

Computer Vision: A Nursery Management Tool¹

Michael P. Rigney and Glenn A. Kranzler²

Rigney, Michael P.; Kranzler, Glenn A. 1990. Computer Vision: A Nursery Management Tool. In: Rose, R.; Campbell, S.J.; Landis, T. D., eds. Proceedings, Western Forest Nursery Association; 1990 August 13-17; Roseburg, OR. General Technical Report RM-200. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 189-194. Available at: <http://www.fcanet.org/proceedings/1990/rigney.pdf>

Abstract.--Computer vision provides quality control for many manufacturing and agricultural processing industries. Objective assessment, high measurement precision, increased inspection rates, and comprehensive production statistics are among the advantages provided by the technology. A brief overview of computer vision technology is presented. Applied research and potential applications for the forest nursery industry are described.

COMPUTER VISION

Computer vision is the integration of image sensors with digital computers to obtain useful information. Physical dimensions, surface features, and color may be quantified. Computer vision systems are used to inspect a wide variety of manufactured and agricultural products. Agricultural applications are generally more challenging due to greater product variation (size, color, and types of defects) and high production rates. In this section we present a brief overview of vision system components. Detailed discussions may be found in Ballard and Brown (1982), Chin and Harlow (1982), Jam (1989), Novini (1985), and Pratt (1978).

standards as well as sensor manufacturing constraints. Color and monochrome cameras are available in a variety of spatial resolutions.

Line-scan cameras contain a single row of sensing elements (128 to 4096). Rectangular images are constructed line-by-line as an object moves past the camera or as the camera moves past an object. These cameras allow independent selection of horizontal and vertical spatial resolution.

Lighting

Selection of illumination technique can be critical to system performance. Front lighting allows inspection of surface color and texture. Backlighting provides a silhouette image of opaque objects, useful for dimensional measurement. Structured lighting allows depth to be measured. Strobe illumination enables sharp images of moving objects to be acquired. Illumination wavelength can also be controlled to advantage. For example, ultraviolet light, invisible to the camera, can give high contrast to objects which fluoresce.

Optical Filters

Contrast between the object(s) of interest and the background or neighboring objects can be increased by exploiting spectral reflectance differences. Band-pass and cut-off filters limit the bandwidth of light reaching the image sensor. Sensitivity to selected wavelengths is thereby increased, allowing object color to be evaluated with a monochrome camera. Infrared (IR) cut-off filters are often used because solid-state cameras have high sensitivity to near-infrared wavelengths which otherwise overwhelm the visible light image. In some cases the IR image is desired, and IR-pass filters are used. Polarizing filters can reduce glare from spectral reflection.

Image Sensors

Solid-state television cameras, incorporating a rectangular grid of discrete photosensitive elements (200 to 600 each direction), are the most commonly used image sensors. These cameras are generally rugged, free from geometric distortion, and tolerant of intense illumination and magnetic fields. Images are typically transmitted from the camera to a vision computer as an analog signal defined by television broadcast standards. This signal is digitized into a rectangular array of picture elements (pixels) in the vision computer. Image resolution (amount of detail) is limited by broadcast

¹Paper presented at 1990 Conference of the Western Forest Nursery Council. [Roseburg, Oregon, August 13-17, 1990.] Paper No. 3334 of the Oklahoma Agricultural Experiment Station.

²The authors are: Michael P. Rigney, Research Engineer and Glenn A. Kranzler, Professor, Agricultural Engineering Dept., Oklahoma State University, Stillwater, OK.

Image Processing Computers

Analog video signals from the image sensor must be digitized before a computer can process the image. Some interfaces accept digital data directly from a camera. The digitizer generates a rectangular array of pixels, each having an intensity or gray level between 0 (black) and 255 (white). A frame buffer is typically available for temporary storage of one or more new, intermediate, or processed images. The digitizer, frame buffer, and other image processing boards are linked by a high-speed image data buss supplementing the host computer buss.

Images as large as 256 K-bytes may be digitized at rates up to 30 per second, far exceeding the computational capabilities of a typical central processing unit (CPU). Specialized computer hardware is required for most inspection applications. Although all image processing operations may be implemented in software by a computer's (CPU), real-time processing constraints require hardware implementation of frequently used and computationally intensive operations.

Hardware implementations of image processing functions may reside with the digitizer or be placed on separate processing boards. Typical hardware functions include histogram computation (counting pixels at each gray level), and thresholding, which transforms a gray-level image into a black-and-white image. Digital filtering hardware allows noise reduction and edge enhancement. Region-of-interest processing, runlength encoding, and color space transformation are useful hardware capabilities.

Many vendors offer modular architectures so that a system may be configured with the desired functionality. Low-level image processing functions are performed by the hardware discussed above. High-level

image understanding algorithms are programmed by the user (or applications engineer) and implemented on the host CPU.

NURSERY MANAGEMENT OPPORTUNITIES

Seedling Inspection and Grading

Current Nursery Practice

Seedling grading is a labor intensive, seasonal operation, performed in an environment optimized for seedling viability, not human comfort. Graders identify culls by visually evaluating several morphological characteristics. It is not feasible to manually inspect individual seedlings or sort into more than two classes (acceptable and cull). Classification is subjective and susceptible to human error. Increasing labor cost and personnel injuries have become a nursery management concern.

Prototype Grading System

The feasibility of grading bare root pine seedlings with computer vision has been demonstrated (Rigney and Kranzler, 1988a,b) and a prototype system tested at a commercial nursery (Rigney and Kranzler, 1989). A specialized computer vision system inspected singulated seedlings moving along a conveyor at a rate of 2 per second. Two low-resolution (256H x 240V) cameras and strobe lamps were used for image acquisition (Fig. 1).

Two images of each seedling were acquired and processed. An image of the entire seedling and close-up of the root collar zone had a spatial resolutions of 2 mm and 0.5 mm, respectively. These resolutions were coarse, considering that many roots have diameters less than 2

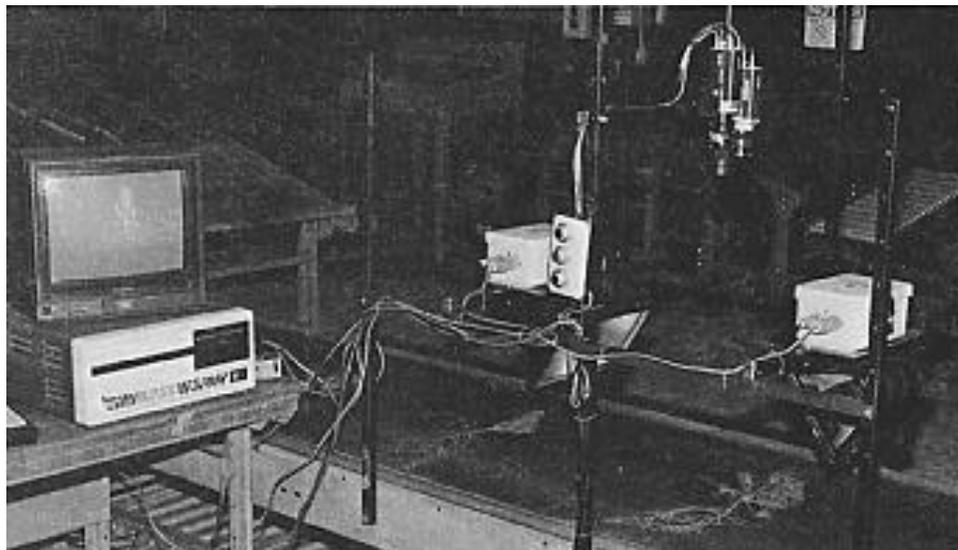


Figure 1.--Vision computer, cameras, strobe lamps, conveyor, and seedlings.

mm, and that 3-mm diameter stems were only six pixels wide. Special image processing operations were implemented to enhance measurement accuracy in spite of limited spatial resolution.

Image processing consisted of several tasks. First, each seedling was detected and images acquired. Seedling orientation on the belt was determined for use in diameter and height computations. Root collar location and stem diameter at the root collar were determined from the close-up image. Seedling height, projected root area, and projected foliage area were extracted from the second image. Sturdiness ratio and shoot/root ratio were computed from primary measurements. Finally, each seedling was classified as acceptable or cull, based on programmable feature setpoints. System performance equaled or exceeded that of manual graders.

Although projected root area cannot be determined for container grown seedlings, plug integrity can be verified. Additional features which may be inspected include stem straightness and multiple leaders. For bare root seedlings, root length and number of root laterals may be quantified.

Line-scan Concept

Conceptual designs for grading systems providing increased measurement accuracy and/or inspection rates have been developed. A concept for a line-scan camera based seedling grader is presented in Figure 2. Line-scan cameras can provide five to ten times the spatial resolution (0.05 mm) of our first prototype, enabling precise measurement of stem diameter and projected root area. Line scan rate may be selected to provide a lower resolution for measurement of shoot height (1.0 mm). High-contrast silhouette images may be acquired by passing seedlings between the line-scan camera and a backlight, increasing measurement precision while reducing computational requirements. Image data may

be processed line-by-line, as opposed to acquisition of an entire frame before beginning processing on conventional systems. Grading rates as high as 15 seedlings per second are feasible. Advantages of line-scan processing for many applications have prompted several equipment suppliers to introduce new hardware for line-scan support.

The requirement of seedling singulation means that automated grading has greater implementation potential at container nurseries than at bare root nurseries. Container-grown seedlings are inherently separated, whereas bare root seedlings may require manual singulation. Fast inspection capability necessitates automated material handling.

Automated Grading Benefits

Automated seedling grading offers the opportunity to sort seedlings into multiple classes defined for optimal performance at various planting sites. Customer specifications may easily be keyed into the system and seedlings sorted accordingly. Increased yields may be realized by sorting and marketing alternate grades, using seedlings normally culled under current practice. These capabilities can increase both nursery yields and seedling value.

Customers can be provided with a statistical description of the seedlings purchased. Accurate seedling package counts are an important additional benefit. Further, package count can set by customer specification, as opposed to the standard single package size currently marketed.

Comprehensive production statistics are often cited as the most valuable benefit of computer vision inspection systems. Applied to nursery management, morphology statistics can be correlated with seed source, weather, cultural practices, and field performance.

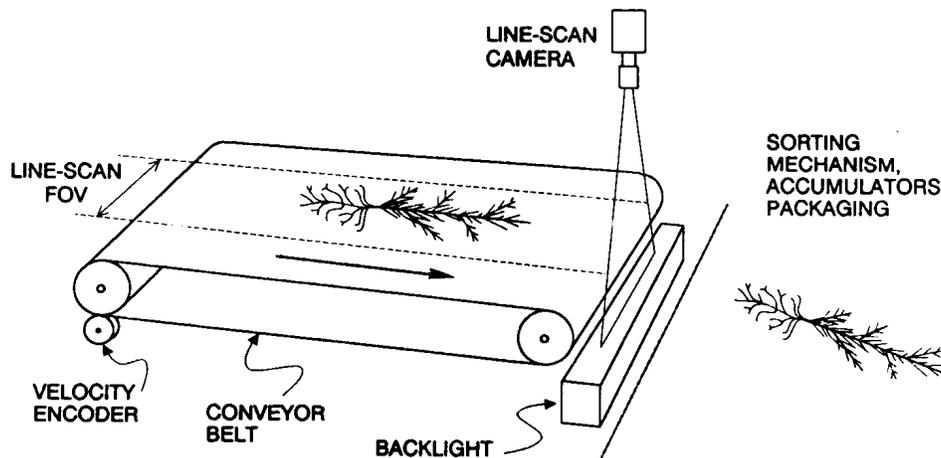


Figure 2.--Seedling grader concept based on line-scan camera and backlighting.

Cost/benefit analysis indicates that implementation of automated grading is economically justified for most large nurseries (Kranzler and Rigney, 1989). Figure 3 illustrates the relationship between manual grading expense and the number of seedlings to be graded in order to recover computer vision equipment costs. We estimate computer vision equipment costs to be \$30,000 to \$40,000 (vision computer, camera, and lighting). This amount does not include one-time inspection software development cost or seedling feeding and sorting equipment. If we assume \$40,000 for equipment and a grading cost of \$4.00/1000 seedlings, Figure 3 indicates that 10 million seedlings must be graded to break even.

Alternatively, a quality control station could provide a low-cost introduction to computer vision benefits. Quality of manually graded seedlings can be evaluated on a sampling basis. A system inspecting one seedling every 2 seconds might be configured for as little as \$10,000.

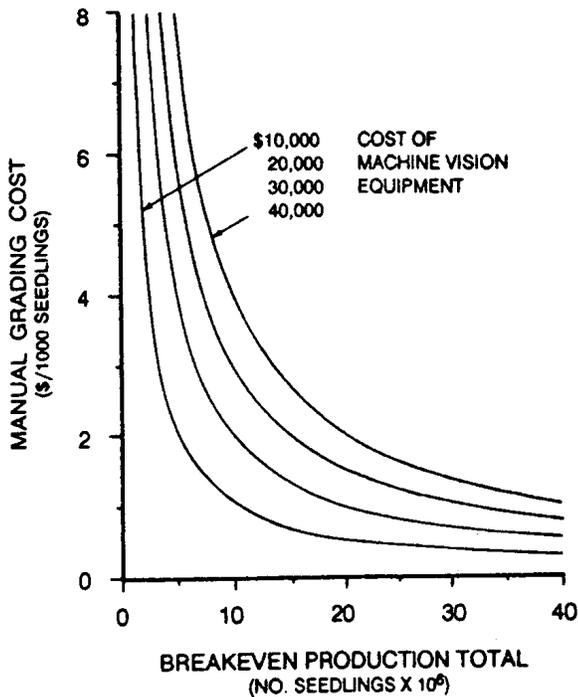


Figure 3.--Seedling production required to recover machine vision equipment costs.

Quantification of New Root Growth

Computer vision systems are currently used to quantify root system morphology for measurement of root growth potential (RGP). Projected root area and total root length are commonly measured (Johnsen et al., 1988; Rietveld, 1989). Current implementations, however, have limited ability to distinguish between new and old root tissue. Root systems are placed on a backlighted diffuser to obtain silhouette images. New

root growth is semi-translucent and shows little or no contrast in backlighted images.

Root system morphology is typically measured before and after a test period during which seedlings are held in an environment favorable to new root growth. New growth tips are removed prior to test initiation, and root system morphology is measured. New root growth is stained after the growth period to enhance contrast, and the root system is measured again. The difference between projected area or total length before and after the growth period is attributed to new root growth.

Rigney and Kranzler (1990) have investigated two techniques allowing quantification of new root growth in a single operation after the growth period. Dark-field illumination and crossed polarizing filters are optical techniques which exploit the translucence of the new root tissue. Existing root measurement systems may be modified to incorporate these techniques. Available software can be used to extract desired features of the new root growth.

Precision of root system measurements can be improved by utilizing a line-scan camera, as discussed above for seedling grading. An early seedling measurement device used a linear 1024-element sensing array to measure projected root area (Buckley et al., 1978). Line-scan cameras with up to 4096 pixels are now available. A simple transport mechanism will be required to either move the camera and backlight past the root system or move the root system between the camera and backlight. A system may be configured at relatively low cost, since seedling handling precludes high inspection rates.

In-Bed Inventory and Emergence Count Bare Root Seedlings

Computer vision may be utilized to improve seedling inventory estimates. Instead of hand counting seedlings in sampling frames, a video camera could be used to acquire images. Seedlings could then be identified and counted by computer vision. Sections or complete beds could be recorded on video tape and later processed automatically by a vision system.

Work by Kranzler et al. (1984) and DeVoe (1987) has shown the feasibility of counting newly emerged and young seedlings with computer vision. Under ideal conditions, simple image thresholding techniques can be used to segment individual seedlings in nursery bed images. DeVoe developed four seedling detection algorithms of varying complexity. These exploited the contrast between the seedling and background, the lines formed by individual needles, and the radial distribution of the needles. A variation on the Fourier transform, although computationally expensive, was able to identify seedlings in noisy images.

Sowing, Emergence Count, and Thinning Container Seedlings

Seedling identification techniques may also be used in the container seedling industry. Here, the problem is much simpler because the environment is highly structured. Expected seedling locations are known. Each cell may be inspected individually.

Computer vision offers the opportunity to sow a single germinated seed in each container. A singulated stream of germinated seeds may be viewed by a vision system programmed to detect newly sprouted roots. Each sprouted seed would be diverted to a waiting cell and sown. Each container block would hold seedlings which sprouted at approximately the same time. This concept provides efficient use of premium seed and eliminates thinning operations.

Algorithms and techniques supporting sprouted seed identification have already been developed. Ling et al. (1990) investigated spectral features for distinguishing between the seed coat and root of germinated tomato seeds. Techniques described by Rigney and Kranzler (1990) for segmentation of new root tissue are also applicable.

Propagation via tissue culture and rooted cuttings are technologies receiving increasing attention. Although currently labor intensive, computer vision guided robots will be key components of future commercial systems (Deleplanque, 1985). Simonton (1989) has developed a computer vision and robotic workcell for vegetative propagation of geranium cuttings.

Under the current practice of sowing multiple seeds per cell, computer vision could determine how many, if any, seedlings have emerged in each cell. A more challenging, but technically feasible task, would be to determine the locations of each of the new seedlings, enabling robotic thinning. Further, the same robot could transplant new seedlings into empty cells.

SUMMARY

Computer vision is a powerful technology offering enhanced product quality and reduced production cost through automation of many nursery operations. Objective assessment, high measurement precision, comprehensive production statistics, and high inspection rates are capabilities of the technology.

Automated tree seedling grading has been demonstrated and is ready for commercialization. Commercial systems are available for measuring root system morphology. Emergence count and bare root seedling inventory applications have been investigated. Computer vision guided robotic sowing, inspection, and thinning of container seedlings have been researched. The versatility and power of computer vision is available

to nursery managers as a tool for growing the target seedling.

LITERATURE CITED

- Ballard, D.H. and C.M. Brown. 1982. Computer vision. Prentice-Hall, Inc. Englewood Cliffs, New Jersey 07632.
- Buckley, D.J., W.S. Reid, and K.A. Armson. 1978. A digital recording system for measuring root area and dimensions of tree seedlings. *Trans. of the ASAE*, 21(2):222-226.
- Chin, R.T. and C.A. Harlow. 1982. Automated visual inspection: A survey. *IEEE Trans. on Pattern Analysis and Machine Intelligence*, PAMI-4(6) :557-573.
- Deleplanque, H., P. Bonnet and J.G. Postaire. 1985. An intelligent robotic system for in vitro plantlet production. *Proc. 5th International Conf. on Robot Vision and Sensory Controls*, 29 - 31 Oct. 1985, Amsterdam. pp. 305-314.
- DeVoe, D.R. 1987. A Fourier transform to detect pine seedlings in a digital image. Unpublished Ph.D dissertation. Agricultural Engineering Department, Oklahoma State University, Stillwater.
- Jain, A.K. 1989. Fundamentals of digital image processing. Prentice Hall, Englewood Cliffs, NJ.
- Johnsen, K.H., P.P. Feret and J.R. Seiler. 1988. Comparison of greenhouse and environmentally controlled growthroom root growth potential testing of 2 + 0 eastern white pine seedlings. *New Forests*, 2: 139-143.
- Kranzler, G.A., D.R. DeVoe and J.P. Gentry. 1984. Opto-electronics and image processing for seedling counting in tree nursery beds. ASAE Paper No. 841091. American Society of Agricultural Engineers, St. Joseph, MI 49085.
- Kranzler, G.A. and M.P. Rigney. 1989. Feasibility of machine vision for tree seedling grading and root growth measurement. Report to USDA Forest Service Technology & Development Center, Missoula, MT 59801.
- Ling, P., G.A. Giacomelli and K.C. Ting. 1990. Feature measurement of germinated tomato seeds for uniform flowering. ASAE Paper No. 907056. American Society of Agricultural Engineers, St. Joseph, MI 49085.
- Novini, A. 1985. Before you buy a vision system. *Manufacturing Engineering*, 49(3):42-48.

- Pratt, W.K. 1978. Digital image processing. John Wiley & Sons, New York.
- Rietveld, W.J. 1989. Evaluating root growth potential of tree seedlings with an automated measurement system. *New Forests*, 3:191-199.
- Rigney, M.P. and G.A. Kranzler. 1988a. Machine vision for grading southern pine seedlings. *Trans. of the ASAE*, 31(2):642-646.
- Rigney, M.P. and G.A. Kranzler. 1988b. Computer vision for grading tree seedlings. Proceedings; Western Forest Nursery Council, Forest Nursery Association of British Columbia, and Intermountain Forest Nursery Association.
- General Technical Report RM-167, USDA Forest Service, Fort Collins, CO. pp. 182-187.
- Rigney, M.P. and G.A. Kranzler. 1989. Performance of machine vision based tree seedling grader. ASAE Paper No. 893007, American Society of Agricultural Engineers, St. Joseph, MI 49085.
- Rigney, M.P. and G.A. Kranzler. 1990. Machine vision technique for measuring new root tissue. ASAE Paper No. 907053, American Society of Agricultural Engineers, St. Joseph, MI 49085.
- Simonton, W. 1989. Geranium stock processing using robotic system. ASAE Paper No. 897054. American Society of Agricultural Engineers, St. Joseph, MI 49085.