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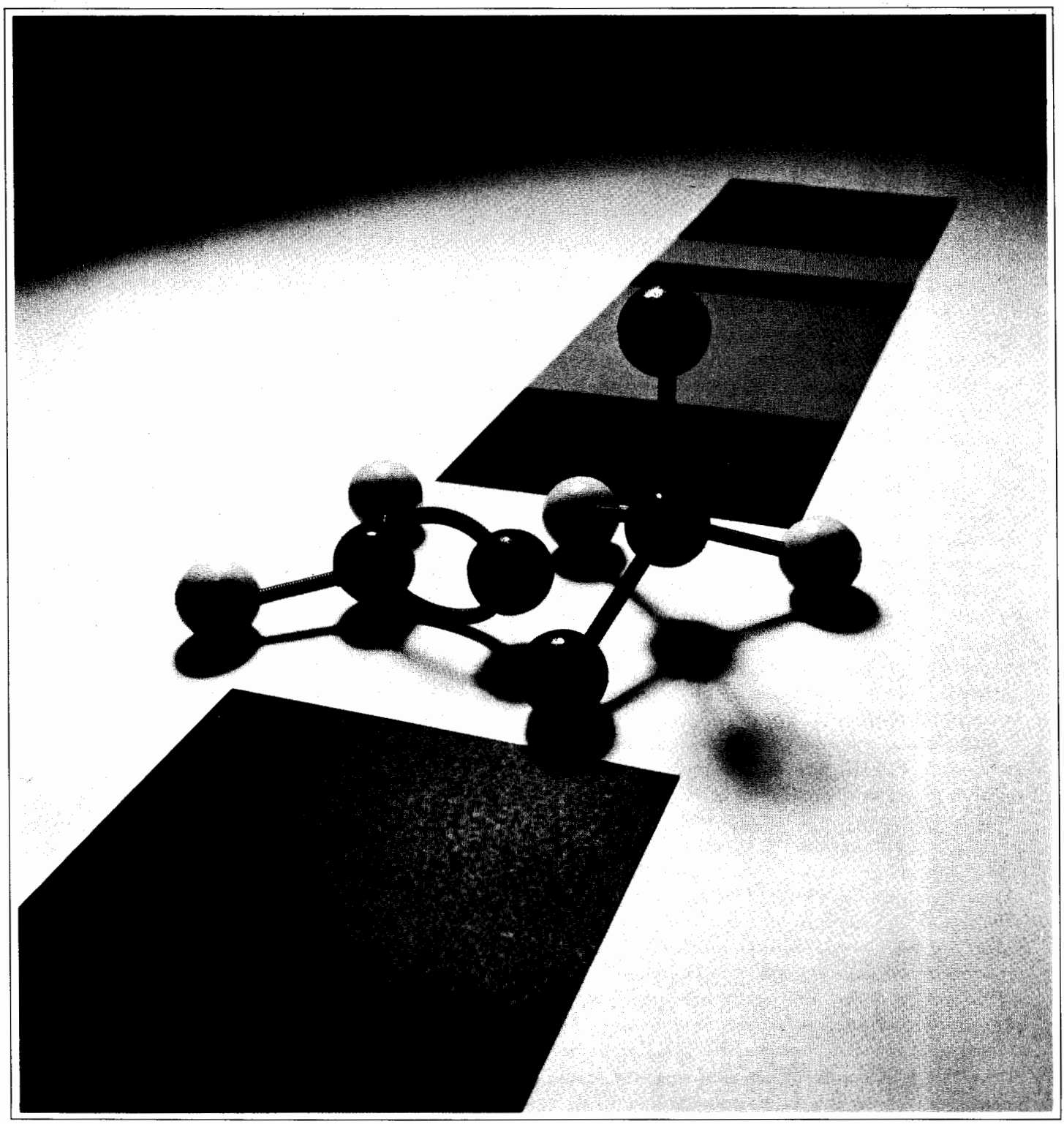

JUNE 1971

# An Easy Way to Analyze Graphs

By Dean C. Millett and Ivar W. Larson

DATA FROM STRIP CHARTS, X-Y plots, oscilloscope photos and even contour maps can be converted into digital form and fed to the Model 9100 desktop calculators for analysis. The Hewlett-Packard Model 9107A Digitizer, Fig. 1, a new calculator peripheral, has three main components: a hand-held cursor, the digitizing surface, and the electronics package. The free-moving cursor contains a transmitting coil and is used to trace the graphic material. Graphs or charts are mounted on a platen, or digitizing surface, which contains a precise grid of conductive strips. An audio-frequency ac field produced by the cursor coil induces voltages in the matrix. Circuitry in the electronics package converts the signals from analog to digital. These digital signals are the X and Y coordinates of the cursor position on the platen.

Resolution of the Digitizer is 0.01 inch (0,25 mm). Tracing speed can be up to 150 inches per second. When set in the continuous sample mode, the Digitizer can feed up to 100 pairs of points per second to the calculator. However, this rate may be limited if a printer or plotter is used. Either a keyboard command or program control of the calculator initiates transfer of coordinate data to the X and Y registers of the calculator.

Four operating control buttons are on the cursor. An (O) button enables the operator to set the origin anywhere on the digitizing surface, for four-quadrant digitizing. Single points may be sampled by pressing the single sample (S) button. Continuous sample mode (C) is used when tracing lines or curves for analysis. The fourth button on the cursor (H) sets the hold.

Any flat non-magnetic material less than 0.025 inch (0,63 mm) thick may be used as graphic media for digitizing without loss of accuracy. The cursor may be lifted 0.04 inch (1 mm) above the platen before data lockout. If this happens, a small 'beep' notifies the user that lockout has occurred.

The 'beep' is also programmable and may be used to give the operator an audible indication that a predetermined condition has been met. For example, the operator may not remember the starting point when he is tracing around an irregular shape to determine the area. The digitizing system may be programmed to 'beep' when the operator reaches the starting point.

The HOLD button can be used to translate the origin. When HOLD is pressed, and the cursor is moved to a new point, and HOLD is pressed again, the new point assumes the coordinate values of the last point digitized. Using this technique, charts larger than the 17 x 17 inch area of the digitizing area can be analyzed.

## Applications of the Digitizer

### Strip Chart Recordings

Strip chart recorders have been used for many years to provide permanent records for various phenomena. The reduction of this data into useful form has presented the recorder user with a tedious and time consuming task, particularly if the recording is not linear in either axis. The digitizer may be used to transform the recording in almost any manner, limited only by the imagination of the user.

For example, an accelerometer response curve might be digitized and replotted to a different scale as the first step in the data reduction. The digitizer is then used to retrace the curve. Plotting the first and second integrals will yield the velocity and displacement diagrams respectively.

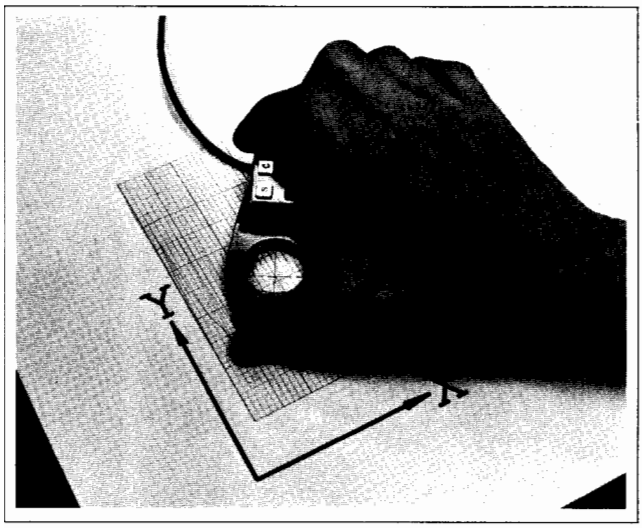

**Fig. 1.** *In using the Model 9107A Digitizer, the graphic data to be analyzed is placed on the platen. The cursor is placed over the chart and the curves traced as shown. Coordinate pairs under the cross hairs are automatically entered into the X and Y registers of the Model 9100 calculators.*

### Analysis of X-rays

For example, the determination of cardiac output and ventricular volume has presented the cardiologist with several data reduction problems. An accurately measured quantity of an opaque (to x-rays) dye is rapidly injected into the heart. A high speed (about 50 frames per second) x-ray camera records the heart in various states of expansion (diastole) and contraction (systole). One technique used to determine the ventricular volume is the length-area method. The ventricle is approximated by an ellipsoid of revolution.

The x-ray is digitized to determine the area and the length of the major axis. The mathematical relationship between length of the major axis and area gives the length of the minor axis. The volume is easily computed by revolving the resulting eilipse through 180 degrees. The program calculates systolic volume, diastolic volume, stroke volume, ejection fraction, and heart muscle mass.

### Photo Analysis

Photographs including oscilloscope photos may be easily analyzed with the digitizer. The photograph is placed directly on the digitizing surface. Calibration to allow for photographic distortion may be incorporated into any program by digitizing the known distance between two points to obtain a scale factor. Since the digitizer always reads the X, Y coordinates directly in inches, the scale factor will be applied to all input values. Additional scaling can also be used to plot on any graph paper.

## Typical Applications

**Statistical Analysis of Data**
Curve fitting—regression analysis
Analysis of strip-chart recordings
Histogram analysis—probability density functions
Mathematical models of families of curves

**Analysis of Irregular Shapes**
Calculate areas within or under irregular shapes
Calculate centroid
Calculate moments of inertia
Determine distance between points over irregular path and lengths of curved and irregular lines

**Analysis of Irregular Waveforms**
Harmonic analysis—determine Fourier coefficients
Find area under curves
Transient analysis from oscilloscope photos or plots

**Teaching Mathematical and Statistical Concepts**
Illustrate integration and differentiation by plotting on calculator plotter as curve is traced

**Contour Maps**
Determine volumes of earth that must be moved for road building or site planning

**Scaling with Plot**
Trace curve and plot to different scale
Change from logarithmic plot to linear or vice-versa

**Coordinate Transformation**
Scaling
Rotation
Translation

### Fourier Analysis

A periodic signal can be defined mathematically by the following equation. Because the waveform repeats itself at regular intervals:

$$f(t)=f(t+nT) \qquad n=1, 2, 3 \ldots$$

where T is the time required for one complete cycle. Periodic signals can be rewritten as

$$f(t)=\frac{a_0}{2}+\sum_{n=1}^{\infty}\left(a_n \cos\frac{2n\pi t}{T}+b_n \sin\frac{2n\pi t}{T}\right) \quad (1)$$

where

$$a_n=\frac{2}{T}\int_{t_0}^{t_0+T} f(t)\cos\frac{2n\pi t}{T}\,dt \quad (2)$$

$$b_n=\frac{2}{T}\int_{t_0}^{t_0+T} f(t)\sin\frac{2n\pi t}{T}\,dt \quad (3)$$

Now, f(t) is sampled at discrete values of t over a complete cycle. The next task is to evaluate the coefficients $a_n$ and $b_n$ by carrying out the integrations of Eqs. 2 and 3.

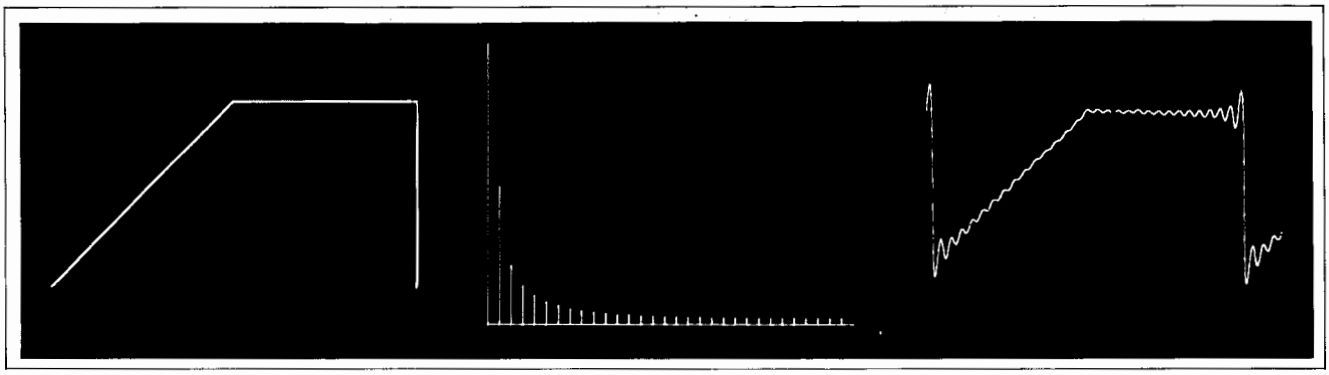

**Fig. 2.** *The time function (A) is digitized, and the frequency spectrum (B) is the resulting plot of the Fourier analysis. Plotting the reconstructed f(t) from the computed coefficients gives an approximation of the original time function (C).*

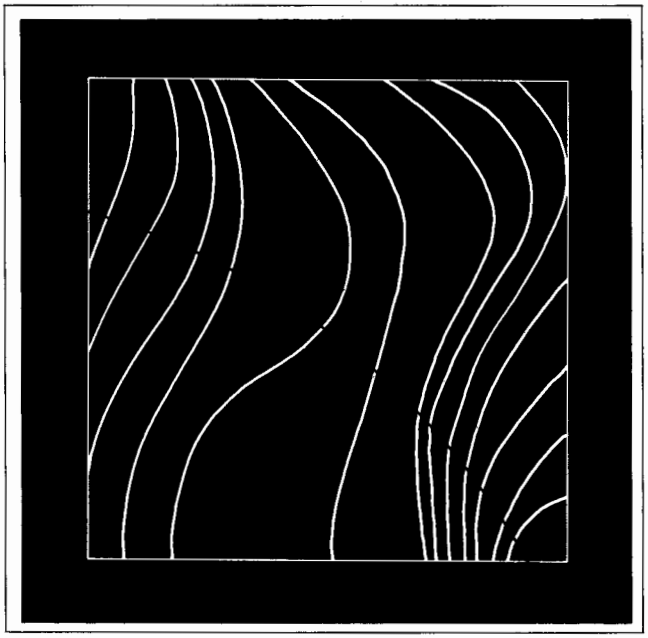

**Fig. 3.** *Contour map used for preliminary studies of most economical freeway route AB. Alternatives may be investigated without sending surveying crews into the field.*

A Fourier series analysis associated with a time function may be performed with the 9100A/B digitizer system to obtain up to 35 sine and cosine coefficients. The waveform in Fig. 2(A) is traced with the cursor to obtain the discrete f(t) values for given t values. The program computes the coefficients and plots the frequency spectrum as shown in Fig. 2(B). The representative Fourier series may be expressed as Eq. 1. This function is reconstructed and plotted, Fig. 2(C), using the derived coefficients, and may be compared to the original function.

### Contour Map Analysis

Highway road building and subdivision layout almost always involve moving volumes of earth. Earth volumes can be calculated from contour maps and surveying data with the digitizer and calculator combination.

Preliminary cost and time studies may be performed using the digitizer, plotter and extended memory. The proposed roadway centerline is drawn on the contour map as shown by the line AB in Fig. 3. The map scale and contour interval, as well as the desired scale for horizontal and vertical distance to be plotted, are entered into the calculator by the operator. The digitizer is then used to enter data at each point where the centerline of the roadway crosses a contour line. This data is scaled in the calculator and is used to plot the existing profile shown in Fig. 4. The proposed grade is drawn on the same plot thus indicating the vertical distance to the existing ground level in either cut or fill at any point along the roadway.

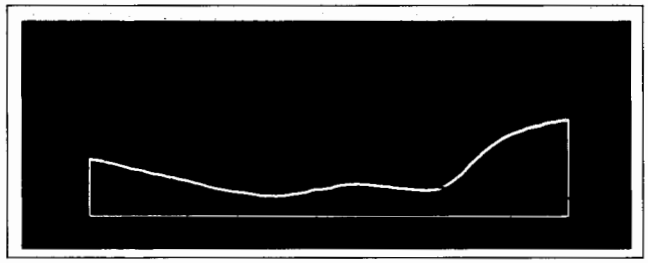

**Fig. 4.** *Profile section shows areas of cut and fill. Successive sections are used to compute the volume of earth to be moved.*

Stations are taken at desired intervals along the centerline and existing elevations are recorded. Successive end areas, or cross-sections, are used to determine the total amount of cut and fill required.

### Acknowledgments

The Model 9107A is manufactured for Hewlett-Packard by Bendix Computer Graphics, an operating section of the Bendix Corp's Advanced Products Division.

We should like to give credit for technical assistance in designing the Calculator-Digitizer interface to Mr. Robert E. Childs of Bendix and Mr. Edward L. Miller of Hewlett-Packard.

### Ivar W. Larson

Ivar is a graduate of the University of Colorado with a B.S. in Applied Mathematics Engineering. He received his MSEE from Bradley University in 1967.

Ivar joined the Hewlett-Packard Loveland Colorado Division in 1967 and has worked on the design and development of advanced calculators and equipment. He is presently Applications Engineering Manager.

A member of Phi Kappa Phi, Ivar's hobbies include woodworking, hunting, fishing and painting.

### Dean C. Millett

Dean has had extensive experience in the field of mass spectrometry, thin-film deposition equipment and programmable calculators before joining Hewlett-Packard. He joined HP in 1968 in calculator sales, and transferred to the Loveland, Colorado Division as applications engineer early in 1970. He is now Product Manager for calculator peripherals.

Dean has a BSME from Heald Engineering College, San Francisco, 1961. He also attended the University of California at Berkeley.

His hobbies include fishing and raising quarter horses.

## PARTIAL SPECIFICATIONS
### HP Model 9107A
### Digitizer

**ACTIVE DIGITIZING AREA:** An area of 17 x 17 inches (431,8 x 431,8 mm)

**RESOLUTION:** 0.010 inch (0,254 mm)

**ACCURACY:** ±0.010 inch (±0,254 mm) per axis from 15°C (59°F) to 30°C (86°F)
±0.030 inch (±0,762 mm) per axis from 30°C (86°F) to 50°C (122°F) and 0°C (32°F) to 15°C (59°F)

**ORIGIN:** Can be placed anywhere on the digitizing surface

**MAXIMUM TRACING SPEED:** 150 inches (3810 mm) per second

**RECORD MODES:** Single (S) — Digitizes one point at a time
Continuous (C) — Digitizes up to a miximum of 110 points per second

**LOCKOUT:** Cursor may be lifted 0.040 inch (1,0 mm) above platen before data lockout. Data lockout is indicated by an audible tone of approximately 0.75 second.

**HOLD:** Pressing the hold button locks in the coordinates of the last digitizer position on the platen. These coordinates may become the initial coordinates for a subsequent cursor position on the platen by locating the cursor over the new coordinates and pressing the hold button again. Coordinates digitized thereafter continue from the locked-in coordinates.

**COMPATIBILITY:** Operates with all HP 9100A/B Calculators and peripherals.

**GRAPHIC MEDIA:** Flat non-magnetic material less than 0.025 inch (0,64 mm) thick may be digitized without loss of accuracy.

**POWER:** 50–60 Hz, 75 Volt Amps, 115/230 V, ±10%

**DIMENSIONS:**
Electronics Package:
5½ inches high (139,7 mm)
17 inches wide (431,8 mm)
18½ inches deep (469,9 mm)
Platen:
22 inches deep (558,8 mm)
22 inches wide (558,8 mm)
2 inches high (50,8 mm)

**WEIGHT:**
Electronics Package:
24 lbs. (10,9 kg)
Platen:
13 lbs. (5,9 kg)

**PRICE: $5900**

**OPTIONS:** 001 Digitizing System — Includes 9107A Digitizer and 9100A Calculator

**Price: $9850**

002 Digitizing System — Includes 9107A Digitizer and 9100B Calculator

**Price: $10,800**

**MANUFACTURING DIVISION:** LOVELAND CALCULATOR DIVISION
Loveland, Colorado 80537

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