Machine Vision Development: Its Use at a Forest Seedling Nursery

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A general overview of the current J. Herbert Stone seedling lifting and processing system is discussed followed by a discussion of the rational and processes of developing a machine vision-based system for grading seedlings.

J. HERBERT STONE NURSERY

The J. Herbert Stone nursery is located in Southwestern Oregon near the city of Medford. It is a U.S.D.A. Forest Service nursery and produces conifer seedlings and other plant materials only for publicly owned lands. The major clients of the nursery are the U.S.D.A. Forest Service and the U.S.D.I Bureau of Land Management and Bureau of Indian Affairs. The capacity of this nursery is approximately 24 million seedlings per year. Since the first shipment of seedlings in 1979, over 275 million seedlings have been shipped to planting sites throughout Oregon, Washington, northern California, northern Idaho, and western Montana.

CURRENT LIFTING AND PROCESSING

One- and two-year-old seedlings are lifted from the nursery seedbeds during the dormant season. The lifting window established for the J. Herbert Stone Nursery is between December 1st and March 1st. The lifting process begins with a machine having a blade spanning the 4-ft wide seedbed. The blade is operated at 10 to 14 inches below the soil surface. There are shaker tines attached behind the blade that shake the seedlings and soil up and down thus loosening the soil from around the seedlings.

The seedlings are then hand-lifted out of the loosened soil with any soil remaining removed from the roots by a gentle shaking motion. The bare-root seedlings are then packed into field containers. Smaller seedlings are placed into plastic tubs and covered with moistened burlap strips. Tall seedlings (over 24 in. tall including roots) are packed into bundles wrapped with burlap. Seedlings to be shipped field-run to clients are placed directly into cardboard boxes which have been lined with a paper or plastic moisture barrier.

The boxes and the plastic tubs are loaded onto pallets on specially designed field trailers. Bundled seedlings are loaded into specially designed steel bins which have been placed on the trailers.

The seedlings are then taken by trailer to the processing facilities. Field-run seedlings boxed for shipment go directly into storage. On especially sunny and/or windy days the entire trailer of tubs or bins may be run under a watering device that wets down the entire load. Eight low-pressure, high-volume nozzles deliver 300 gal of water per minute to soak down the seedlings and initiate a presorting, conditioning treatment. The pallets of tubs and the bins are then moved by forklift into a precooler that is maintained at 34 to 36F and 90% to 100% relative humidity. Additional moisture may be added through fogging devices to assure that the seedlings reach a very low moisture gradient monitored with a Plant Moisture Test device.

Seedlings are transported to the processing shed using a forklift. The plastic tubs or wrapped bundles of seedlings are placed on a moving belt 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 5 or 10 "shippable" seedlings are placed on the same moving belt. This belt moves the shippable seedlings to the front of the processing line where the seedlings are gathered, root pruned, and placed into their final storage and shipping containers.

The shipping containers are either 3-ply brown paper bags with a spray-on liner of plastic (for cooler storage) or cardboard boxes with a 3 mm plastic bag liner (for frozen storage). The bags are closed by either sowing, strapping, or both depending upon the request of the clients. Boxes are stapled closed.

Quality inspection is performed throughout the entire process. A minimum of 1% of all seedlings is inspected for sorting, root trimming, count, etc. Samples of culls are also inspected prior to disposal to assure that we are not destroying too many shippable seedlings.

THE CASE FOR MACHINE VISION

Unlike advances made in preparation of seed and sowing, and the culturing of the seedlings, very little has changed in the lifting and processing of tree seedlings. With the exception of forklifts and conveyers, most of the work is performed manually as it has been for decades. A visit to the J. Herbert Stone Nursery seedling processing shed, like most other nursery processing operations, reminds me of the potato and onion processing sheds in which I worked as a youth in the mid 1950s.

Within the past 10 years, the cost of seedling production has totally reversed. Ten years ago, the cost of tree 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/fail information. Our personnel only take time to determine if grading, pruning, etc. is done to our standards. They do not take time to gather and record actual data such as caliper and height.

Our clients have expressed interest in having actual data on various attributes for each seedling lot they receive. They would utilize this information in making final plans for the use of the seedlings, such as, reserving the seedling lots with heavier root systems and/or larger caliper for the more harsh sites. Having nearly 100 clients and over 650 individual seeding lots each year would require some sort of Automated Data Processing system.

THE PLAN

A few years ago, Paul Morgan, Manager of the D. L. Phipps Nursery operated by the State of Oregon, called me to discuss the possibility of cooperating in the development of an automated system for sorting and handling seedlings. We had both seen attempts being made by researchers. In the mid 1980s, the State of Iowa Forest Nursery had been working with the State University at Ames, Iowa to determine root mass and other characteristics using a camera device linked to a computer. We were also aware of the growing trend towards "machine vision" in the sorting of agricultural seed such as corn and the grading of various commodities such as tomatoes, peanuts, oranges, and french fries.

We agreed to begin actively supporting an effort to develop a machine vision process for grading tree seedlings assuming that the very difficult logistics of handling them would be developed once the visual technology was available. Paul is working through his state procurement folks and I am working though the U.S.D.A. Forest Service Missoula Technology Development Center at Missoula, Montana. We are actually working individually on our own projects, but we are knowingly and willingly sharing information and are actually using a leapfrog system to progress from one stage of development to the next.

THE BEGINNINGS

The project has progressed through several stages of development beginning with lengthy discussions about grading criteria and various technologies available for sensing seedling attributes and computing data. One major choice was whether to utilize an area scan or a line 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 that had been developed, but had not yet been manufactured and released on the market.

In the summer of 1992, Dr. Glenn A. Kranzler and Dr. Michael P. Rigney of the Agricultural Engineering Department at Oklahoma State University successfully demonstrated a prototype machine vision unit at the D. L. Phipps nursery. That fall, the Missoula Equipment Development center issued a solicitation for technical proposals for the development of a Machine Vision Seedling Inspection Station. Oklahoma State University was successful in developing a proposal that met all requirements of the solicitation. A contract was subsequently awarded to the University for development of the Inspection Station.

THE CURRENT MACHINE

In Feb. 1994, the Machine Vision Seedling Inspection Station was delivered to the J. Herbert Stone Nursery. The unit consists of two 18-inch-wide conveyor belts mounted end-to-end to each other on a single frame. The first (upstream) belt is about 6 ft long and the second (downstream) belt is approximately 3 ft long. These belts operate at the same speed and have an electronic variable speed control that allows operating them at speeds of 1 to 3 m sec^{-1}. The distance between the first (upstream) conveyer and the second (downstream) conveyer is about 1/2 inch. This allows a space for the high-intensity fluorescent back-light mounted under the belts to shine upwards between them. A line scan camera is mounted above the conveyers and directly above the light.

This device is manually fed requiring that the seedlings be placed on the conveyer by hand. There is no supporting equipment to feed the seedlings nor to process them after going though the device (such equipment has yet to be developed). Seedlings are placed on the belt top first with their long axis running parallel with the direction of belt travel. As they cross the gap between the two belts, 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 the data is sent to a 50 MHz 486 computer.

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

The seedling features measured include stem diameter, top height, sturdiness ratio, projected shoot area, projected root area, shoot-root ratio, root length, percentage of root area outside the root zone, percentage of fine roots, and root mass length.

Initial testing has shown that the device has some difficulty in calculating the exact location of the root collar. It also has difficulty "seeing" the terminal bud on species such as ponderosa pine where the terminal is covered by long needles. Because of these difficulties, the calculated top heights may vary from actual heights. New software upgrades have been installed, but have not been evaluated. In spite of the difficulties listed above, the stem caliper measurements are very accurate. Other measurements also appear to be accurate. Consistency of measurements has been checked against experienced quality monitors and the machine consistency is very high.

Operational speeds vary depending upon the average length of the seedlings and the distance allowed between scan lines. The machine is designed to handle seedlings with tops ranging from 7 to 91 cm tall and with roots up to 36 cm long. Operational speed will allow from 1 to 10 seedlings/sec at the 1-mm scan interval.

WHAT IS NEXT?

Paul Morgan of the State of Oregon, D. L. Phipps nursery is working with Oklahoma State University to evaluate the use of color and shades of grey in determining off-color foliage and recognizing damage such as stripped roots and other wounds. He reports that excellent progress is being made in this area.

The J. Herbert Stone Nursery will carry out more testing on the current machine. New grading criteria may 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 much better indicators of survival and initial growth than those currently being used.

The development of a complete system is and will remain our final goal. This will include equipment that is capable of singulating and feeding seedlings to the machine, separating out two, three, or more grades of seedlings, performing root trimming and other final preparation of the seedlings, and finally packaging the seedlings. Some of these advances are difficult to even envision. Especially the singulation of the seedlings. However, need drives ingenuity. Separating the seeds and hulls from cotton was a hands-only task not all that many years ago.