A DIGITAL LEAF-AREA MEASURING SYSTEM USING A TELEVISION-SCANNED CONVEYOR

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INTRODUCTION

The measurement of leaf area is important in plant breeding, growth, and competition studies and in determining insect and virus damage to plants. Because large numbers of samples are usually considered, a rapid, accurate method of measurement is required and digital outputs suitable for automatic computer-compatible data recording equipment are desirable. The many analog photoelectric leaf area planimeters previously described (2, 3, 4, 6, 7, 8) are not readily adaptable to sample feed mechanisms for rapid sample measurement; require elaborate optical systems to reduce errors due to variation in transmission, reflectance, and texture characteristics of different leaves (5); require frequent calibration to compensate for aging of light sources and photocells; and lack digital outputs necessary for automatic data recording. Digital leaf area planimeters with conveyor transports for rapid sample measurement are available commercially (Paton Industries Pty. Ltd., 35 Henry St., Stepney, Australia, and Hayashi Denko Co. Ltd., Tokyo, Japan). The former instrument uses discrete photocells in a digital array and the latter uses a scanning light spot with digital processing to overcome errors due to variation in leaf light transmission or reflectance. However, these instruments can only accommodate leaves up to 10 cm in width and do not provide digital outputs for data recording.

The instrument described here can measure the area, the maximum length, and the maximum width of leaves up to 18.5 cm in width and 99,999 cm^2 in area, and uses a leaf-flattening conveyor for rapid measurement of samples. The instrument, an adaptation specifically for leaf area measurement of a previous device (1), uses a standard close-circuit television camera to provide transverse scan measurement and a conveyor to provide longitudinal scan measurement. The measurements are displayed on three separate digital readouts and binary-coded decimal (BCD) outputs are provided for data recording.

DESCRIPTION AND OPERATION

The instrument (Figure 1) consists of a leaf transport assembly and a video processing and digital display unit. Details of the operation and circuitry of the system have been described previously (1) and apply to the system described here (Figure 2), with the exception of minor circuitry additions and the transport unit, which were designed specifically for leaf area measurement.

Basically, the television camera scans a portion of the leaf as the leaf is conveyed through the camera's viewing field by the transport unit. The video processing unit selects one center region horizontal line from each of the camera's picture fields and produces a voltage pulse whose width corresponds to the physical width of the leaf appearing in the selected line. This pulse width can be considered as the length of a narrow transverse element of the leaf. The area is then measured by summing, in an accumulating digital counter, the lengths of each narrow transverse element of the leaf as the leaf is conveyed at a fixed speed past the camera. Measurement of maximum leaf width is determined by a maximum detector circuit that stores only the value of longest transverse element that occurred during the leaf's transfer through the system. Maximum leaf length is measured by counting the number of horizontal lines in which the leaf appeared during passage through the system. On comple-

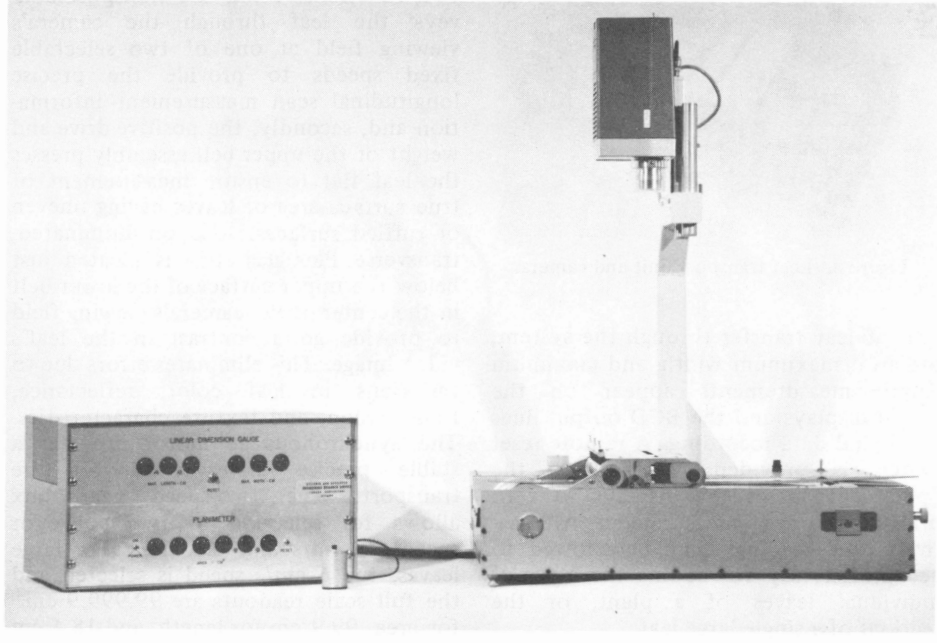

Figure 1. The leaf-area measuring system showing the processing and digital display unit, and the leaf transport unit.

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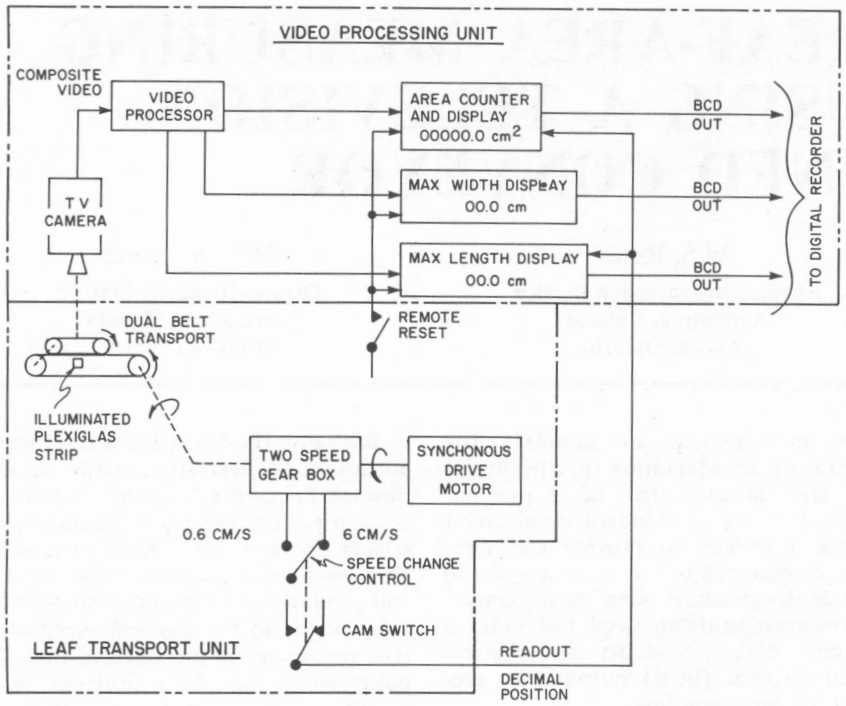

Figure 2. Block diagram of leaf-area measuring system.

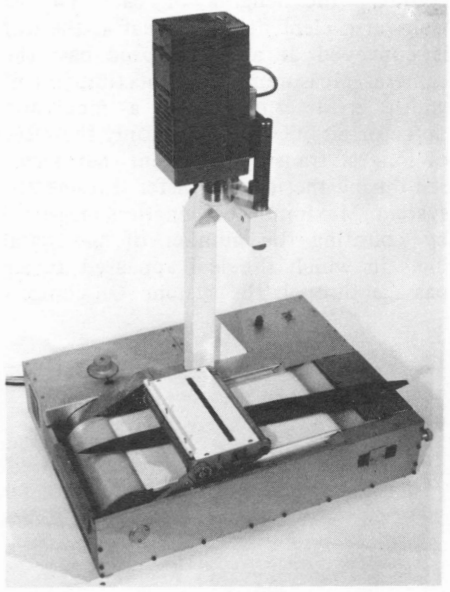

Figure 3. Leaf transport unit and camera.

tion of leaf transfer through the system, the area, maximum width, and maximum length measurements appear on the digital displays and the BCD output lines for digital data recording. A remote reset switch is provided that allows the operator to reset the displays to zero prior to the next measurement. Alternatively, the readings may be allowed to accumulate, say for adding the areas of individual leaves of a plant, or the sections of a single large leaf.

The leaf transport unit (Figure 3) consists of a dual-belt transport, a two-speed gear box with speed changer, a synchronous ac drive motor, and a cam-operated decimal point switch. The transport consists of two continuous roller-friction driven belts located one on top of the other. The upper belt (clear polyethylene) is equal in width but shorter in length than the lower belt (mylar) to allow for optimum placement of the leaf on the lower belt prior to measurement and compression beneath the upper belt. The transport provides two functions. First, the transport conveys the leaf through the camera's viewing field at one of two selectable fixed speeds to provide the precise longitudinal scan measurement information and, secondly, the positive drive and weight of the upper belt assembly presses the leaf flat to ensure measurement of true surface area of leaves having uneven or ruffled surfaces. Also, an illuminated, transverse Plexiglas strip is located just below the upper surface of the lower belt in the center of the camera's viewing field to provide good contrast in the leaf's video image. This eliminates errors due to variations in leaf color, reflectance, transmission, and texture characteristics. The synchronous ac motor provides a stable precise drive speed for the transport. The two-speed gear box allows for selection of two conveyor speeds, 6 cm/s and 0.6 cm/s. For large leaves, the 6 cm/s speed is selected and the full scale readouts are 99,999.9 cm^2 for area, 99.9 cm for length, and 18.5 cm for width. For smaller leaves, the 0.6-cm/s speed may be selected to increase the measurement range. In this case, the full scale readouts are 9,999.99 cm^2 for area, 9.99 cm for length, and 18.5 cm for width.

A cam-operated switch, controlled by the speed change control, locates the readouts' decimal points in the correct positions corresponding to the selected conveyor speed.

PERFORMANCE AND DISCUSSION

Black rectangular test pieces of known dimensions and area were used to determine the system's accuracy (Table I). Assuming the measured area to be the average of 10 readings per test piece, the error for test pieces less than 5 cm^2 was found to be within ±2% of the true area, whereas the error for test pieces greater than 5 cm^2 was within ±0.85% of the true area.

Also, the areas of soybean, alfalfa, grass, and vetch leaves were measured with a mechanical planimeter (Keuffel and Esser Model 4242; accuracy within ±0.5%), and these readings were compared with those obtained using the electronic instrument (Table II). Again, averages of 10 samples were considered. The error on soybean leaves was within ±0.2%; on alfalfa within ±1%; on grass, within ±3.5%; and on vetch, within ±7.25%. The rather large errors for vetch are due to the small individual leaflets that comprise the compound leaf. The dimensions of both the long narrow grass leaf and the small vetch leaflet approach the horizontal and vertical lineal resolution of the system (about 0.1 cm). Increased accuracy in measuring the area of smaller leaves could be obtained by increasing the magnification and hence lineal resolutions (by placing the camera closer to the sample), at the expense of reducing the maximum width of leaf that could be measured.

The cost of materials for the system was about $2,500 apportioned as follows: the component cost of the video processing unit was about $1,000 including the camera at $550; the material cost of the leaf transport unit was about $1,500, consisting of $300 for standard commercial components and $1,200 for custom machined parts.

CONCLUSIONS

The system described provides a means for rapid measurement of the area of leaves up to 18.5 cm in width and 99,999 cm^2 in area with an accuracy within ±2% for leaves or leaflets about 10 cm^2 in

TABLE I AREA MEASUREMENT PERFORMANCE ON RECTANGULAR TEST PIECES

Transport speed (cm/s)	Size (cm)	Actual area (cm^2)	Measured area (mean of 10 readings) (cm^2)	Range of readings (cm^2)	SD ($\pm cm^2$)	Average error (% of actual area)
6	1.0X1.0	1.0	1.0	0.9-1.1	0.05	0
0.6	1.0X1.0	1.0	0.99	0.96-1.02	0.02	−1.0
6	0.99X4.0	3.96	4.04	3.9-4.1	0.09	1.0
0.6	0.99X4.0	3.96	3.99	3.96-4.05	0.03	0.75
6	0.505X9.9	5.0	4.89	4.8-5.0	0.08	−2.0
0.6	0.505X9.9	5.0	5.00	4.82-5.16	0.09	0
6	1.0X19.9	19.9	19.73	19.6-20.0	0.14	−0.85
0.6	1.0X19.9	19.9	19.96	19.82-20.04	0.09	0.28
6	1.5X26.5	39.75	39.92	39.1-40.4	0.50	0.43
6	5.05X20.0	101.0	100.74	100.2-101.3	0.41	−0.26
6	5.05X30.0	151.5	150.9	150.5-151.2	0.28	−0.4
6	5.01X91.65	459.17	457.69	455.6-459.6	1.21	−0.32
6	8.05X40.05	322.4	320.62	318.5-322.6	1.20	−0.55
6	10.0X91.65	916.5	915.63	914.6-916.9	1.29	−0.095
6	15.0X66.8	1002.0	1002.87	1001.0-1004.2	1.25	0.085
6	15.05X91.65	1379.33	1369.76	1367.6-1372.7	1.76	−0.69

TABLE II COMPARISON OF MECHANICAL AND ELECTRONIC PLANIMETERS IN MEASURING AREA OF SOYBEAN, GRASS, ALFALFA, AND VETCH LEAVES (AREAS SHOWN ARE MEANS OF 10 READINGS, TRANSPORT SPEED 6 CM/S FOR ALL ELECTRONIC PLANIMETER READINGS)

Plant	Area, mechanical planimeter (cm^2)	SD ($\pm cm^2$)	Area, electronic planimeter (cm^2)	SD ($\pm cm^2$)	Difference error (% of reading)
Soybean	56.09	0.68	56.14	0.19	+0.089
Soybean	39.88	0.24	39.87	0.29	−0.025
Soybean	35.82	0.38	35.88	0.20	+0.168
Alfalfa	3.48	0.13	3.51	0.03	+0.862
Grass	9.63	0.16	9.96	0.14	+3.42
Vetch	33.45	-	31.02	0.16	−7.25

area. The measurements are displayed digitally and presented also in BCD format for automatic data recording. For equivalent system accuracy for measuring leaf areas below 10 cm^2, increased magnification along with reduced leaf width handling capability could be implemented.

SUMMARY

A digital leaf area measuring system accurate to within plus or minus 2 percent is described. The system uses a standard television camera to provide transverse scan measurements and a fixed-speed leaf-flattening conveyor device to provide longitudinal scan measurements. The system can accommodate leaves up to 18.5 centimeters in width and up to 99,999.9 square centimeters in area. Maximum leaf length and width measurement readouts are also provided. For smaller leaves, a divide-by-10 conveyor speed reduction control is provided to increase the measurement range. The maximum readout for the latter case is 9,999.99 square centimeters.

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REFERENCES

1. Buckley, D.J. and W.E. McAdam. 1972. A television-scanned, digital planimeter and dimension gage for measuring size of agricultural produce. Amer. Soc. Agr. Eng. 15: 324-326.

2. Carmen, P.D. 1963. A large-stage photoelectric planimeter for leaves. Appl. Opt. 2: 1317-1321.

3. Davis, R.G., G.W. Robertson, W.C. Johnson, and A.F. Wiese. 1966. A modified optical planimeter for measuring leaf area. Agron. J. 58: 106-107.

4. Frear, D.E.H. 1935. Photoelectric apparatus for measuring leaf areas. Plant Physiol. 10: 569-574.

5. Hurd, R.G. and A.R. Rees. 1966. Transmission error in photometric estimation of leaf area. Plant Physiol. 41: 905-906.

6. Miller, E.E., C.A. Shadbolt, and L. Holm. 1956. Use of an optical planimeter for measuring leaf area. Plant Physiol. 31: 484-486.

7. Robinson, P.P., W.A. Shands, C.L. Stormann, and G.W. Simpson. 1970. An improved optical planimeter for measuring area of detached leaves used in estimating populations of aphids. J. Econ. Ent. 63: 1159-1162.

8. Voisey, P.W. and M. Kloek. 1964. A portable leaf area measuring instrument. Can. J. Plant Sci. 44: 389-391.