and other electrical components are housed in an environmental enclosure mounted above the conveyor (Fig. 3). The keyboard and a trackball pointing device are mounted externally in a protective drawer for easy access. Enclosure cooling is provided by filtered air from the lamphouse blower system.

SYSTEM DESCRIPTION— SOFTWARE

Software was written in the C programming language and runs under the Microware OS-9000 operating system. OS-9000 is a real-time, multi-tasking operating system which supports the time-critical needs of the high-speed image processing software. Image processing is performed on a line-by-line basis as data become available from the camera. Measurement data can be written to a DOS-format hard disk partition or 3.5 inch diskettes and may be processed by many popular spreadsheet and statistical analysis programs. Simple statistical analysis of seedling features and compliance with grading criteria are incorporated in the inspection software, as described below.

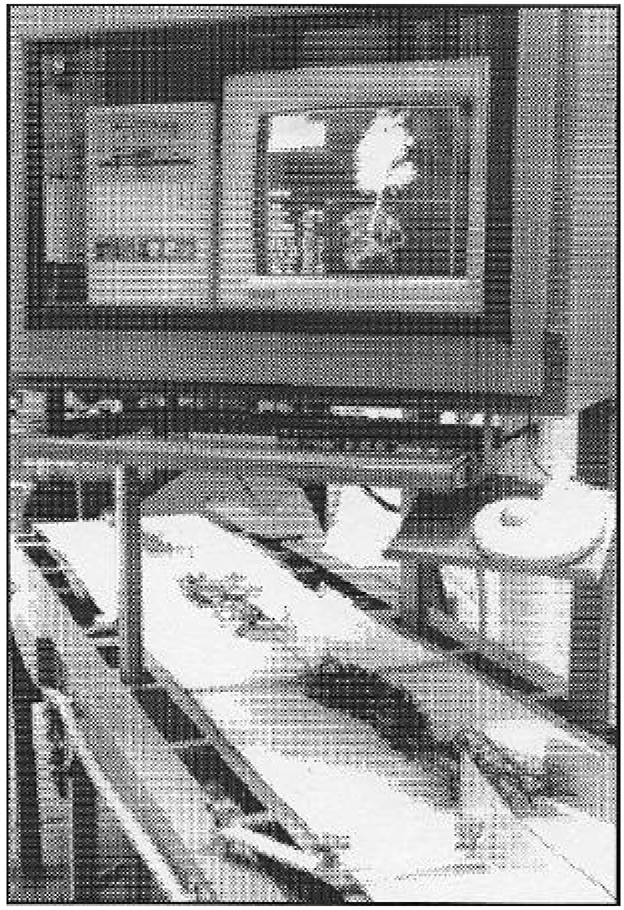

Figure 3. Seedling inspection system showing Interactive inspection display.

All program interactions are conducted through a user-friendly, menu-driven graphical user interface. Most inspection system functions are executed by simply selecting a menu item or a filename from a directory. Some selections prompt the user to enter data such as a setpoint or filename. The software supports camera alignment and adjustment, calibration, grading criteria selection, seedling inspection, data storage, statistical reports, and options such as seedling image storage and display.

System Calibration

The system is calibrated by acquiring several images of a calibration tool (wood dowel) with known diameter and length. Calibration constants are stored in a file and retrieved each time the inspection system is used. Calibration is only required after changing the lens or camera position. Calibration constants are included in summary reports and may be viewed through a menu selection.

Algorithm Parameters

Nineteen parameters affect the behavior of the inspection program. Most parameters control the search for the seedling root collar. Others constrain diameter measurement and the search for the seedling top, and define the root zone and maximum fine root width. The parameters are adjusted to obtain the desired measurements or exploit differences between different species or age classes. Parameter tuning may be performed interactively while observing the effects of parameter changes on a seedling image. Algorithm parameters are stored along with grading criteria in a file which is read before inspecting seedlings.

Seedling Features

Custom image processing software is used to locate the seedling root collar and extract several features which are dependent on root collar location. Locating the root collar is a pattern recognition problem and the most challenging task the system must perform. The seedling features described below are measured after locating the root collar. Several feature measurement algorithms utilize user-defined parameters mentioned above.

1. Stem diameter. Stem diameter is computed as the average stem width in the root collar zone, corrected for local stem orientation. The size of the root collar zone and its position with respect to the root collar are defined by algorithm parameters. The diameter measurement algorithm discards large line widths in preference to small widths, if width variance exceeds a threshold (example, 0.5-mm). This procedure reduces errors caused by attached debris which increase the apparent diameter.

2. Shoot height. A seedling top detection algorithm attempts to locate the terminal bud using two algorithm parameters. A width threshold is set to the average terminal bud width. A distance limit is set to the approximate needle length. Height is computed as the distance from the root collar to the seedling top.

3. Sturdiness ratio. Computed as height (cm) divided by diameter (mm).

4. Projected shoot area. Total area above the root collar.

5. Projected root area. Total area below the root collar.

6. Shoot-root ratio. Projected shoot area divided by projected root area.

7. Root length. Longitudinal distance from root collar to the end of longest root, which is on the last line in the image. This computation does not take root bending or curvature into account.

8. Root mass length. Distance from the root collar to the first horizontal line which has less than a minimum number of root crossings. The number of crossings is an adjustable algorithm parameter (example, 5 roots).

9. Percentage of root area outside the root zone. Used to detect stiff root laterals or poorly shaped root systems. The root zone is defined as the region within a downward opening 60° angle, or any other operator-selected angle, with vertex at the root collar. The root area outside the root zone is divided by the total root area to compute this feature.

10. Percentage of fine roots. Area of roots with a horizontal width less than or equal to a threshold is determined and divided by the total root area. The width threshold (example, 0.75-mm) is an adjustable algorithm parameter.

Grading Criteria

Seedlings may be classified as acceptable or cull by comparing the features described above with user-defined classification criteria. As many as eight acceptable classes may be defined. Seedlings which do not meet all of the criteria for any acceptable class are graded as cull. A given class may be removed from the conveyor at any of eight possible sorting stations. Classification may be based on all, or an operator-selected subset, of the criteria listed below:

1. Minimum and maximum diameter.

2. Minimum and maximum height.

3. Minimum and maximum sturdiness ratio.

4. Minimum and maximum shoot area.

5. Minimum and maximum root area.

6. Minimum and maximum shoot-root ratio.

7. Minimum and maximum root length (longest root).

8. Minimum root mass length (5 roots).

9. Maximum percentage of root area outside the root zone.

10. Minimum percentage of fine roots.

These criteria are defined in a grading criteria file which also contains the algorithm parameters. Inspection and modification of the grading criteria are supported by the graphical user interface. Different grading criteria files are typically defined for different seedling types (species, age class, seed lot, customer, etc.) and organized in a hierarchical directory structure for easy access.

Data Files and Summary Reports

Measured seedling features and compliance with the grading criteria may be stored for each seedling in a user-specified data file. This information is also presented on the monitor as each seedling is inspected.

Inspection results for a group of seedlings are presented in a summary report. The report includes inspection time and date, seed lot and customer identification, calibration constants, algorithm parameters, grading criteria, the data file name, measurement statistics and a classification summary. Measurement statistics include the number of observations, mean, standard deviation, minimum, and maximum for each feature. The classification summary lists, for each class, the number of seedlings which passed the classification criteria and the number which failed. The summary also lists, for each class, how many class failures are attributed to each feature criterion. This information readily tells the operator if, for example, more seedlings are failing due to the diameter or the height criterion. The measurement statistics and classification summary reports may be viewed on the monitor, written to a file, and/or printed.

Seedling Inspection

The inspection procedure is fast and easy, after the system has been calibrated and a grading criteria file has been created. The operator first selects an existing grading criteria file from a directory. If measurement data and/or a summary report is to be stored in a file, those files must be opened next. Seedlings may then be inspected in either of two modes; interactive or continuous. Seedling images are displayed if the interactive inspection mode is selected. The operator may easily modify algorithm parameters and observe the results. Graphical indicators showing various feature locations (root collar, root zone, seedling top, etc.) are superimposed on the seedling image. The assigned class, value of all measured features, and an indication of which features failed grading criteria are displayed next to the seedling image. Inspection rates are slow (3 seconds per seedling) in the interactive inspection mode, but the system is ready to inspect another seedling as soon as the image of the last seedling is displayed. The continuous inspection mode is much faster (4 seedlings per second), because only seedling data are displayed.

Container Grown Seedlings

Although developed for bare-root seedlings, the system will locate the root collar, measure diameter, height, sturdiness ratio, and foliage area on container grown seedlings. Faster processing speeds could be achieved by exploiting the presence of the plug, and plug integrity inspection could be incorporated. Automated extraction and conveying systems could be integrated with the machine vision system to obtain 100% product inspection.

SYSTEM PERFORMANCE

System performance was evaluated first by repeatedly inspecting dowels of known dimension, and second, by inspecting seedlings on which manual measurements were also obtained. Both tests were conducted at a commercial forest nursery. The system was operated at a belt speed of 2 m/s, with a longitudinal resolution of 1 mm and a transverse resolution of 0.1 mm.

A test was conducted with wood dowels to determine machine precision and accuracy. Dowels were used because they are relatively uniform in diam-eter and of fixed length, whereas seedling stems are not uniform in diameter nor of fixed length due to debris, bending, foliage movement, and root movement.

Three 300-mm long dowels having diameters of 6.11, 7.89, and 13.27 mm were used. The system had been calibrated with the 6.11-mm dowel. Twenty measurements of each dowel were obtained in each of three orientations; aligned with the belt centerline, angled +/- 15 degrees with respect to the belt centerline, and angled +/- 30 degrees with respect to the belt centerline. The 15 and 30-degree angles were approximated when placing the dowel on the moving belt.

Table 1 shows system measurement accuracy. The differences between known dimensions and the average machine vision measurement for the 6.11-mm dowel at three orientations are tabulated. The vision system measured diameter slightly larger than actual at unaligned orientations. However, the difference was small, approximately one-third of the camera transverse resolution. Orientation correction applied by the diameter measurement software worked well. Without correction, diameter error would have been 0.94 mm for the 6.11-mm dowel oriented at 30 degrees. Length measurement error is equal to two image lines for the aligned orientation and increased with orientation angle (as expected), because no orientation correction is applied to length. Area measurement error also increased with orientation angle. However, at 30 degrees the error was only 0.7% of the dowel area. Data for the 7.89 and 13.27 dowels yielded similar results.

Table 2 shows system measurement precision. The standard deviation for 20 measurements of each feature at three orientations is tabulated. Diameter variation in the aligned orientation is very low (CV = 0.4%). Three standard deviations (0.06 mm) are less than the camera transverse resolution. Length variation (CV = 0.6%) for the aligned orientation is partially due to non-uniform slippage of the dowel as it was transferred from one belt to the other at the inspection area. A

Table 1. System measurement accuracy, average error.

	Tool Orientation			
Feature	Aligned	+/- 15 Deg.	+/- 30 Deg.	Units
Diameter	0.0	0.03	0.03	mm
Length	-0.2	-0.8	-2.5	cm
Area	0.0	0.1	0.2	cm^2

20 obs. for each orientation of 6.11 mm dia. X 300 mm calibration tool.

Table 2. System measurement precision, STDEV.

Feature	Tool Orientation: Aligned	+/- 15 Deg.	+/- 30 Deg.	Units
Diameter	0.02	0.04	0.06	mm
Length	0.2	0.3	0.9	cm
Area	0.2	0.2	0.3	cm^2

20 obs. each of 6.11, 7.78, 13.27 mm dia. X 300 mm calibration tools.

significant part of the increased variation with orientation angle (CV = 3.4% at 30 deg.) is probably due to variation in actual orientation (and thus, the longitudinal projection); the tool was manually placed on the moving belt. Area measurement variation remained relatively constant with increasing orientation angle (CV = 1.1 to 1.4%).

A second test was conducted to compare machine and manual measurements of actual seedlings. One hundred seedlings each of 2-0 ponderosa pine and 2-0 Douglas-fir were measured four times each by the vision system and once each by four different quality control personnel. Manual diameter measurements were obtained with a digital caliper and recorded to the nearest 0.1 mm. Manual height and root mass length measurements were obtained with a meter stick and recorded to the nearest mm. Seedlings were rotated about their longitudinal axis between repeated machine vision measurements.

Table 3. Machine vs. manual measurement precision.

Feature	Machine STDEV	Machine CV%	Manual STDEV	Manual CV%	Units
Diameter	0.09	1.4	0.41	6.6	mm
Height	0.8	2.7	0.7	3.0	cm
Root Mass Length	1.4	6.6	1.1	4.8	cm
Sturdiness	0.2	3.9	0.3	7.3	ratio
Shoot/Root	0.1	3.5	-	-	ratio
Fine Roots	1.2	6.0	-	-	%
Root Area	1.2	2.5	-	-	cm^2
Shoot Area	2.3	1.8	-	-	cm^2

200 seedlings, 4 reps.

Table 3 provides a comparison between machine and manual measurement precision. Vision system diameter measurement variation is larger for seedlings than for the wood dowel because: 1) seedlings are not uniform in diameter, 2) the root collar may not be found at exactly the same location during repeated inspections of a seedling, and 3) debris tends to decrease with repeated handling. Still, vision system diameter measurement standard deviation was approximately equal to camera transverse resolution. Machine diameter measurement variation was approximately one-fourth that of manual measurement. Machine and manual measurements had similar variation for height. Vision system measurements showed 50% less variation in sturdiness ratio compared with manual measurements.

Manual root mass length measurement variation was smaller than that of the vision system. This result is due in part to measurement method. Manual root mass length measurements were obtained with the seedling held in a vertical orientation, such that gravity tended to extend the roots. On the horizontal conveyor belt, however, roots contracted more readily, yielding more variation and a smaller average value (Table 4) for the machine measurement.

Table 4 presents the difference between manual and machine measurements. Machine

Table 4. Difference between machine and manual measurements.

	Machine - Manual		
Feature	MEAN	STDEV	Units
Diameter	0.34	0.53	mm
Height	3.7	2.2	cm
Rt. Mass Len.	-1.9	2.0	cm

200 seedlings, 4 reps.

diameter measurements were, on average, 0.34 mm larger than manual measurements. This result may be due to debris on the stem and/or the non-contact nature of machine vision measurements. The standard deviation of measurement differences indicates that the two methods could easily differ by one mm. Most of this variation (error), however, may be attributed to the manual measurements, as shown in Table 3.

Machine height measurements were significantly larger than manual measurements (Table 4). This result is partially due to difficulty in locating the terminal bud on many seedlings. The vision system also tended to locate the root collar slightly lower on the stem than the quality control personnel. The difference between manual and machine root collar location was partially responsible for shorter machine measurements of root mass length. Root bending on the conveyor belt, described above, also contributed to shorter root mass length as measured by the machine. Time measurements indicate that the system can inspect a seedling with a total length of 500 mm in approximately 0.25 seconds. Shorter seedlings are inspected proportionately faster. Most of the inspection time is consumed by the relatively slow transfer of data from the image digitizer into system memory, rather than image analysis. Recently introduced digitizers operating through VESA or PCI local buses eliminate the data transfer bottleneck and should enable significantly higher inspection rates.

CONCLUSIONS

A PC-based machine vision inspection system which provides high-resolution imaging, automatic measurement, and quality assessment of conifer seedlings at rates of up to four per second has been described. The system measures ten morphological features, stores measurement data to files, and generates statistical and quality reports, all through a menu-driven, user-friendly interface. Performance tests show that machine vision measurement precision is four times greater than that of manual measurements for stem diameter. Machine and manual measurements had comparable precision for shoot height and root mass length. Inspection rates exceed the needs of a quality control system and can be increased by utilizing new digitizer hardware, enabling 100% production inspection.

ACKNOWLEDGMENTS

Approved for publication by the Director, Oklahoma Agricultural Experiment Station. This research was supported, in part, under project H-1973. Development of the prototype described in this paper was funded by the USDA Forest Service, Missoula Technology & Development Center. System performance was tested at the J. Herbert Stone Nursery, Central Point, OR. The authors wish to thank the quality control personnel at the J. Herbert Stone Nursery for their assistance.

REFERENCES

Hassan, A.E., A.S. Tohmaz, and J.P. Roise. 1992. Evaluation of manual sorting in three pine nurseries. Transactions of the ASAE, 35(6):1981-1986.

Kutz, L.J., J.H. Wilhoit, and D.E. Fly. 1993. Multiple camera machine vision systems for pine seedling measurements. ASAE Paper No. 933028, ASAE, St. Joseph, MI 49085.

Rigney, M. P. and G. A. Kranzler. 1988. Machine vision for grading southern pine seedlings. Transactions of the ASAE, 31(2):642-646.

Rigney, M. P. and G. A. Kranzler. 1989. Performance of a machine vision based tree seedling grader. ASAE Paper No. 89-3007, ASAE, St. Joseph, MI 49085.

Rigney, M P. and G. A. Kranzler. 1992. Line-scan inspection of conifer seedlings. Optics in Agriculture and Forestry. SPIE Proceedings, Vol. 1836, pp. 166-174.