Automated Analysis of Charts From Continuously Recording Weather Instruments

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ABSTRACT

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A graphics digitizer linked to a computer can be used to transcribe data rapidly from recording instruments such as hygrothermographs with rectangular charts or leaf wetness recorders with circular charts. Equations are presented that correct digitized data for circular charts, pen arm curvature, and clocking errors. The techniques described can be adapted to nearly any type of rectangular or circular chart and require less than one-tenth the time required to transcribe and code the same data manually. Digitizer accuracy is well within error range normally associated with devices such as hygrothermographs.

Additional key words: temperature, humidity, epidemiology.

Weather instruments that record on clock-driven rotating charts (eg, thermographs, hygrothermographs, mechanical leaf wetness recorders, etc.) have been used extensively for measuring environmental conditions associated with the development of plant disease (7,8). Simple operation, portability, internal power, low cost, and availability make these instruments ideal for field applications where a continuous record of weather conditions is desired. However, the operational overhead cost of transcribing the chart data into a usable form is a major, but often overlooked, expense of using these instruments. It has become desirable to use hourly data for analyzing plant disease epidemics (4), and this requires manual conversion of temperature, humidity, or leaf wetness values to machine-readable (digital) form before the data can be analyzed. This procedure is costly, it delays access to the data, and is subject to errors that arise from job tedium and the difficulty of correcting clocking errors (ie, a slightly fast or slow clock). Use of a graphics digitizer to transcribe chart data has been

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suggested (6), and a method has been published recently (2). Our procedure is faster and more accurate than the one described by Anthony (2) because we have developed generalized methods that allow transcription of hourly values from rectangular or circular charts and corrections both for pen arm curvature and clocking errors.

EQUIPMENT

Environmental data were recorded on hygrothermographs that used standard charts (U.S. Weather Bureau, / W.B. 207), and hemp string leaf wetness meters (DeWit type, Valley Stream Farms, Orono, Ontario, Canada) that used circular charts. Data were transcribed with a graphics tablet and digitizer (Model HW-2-14, Summagraphics Corp., Fairfield, CT 06430) connected either to a single process computer (IBM 1800) through a parallel interface or to a time share computer (Prime 400) through a serial interface. The graphic digitizer electronically sensed the position of a pen-like stylus when placed on the digitizing field (a 35 cm × 35 cm flat tablet). Thus, lines, points, or flat objects traced on the field can be characterized by sets of x,y coordinates. A stream of coordinates was transmitted to the computer at the rate of one point for every 0.025 cm of stylus movement across the tablet. A FORTRAN program was written to control data flow from the digitizer, process the coordinates accepted from the digitizer, and to make necessary conversions or corrections of the data. The program then stored the corrected, digitized data on a bulk storage device in a form ready for further computer manipulation or analysis.

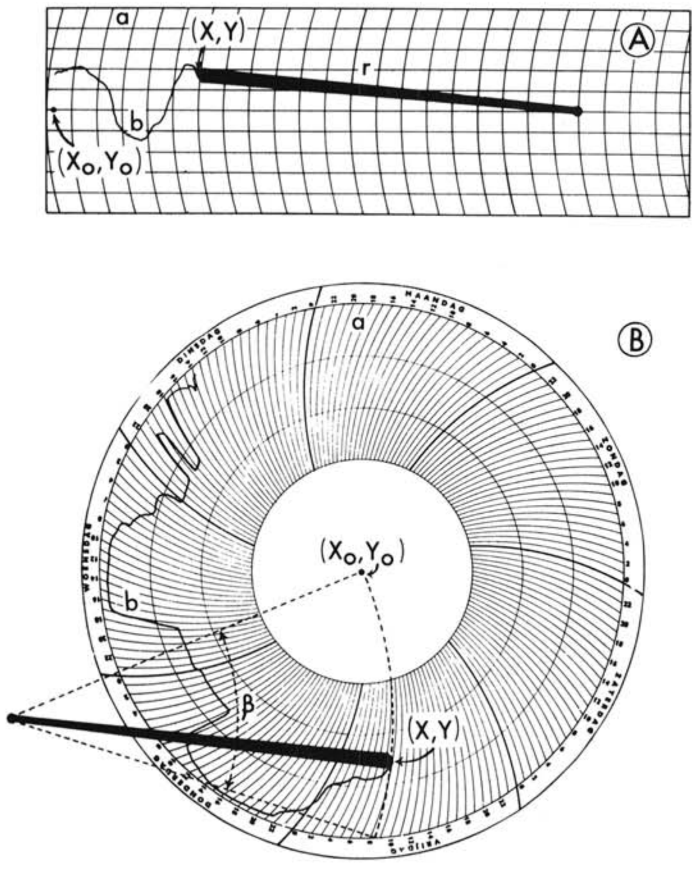

Fig. 1. Diagram of important variables associated with the conversion of data from a non-Cartesian coordinate system to a Cartesian coordinate system. **A,** Typical thermograph portion of a hygrothermograph chart and variables for Eq. 1 and 2. **B,** DeWit leaf wetness recorder chart values for Eq. 3 and 4. Legend: a = chart; b = pen trace; r = pen arm and arc radius; x_0, y_0 = Cartesian coordinates of chart origin; x, y = Cartesian coordinates of data point; and β = maximum angle of pen arm swing.

THEORETICAL CONSIDERATIONS

Most recording devices, such as hygrothermographs and leaf wetness recorders, utilize a pen in a fixed pivot which causes one of the coordinates to follow an arced path. Digitizers use a simple Cartesian coordinate system, which requires that data coming from the digitizer must be corrected for the curvature. The basic correction for hygrothermograph data was accomplished with the following equations:

$$x_c = x - r + [r^2 - (y-y_0)^2]^{1/2} \qquad \text{Eq. 1}$$

$$y_c = y_0 + r(\arctan[(y-y_0)/(r^2 - [y-y_0]^2)^{1/2}]) \qquad \text{Eq. 2}$$

in which x_c and y_c are the corrected x (time) and y (temperature or humidity) values, respectively, x is the uncorrected x coordinate, y is the corresponding coordinate value of x, y_0 is the y component of the starting time coordinates, and r is the arc radius (pen arm length). The variables on the right side of Eq. 1 and 2 are illustrated in Fig. 1A. Equation 2 corrects for the increasing length of arc travel between horizontal lines at the extremes of the y value range. This correction is relatively insignificant so the uncorrected y value normally can be used in any further calculations.

The coordinate correction for the leaf wetness recorder is more complex because the x coordinate has a circular orientation and the y coordinate is on an arc. The corrections are made by the following equations:

$$x_c = Q - \beta/2 + \sin^{-1}([(x-x_0)^2 + (y-y_0)^2]^{1/2}/2r) \qquad \text{Eq. 3}$$

$$y_c = r[\beta - 2\sin^{-1}([(x-x_0)^2 + (y-y_0)^2]^{1/2}/2r)] \qquad \text{Eq. 4}$$

in which $Q = \tan^{-1}[(y-y_0)/(x-x_0)]$

if $x-x_0 \geqslant 0$ and $y-y_0 \geqslant 0$

$Q = \tan^{-1}[(y-y_0)/(x-x_0)] + \pi$

if $x-x_0 < 0$

$Q = \tan^{-1}[(y-y_0)/(x-x_0)] + 2\pi$

if $x-x_0 \geqslant 0$ and $y-y_0 < 0$

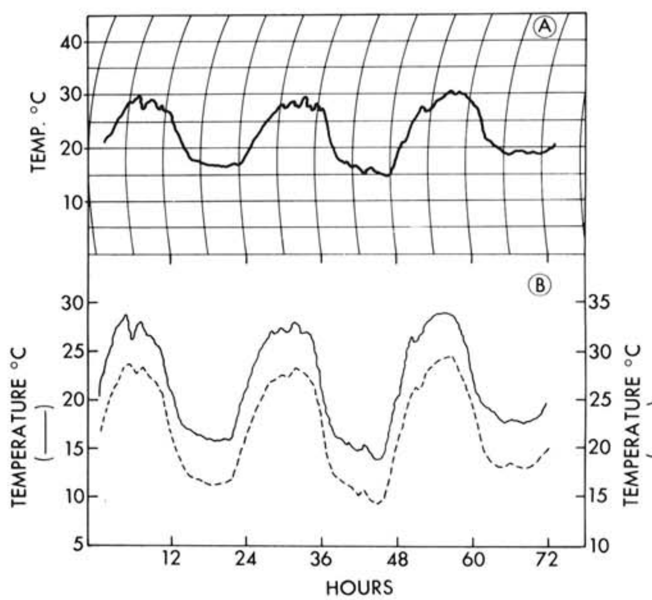

Fig. 2. Comparison of a 72-hr temperature plot from **A,** an actual hygrothermograph chart, and **B,** the data stream coming directly from the digitized hygrothermograph chart (——) and the closest hourly temperature values selected by the program (----).

β is the maximum angle (in radians) of pen arm swing across the chart, x and x_0 are the x coordinate (time) values of the data point and origin (center of chart), respectively, y and y_0 are the y coordinate (wetness) values of the data point and origin, respectively, and r is the length of the pen arm. A graphic presentation of the variables is shown in Fig. 1B.

Once the basic corrections were made, predetermined scaling factors were used to convert the coordinate values into actual time, temperature, humidity, or proportion of leaves wet.

DIGITIZER OPERATION

The use of a graphic digitizer greatly reduced the physical and mental effort usually required to transcribe continuous chart data. Hourly temperature and humidity values can be manually transcribed from a hygrothermograph chart (1 week's data) in 30–60 min. With our system the same chart can be digitized in 3–5 min and the data are immediately available to the computer. Digitizer resolution was 0.025 cm, thus the system accuracy depended largely on user care to precisely trace the ink line on the chart. A comparison of temperature data from the actual ink line on a hygrothermograph chart (Fig. 2A) with the plot of the corresponding continuous point stream from the digitizer and the plot of hourly temperature values derived from the program (Fig. 2B) indicates the accuracy of the digitizer and the program. Deviation of digitized temperature from the chart temperatures was less than 0.6 C (1 F). Deviation of relative humidity values was about 1%. Correction for a fast or slow clock was accomplished by distributing the time error over the real time period as determined from the actual start and stop times of the hygrothermograph (Fig. 3).

The program for digitizing circular leaf wetness recorder charts is similar to that for hygrothermograph charts, although the output values are fractional portions of complete leaf wetness (0 = dry, 1 = wet). As long as one completely dry and one completely wet period occurs during the week (either naturally, or by calibration), all intermediate periods can be adjusted accordingly; therefore, it is not essential for the physical position of the dry (0) and wet (1) lines to be the same from chart to chart.

Blume et al (3) provided a more detailed description of the operation of the digitizer and the programs.

DISCUSSION AND APPLICATION

The techniques described herein can be used in conjunction with most graphic digitizers (1) to provide rapid transcription of chart data to a computer-usable form. Digitizing rates can be more than 10 times faster than manual transcription. Digitizing at a continuous and rapid rate (> 50 coordinates per second) is not only faster than digitizing individual values point by point as suggested by Anthony (2), but also allows, with appropriate programs, the ability to automatically select the value closest to the whole hour, to select the average value about the whole hour, or to integrate the values about the whole hour. If the digitizer is used with a time share computer system, a serial transmission rate of at least 2,400 baud is desirable to record a sufficient number of coordinate points to calculate an accurate hourly value. However, we have been able to transmit at 1,200 baud with good results if the manual tracing rate is reduced slightly.

When digitizing hygrothermograph charts, the system accuracy of ± .6 C and ± 1% relative humidity is well within the accuracy of the instrument itself (5). Most of the random error results from failure to precisely trace the ink line on the chart, however, some biasing error occurs if initializing values are not precise or if the chart moves slightly during the digitizing process. Rectangular charts must be precisely aligned with the x axis of the digitizer tablet. Errors of these types can be reduced if the user is careful and deliberate. Digitizing accuracy of the leaf wetness chart also is well within the instrument's accuracy particularly if an arbitrary breakpoint between 0 and 1 is assigned for considering leaves as either dry or wet. With data from instruments that have greater resolution than the digitizer itself, the precision of the digitized data is limited by the digitizing process and should be interpreted accordingly.

We currently use the digitizer to archive historical weather data related to apple tree phenology and the epidemiology of apple scab (caused by *Venturia inaequalis* [Cke.] Wint.), cedar apple rust (caused by *Gymnosporangium juniperi-virginianae* Schw.), brown rot of stone fruits (caused by *Monilinia fructicola* [Wint.] Honey), and other fruit and vegetable diseases. Hourly temperatures are used to calculate accumulated heat units in relation to plant and fungal development. Hourly temperature, humidity, and leaf wetness values also are used in analysis of temporal occurrence of airborne spores. Approximately 600 hygrothermograph charts have been digitized with a total expenditure of 80 man-hours.

Nearly any type of rectangular or circular chart can be digitized using the techniques described. The only qualification for the use of Eq. 3 and 4 is that the arc of the pen arm must pass through the center of the circle. Although our computer programs were written to digitize hygrothermograph and DeWit type leaf wetness recorder charts, modifications easily can be made to accomodate other chart designs, or other analysis functions such as integration under a curve. A complete listing of the FORTRAN source code is available (3).

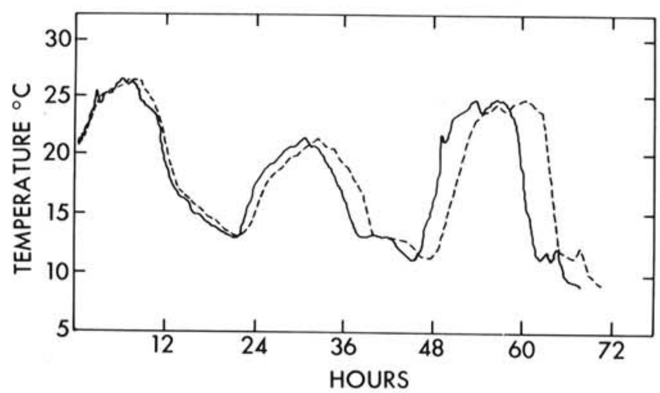

Fig. 3. Clocking correction of a 72-hr temperature plot which showed only 68 hr of movement on the hygrothermograph chart (———), but was correctly adjusted by the digitizer program when hourly temperatures were plotted (----).

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