# 컴퓨터 畵像處理에 의한 苗木의 형태학적 성질 측정

# Measurement of Morphological Properties of Tree Seedlings Using Machine Vision and Image Processing


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## 摘 要


컴퓨터 畵像處理에 의한 苗木의 형태학적 성질을 측정하기 위하여 화상포착방법과 화상처리 기술 및 관련 연산법을 개발하였다. 이러한 방법에 의한 측정결과를 기존의 측정방법에 의한 측정결과와 비교하여 그 精密度를 分析하였으며, 컴퓨터 畵像에 의한 측정방법의 장점을 고찰하였다.


## I. Introduction

Measurement of morphological properties of tree seedlings, such as stem diameter at the root collar, shoot height, root area, root volume and total weight is a common method of assessing quality (Morrison and Armson, 1968; Buckeley, et al., 1978; Schmidt-Vogt, 1981; Duryea and Landis, 1984; Rigney, 1986). Recently, digital image processing techniques using moderately-priced, powerful microcomputers, and specialized hardware have been introduced, and realtime operations have become possible. The techniques have numerous agricultural applications (daSilva et al., 1985; Meyer and Davison, 1985; Guyer, et al., 1986).

Rigney (1986) developed algorithms for a machine vision grading single-tree seedlings. They measured stem caliper at the root collar, height (length from the root collar to tip of seedling) and projected area of roots. A problem encountered was location of special points in a seddling, i.e., root collar and terminal bud which are barely visible. The root collar is very difficult to locate accurately. Repeated observations of the same seedling could result in differences of several millimeters. The terminal bud is hidden by needles and care must be taken not to damage it.

The objectives of this study was to develop machine vision techniques for measuring stem diameter, shoot height, root volume and seedling mass. The desired precision was 0.2 mm for stem diameter, 1 mm for shoot height, 0.05 cubic cm for root volume and 0.1 gram for seedling mass. Accuracy, or repeatability of measurements was desired to be at least 2%.


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## II. Methods and Materials

### A. Pine Seedlings

The tree seedlings used in this study were loblolly pine, approximately one year old, grown in Hot Springs, Arkansas. Fifty seedlings were selected randomly as samples. The morphological properties were measured by direct methods; shoot height was measured with a ruler with 1 mm minimum scale, stem caliper was measured with a micrometer with 0.05 mm least scale, root volume was observed with a mass cylinder with 0.01 cubic cm minimum scale, and weight was measured with a balance with 0.01 gram least scale.

### B. Machine Vision Hardware

The hardware used for digital image processing were a DT-2851 Frame Grabber and a DT-2858 Auxiliary Frame Processor produced by Data Translation, Inc. The two image processing boards were installed in an IBM-AT microcomputer which was networked to a Sun Microsystems Engineering Workstation (Sun 3/280) for disk file storage. The frame grabber digitizes an entire scene into a 480x 512 array format with 8 bits resolution for each picture element (pixel). The frame processor provides high speed image processing. The digital image processing system includes a separate system monitor which is capable of analog (RS-170) and digital RGB (red-green-blue) input, and a VCR.

Images were taken by an RCA Camcorder Model CMR 300 and stored on video tapes. The video camera has a zoom lens, auto-focus, auto-iris, auto-white-balance and macro functions. The highest resolution of the camera is about 0.2 mm/pixel, when in the macro position. All the images were taken at modes of manual-focus, auto-iris and auto-white-balance. The zoom and macro function were used to provide the necessary field of view.

Backlighting provided a sharp contrast image, or silhouette, which was necessary for dimension measurements, and eliminated the need for further preprocessing. A backlighting table sized 103x134 cm with 4, 34 W fluorescent bulb was used.

Two fields of view (FOV) were used; one for a whole seedling to measure shoot height, root volume and weight, and the other for close-up of stem to measure stem caliper.

FOV for the whole seedling (FOV-1) provided a resolution of about 1 mm/pixel, for a horizontal alignment of camera and seedling. Since the samples had a total length up to 90 cm, it was necessary to take 2 images per seedling. A cross shaped marker was located in the middle of the lighting table to permit programmed connection of the two images.

FOV for the stem caliper measurement (FOV-2) was chosen to be the highest resolution of the camera because of the high degree of precision required.

### C. Experimental Design

The first experiments were performed with geometric samples of known dimensions in order to determine proper threshold values, and horizontal and vertical scale factors. The second experiments were conducted to determine accuracy of the measurements for loblolly pine seedlings.

Experiments with the geometric samples were conducted for both field of views. For FOV-1, two sets of samples were used. The first set consisted of 11 shapes have the same area, sized 24x3,20x3.6, 16x4.5, 12x6,10x7.2, 8x9, 7.2x10, 6x12, 4.5x16, 3.6x20, and 3x24 cm. The second set consisted of 9 different areas 3x3, 4x4, 5x5, 6x6, 7x7, 8x8, 8.5x8.5, 9.3x9.3, and 10x10 cm. The two sets of samples were tested separately in order to check for an effect of variation of whiteness (white and black ratio) in an image on the accuracy of the dimensional measurement. For FOV-2, the geometric samples consisted of 12 pieces sized 0.2x6, 0.3x6, 0.4x6, 0.5x6, 0.6x6, 0.8x6, 0.9x6, 1x6, 1.1x6, 1.2x6, 1.5x6, and 2x6 cm.

Pine seedling samples were video-taped with two kinds of markers, triangular and circular, to locate the root collar and the terminal bud, respectively.

The triangular marker was fixed on the backlighting, but the circular marker was movable. Each seedling was placed on the lighting table so that the root collar aligned with tip of the fixed triangular marker. Then the center of the circular marker was moved horizontally to be in line with the terminal bud.

## III. Analysis Procedures and Algorithms

All images were thresholded without preprocessing. Threshold values which gave the minimum measurement error were determined from experiments with the geometric samples. Images of geometric samples were thresholded at different levels, and the dimensions measured by counting pixels three times for each dimension and averaged. Areas were determined by counting all black pixels. Scale factors, or image resolution in millimeters per pixel, were calculated by dividing the measured length by the number of pixels for the two largest geometric samples, and averaging the results. Measurement errors were calculated for each threshold value by comparisons between the known dimensions and the measured values. The threshold value which resulted in the most accurate measurement was then used for all images taken at the same field of view.

Pictures of pine seedlings were thresholded and the markers were located using a template technique. Centers of the cross and circular markers, and the tip of the triangular marker were located using templates constructed with 8, 17 and 10 pixels, respectively. About one half of the pixels for the templates was for black pixels and the other half was for white pixels in the background near the marker. When the markers were located, the markers were removed from the displayed image.

Shoot height was measured by counting the number of horizontal pixels from tip of the triangular marker to the center of the cross marker in a root scene and from the center of the cross marker to the center of the circular marker in an image of the upper part of a seedling.

Stem diameter was measured by counting black pixels located on a line above the tip of the triangular marker. The number of black pixels for each segment of continuous black pixels on the line was counted separately in order to eliminate the effect of lateral roots which might exist. The largest number continuous black pixels was selected as the stem diameter. Besides this measurement at the root collar, stem diameter was measured at 11 points located evenly on the right and left side of the root collar at about 1 mm interval. Average and median values were calculated to compare with the stem diameter at the root collar. Projected area of the roots was measured and compared to the root volume observations. Root area was measured by counting all black pixels to the left of the root collar. Projected area of the whole seedling was measured and compared to the weight of a seedling. The area was determined by counting all black pixels in the two frames for each seedling.

## IV. Discussion of Results

### A. Geometric Samples Measurements

The accuracies obtained from the measurement of geometric samples were averaged for each threshold value and the results are shown in Fig. 1, 2 and 3. Images taken from FOV-1 for the test pieces of same area (Fig. 1) and various area (Fig. 2) resulted in almost

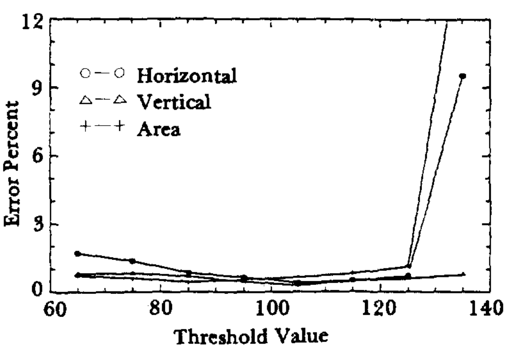


Fig. 1. Relationships between threshold value and measurement error for horizontal and vertical lengths and areas of the same area geometric sample images taken at the FOV-1.

the same pattern of variation of the accuracy for both of horizontal and vertical lengths and area. The accuracies were almost the same for threshold values between 85 and 115. A threshold value of 105 was selected and the previously determined scale factors were used for all pictures taken from FOV-1.

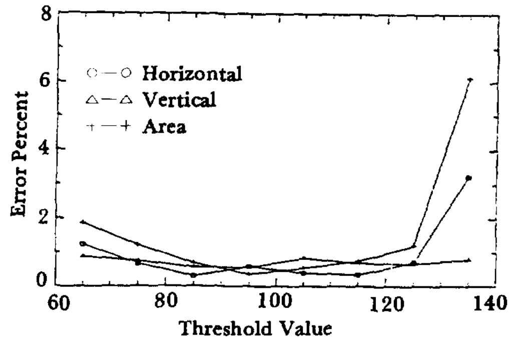


Fig. 2. Relationships between threshold value and measurement error for horizontal and vertical lengths and areas of the various area geometric sample images taken at the FOV-1.

Images taken from the FOV-2 for the stem diameter measurement resulted in almost the same pattern of accuracy; however, the range of threshold value for the same accuracy was slightly lower (85 – 105). A threshold value of 95 was selected and scale factors derived were used for all pictures taken from FOV-2.

Measurements from FOV-1 images were more accurate than FOV-2. Precision of the dimensional measurement is affected by location of an image in the lattice of the pixel array. Usually, borders of an image do not match exactly with the boundary of picture elements. When a picture is thresholded, the border pixel might or might not belong to the object. Normally the border pixel belongs to the object if the pixel covers more than 50 percent of the object. Hence a maximum error due to the coverage at a border is ± 1/2 pixel for each side, or ± 1 pixel for the whole object. Therefore, the precisions were ±1/512 and ±1/480 of full scale for horizontal and vertical lengths, respectively.

The precision of each machine vision measurement depends upon length of the object. Since horizontal and vertical dimensions of the geometric samples for FOV-1 were almost the same the average accuracy was close. However, test pieces for FOV-2 had quite different horizontal and vertical dimensions. Horizontal lengths were 6 cm while vertical lengths ranged from 0.2 to 2.0 cm. This is why the accuracies were different in Fig. 3. This accounts for the difference in measurement accuracy between FOV-1 and FOV-2.

The geometric samples were nearly ideal objects to be measured by machine vision. These provided theoretical accuracies for measurements of seedling features.

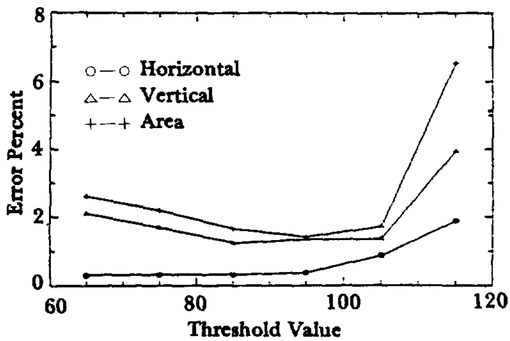


Fig. 3. Relationships between threshold value and measurement error for horizontal and vertical lengths and areas of the geometric sample images taken at the FOV-2.

## B. Pine Seedling Measurements

1) Shoot Height

Shoot height measured by machine vision is compared to hand measurements in Fig. 4. The strong correlation coefficient indicates that machine vision can be used to accurately measure seedling height with this procedure. Error and accuracy for each measurement by machine vision were calculated using the same procedures as for the geometric samples. The errors were in a range of ± 4.5 mm with a standard deviation of 2.0 mm. The relative errors averaged 0.87 percent with a standard

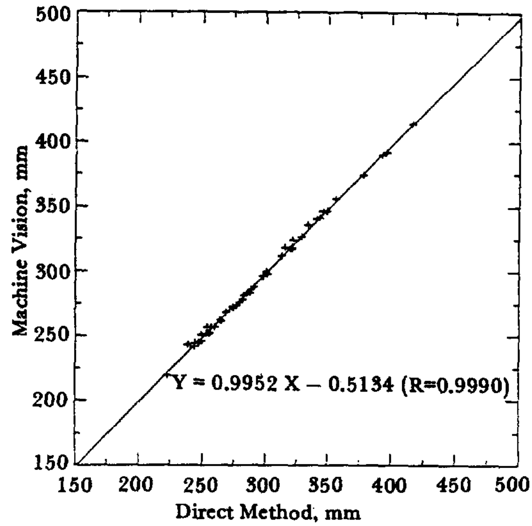


Fig. 4. Comparison of direct manual measurements and machine vision measurements of shoot height.

deviation of 0.45 percent.

The average accuracy was about 2 times higher than that of the geometric samples for FOV-1. The height measurement by the machine vision was similar to the geometric samples and the hand measurements except for the connection of the two frames for each picture. Location of the cross marker for the connection of the two frames for each picture has an uncertainty of 1 pixel; however, the main sources of inaccuracy were due to the uncertainty in locating the root collar and placing the circular marker to locate the terminal bud. Repeated, manual observations of the same seedling resulted in differences of 1 to 3 mm, or about 0.1 to 1 percent of shoot height. It was concluded that machine vision measurement of seedling height is at least as accurate as direct manual observations.

2) Stem Diameter

Mean values of the stem diameter observations at 11 locations surrounding the root collar were correlated with the stem diameter

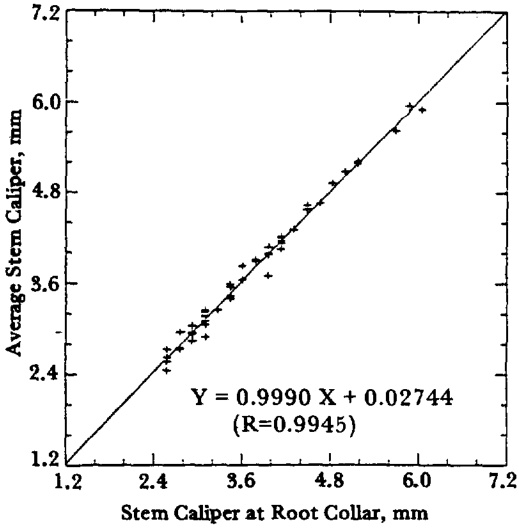


**Fig. 5. Comparison of stem diameters at root collar and average stem diameters.**

at the root collar, and a correlation coefficient of 0.9945 was obtained (Fig. 5). The result implies that difference between the two machine vision methods was not significant, and one time measurements of stem diameter at the root collar is sufficient. Median values of the stem diameter at the 11 locations were correlated with the stem diameter at the root collar with a coefficient of 0.9997.

Stem diameter at root collar as measured by machine vision were compared with the direct hand measurements. A correlation coefficient of 0.9827 exists between the two (Fig. 6). Differences between the two observations averaged ± 0.4 mm, with a standard deviation of 3.0 percent. The relative accuracy was 3.8 percent. One factor contributing to these differences is the fact that the sectional shape of the stem is not a perfect circle. Stem diameters measured by a micrometer showed differences of 0.1 – 0.3 mm which were 2 – 6 percent of measured value. Hence the differences between the two methods are considered not significant, and machine vision is concluded to be an accurate method of measuring stem diameter.

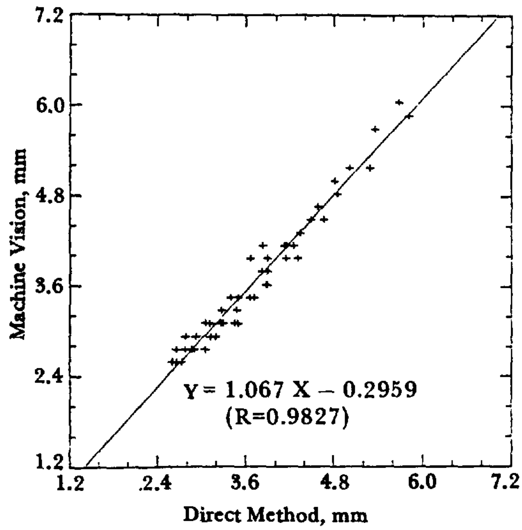


**Fig. 6. Comparison of direct manual measurements and machine vision measurements of stem diameters.**

3) Root Volume

The projected areas of roots measured by machine vision were compared to measured root volumes, and resulted in a correlation coefficient of 0.8051. A common logarithmic transform was performed on the experimental data because the general shape of a root could be assumed as a long cylinder and the volume of a cylinder is proportional to the square of its sectional area. A correlation analysis was performed on the transformed data, and resulted in a higher coefficient, 0.8578 (Fig. 7).

It should be noted that projected area might be better correlated with surface area than with root volume. The machine vision technique used here is essentially the same as the method developed by Morrison and Armson (1968) who employed a photocell to estimate root surface area and called the result

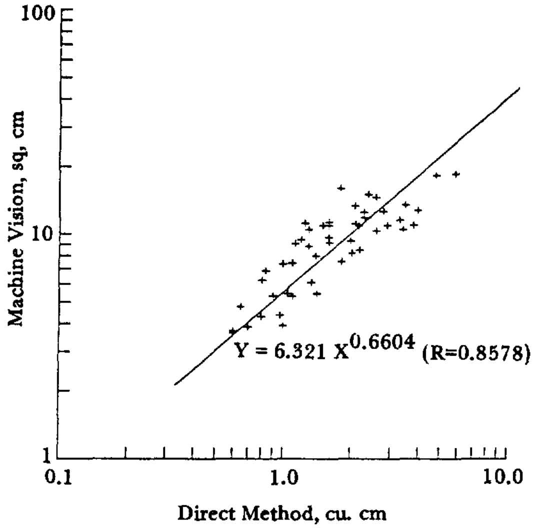


Fig. 7. Comaprison of direct manual measurements and machine vision measurements of root volume.

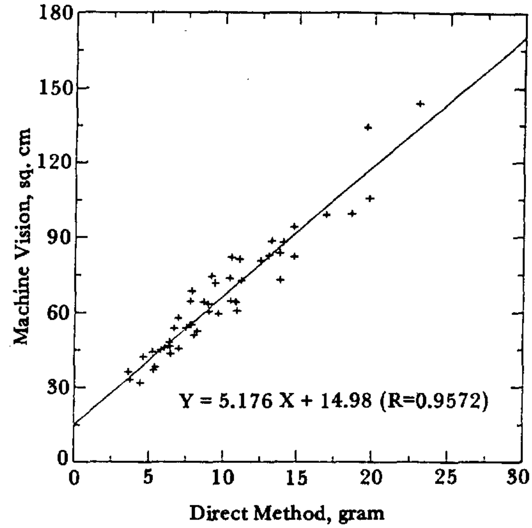


Fig. 8. Comparison of direct manual measurements and machine vision measurements of weight of a seedling.

"root index". They reported a correlation coefficient of 0.98 between the root surface area and the root index. Because root surface area is a good estimate of physiological quality of seedlings (Duryea and Landis, 1984), it is concluded that machine vision can be used, despite the lack of an extremely strong correlation between projected area and volume of roots.

4) Seedling Weight

Projected areas of whole seedlings measured by machine vision were compared to the weight of the seedlings (Fig. 8). The analysis showed that projected area is highly correlated (0.9572) to weight. A linear regression model was developed using the first 20 seedlings. The model's validity was tested using the experimental data for 50 seedlings. Errors of the estimates ranged from −2.6 to +2.7 grams. Relative errors averaged 11.1 percent with a standard deviation of 8.4 percent. Although this accuracy is less than the desired value for research purposes, machine vision estimates of seedling weight may be accurate enough for production situations. Machine vision makes it possible to make non-destructive estimates of the shoot weight to root weight ratio, or the sturdiness ratio (Duryea and Landis, 1984).

5) Time Requirements

On the IBM AT microcomputer-based imaging system available in the Agricultural Engineering Department, an image took about 5 seconds for thresholding, 4 seconds to locate the markers, and less than 1 second for other steps. Total time requirement for the measurements from the location of a seedling on the lighting table to recording the final data on a computer disk was about 40 seconds for a seedling. The direct measurements took about 5 to 7 minutes for a seedling by the methods used in this study and about 50 seconds with the transducers (Buckley et al., 1978) for length measurements and the other instruments used in this study. Rigney (1986) reported a time requirement of 0.25 second for grading a singulated pine seedling with a machine vision system. Hence, it was expected that the time requirement for the measurement could be reduced remarkably by using special purpose, high-speed machine vision hardware.

## V. Conclusions

The results of this study prove that machine vision can be used to measure morphological features related to seedling quality. In some cases measurements were of secondary features (i.e., projected root area) rather than a primary feature (i.e., root volume) and because the two are not perfectly correated, the accuracy of measurement was less than desired for research purposes. However, machine vision and image processing may be adequate for grading seedlings in a production environment, especially when other quality indicators, such as sturdiness ratio, are included.

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