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OSCILLOSCOPE TRACE PHOTOGRAPH

DIGITIZING SYSTEM

(TRACE)

MASTER

Mark Richards 5242*

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Oscilloscope Trace Photograph

Digitizing System

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Sandia Laboratories, Albuquerque, NM 87115

ABSTRACT

This report attempts to summarize the digitizing system put together by Bill Boyer and Mark Richards. The system allows the user to digitize photographs or sketches of waveforms and use the computer to reduce and analyse the data. The software allows for alignment, calibration, removal of baselines, removal of unwanted points and addition of new points which makes for a fairly versatile system as far as data reduction and manipulation are concerned.

System considerations are introduced first to orient the potential user to the process of digitizing information. The start up and actual commands for TRACE are discussed in the next few sections. Detailed description of each subroutine and program section are also provided. Three general examples of typical photographs are included in Appendix A. A partial listing of FAWTEK is made available in Appendix B. Once the user has created suitable arrays that contain his data, the user may "GO FA" (activate FAWTEK) and perform many mathematical operations to further analyse the data.

1. General Introduction

A system to digitize and process oscilloscope trace photographs, (TRACE), has been implemented as instrumentation support for the electron beam accelerators and related experiments. Throughout this report TRACE will refer to both the hardware and software aspects of this system. This report is meant to serve as both a brief explanation of the system and a user's manual.

1.1 System Concepts

The present data acquisition system for the Hydra, Proto I, and Proto II E-beam machines consists of Tektronix R7912 transient digitizers interfaced with a Modcomp Minicomputer. A large battery of mathematical programs, residing under the control program FAWTEK,¹ are available to perform many operations on the data such as basic arithmetic operations, differentiation, integration, convolution integrals, trace comparison, and calibration. The purpose of TRACE is to digitize oscilloscope trace photographs, convert the digitized trace to a format compatible with R7912 input to FAWTEK, and make the data available to FAWTEK. The user, with 5-10 minutes work on TRACE, can therefore have most of the capabilities of the R7912 digitizers available to simple scope and camera instruments.

1.1.1 Data Format

In addition to the ability to digitize oscilloscope trace photographs, which have a format of white on black, TRACE can also digitize data based on a black on white format. The only difference is that the digitizing of a black on white image causes the generation of extraneous points which appear as a line in the upper part of the digitized data as

¹Boyer, William B.; FAWTEK Manual SAND77-0210; Albuquerque, NM; Feb. 1977.

Figure 1.1 System Schematic TRACE Hardware

displayed on the Tektronix 4010 crt-display terminal. These unwanted points pose no problem since the system software allows for deletion of unwanted points.

The ability of the system to digitize black on white allows the user to free hand sketch or plot waveforms and analyze them with the computer.

1.2 System Hardware Interactions

The heart of TRACE is the Video Digitizer² (CVI 270) as seen in Fig. 1.1. The camera system (COHV Model 6000-High-Resolution Monochrome) sends a 525 line TV picture to the digitizer. The computer sends the digitizer the location of a point on the TV image via Cursor Control. The digitizer responds by converting the analog intensity signal for that point to a digital intensity level. This intensity level is bussed to the computer. The digitizer is capable of a 480 horizontal x 512 vertical scan field.

The controlling software scans vertically gradually moving from left to right (1 - 512) on the screen. Each vertical scan contains 480 points from top to bottom. It takes about 1/30 sec to digitize a scan and a total of 17 sec to digitize an entire image. The actual digitizing process requires no user control.

Two peripheral units provide user interaction. The video monitor allows the actual camera picture to be seen just as the digitizer "sees" it. In addition the digitizer places its own display on the monitor. This display includes a cursor to indicate the position at which the digitizer is looking and an intensity level display at the right of the screen. The intensity of the image along the cursor is indicated by the dashed line between the black level (Zero level) and the white level (maximum intensity--8-bit

²Colorado Video Inc., "Instruction Manual Model 270 Video Digitizer," Boulder, 1975.

binary or 256 decimal maximum). As will be seen in section 2, this display is essential to the alignment and calibration procedures that must precede the digitizing process.

Figure 1.2 Monitor Display

The other user interactive device is the Tektronix 4010 terminal with CRT-display. This terminal allows the user to talk to the computer and digitizer during calibration and alignment procedures. Also, manual control of the cursor is possible from the 4010.

The photograph mount has two (x,y) translational movement controls and a rotational (tilt) control. The distance between the camera and the photograph can be adjusted using the camera mount. These four motions combined allow for excellent alignment and a variety of image sizes. The entire system is installed in a single electronics rack beside the computer.

2. Input and Control Requirements

Certain input and control data are provided by the user to TRACE. essential among these are calibration and alignment information.

2.1 Calibration Requirements

In order to calibrate the x and y axes of a picture the user must know the vertical units "distance" (see Fig. 2.1) between two vertical points and the horizontal units "distance" between two horizontal points. In addition, these points must be clearly visible on the monitor screen.

Figure 2.1

2.2 Alignment Requirements

The picture must be aligned correctly to produce accurate results. In order to accomplish this, the user must have some reference parallel to either the x or y axis of the picture. A baseline or graticule line is quite satisfactory. However, the following considerations must be taken into account:

- The intensity of graticule lines must be considerably less than the trace intensity in order to separate trace from graticule.
- Although there is a routine to remove baselines from traces, this routine invariably causes some loss of valid data points. If the baseline intensity is kept well below the trace intensity, the baseline removal routine is unnecessary.

2.3 Moving the Cursor

Presently, the cursor is moved on the TV monitor by typing a character on the 4010 terminal and returning:

- 1) The cursor display and a grid will appear on the 4010 terminal when the cursor is enabled. Using the grid for reference, the 4010 cursor should be moved to the approximate position desired by using the 4010 thumbwheels.
- 2) A character should be typed to the 4010 terminal and a "RETURN" keyed in. This will cause the monitor cursor to move to the approximate position of the 4010 cursor. The character used will affect the action taken.

In the following instructions, the above procedure will be referenced by instructions such as "move the monitor cursor with a 'T'".

Construction of a unit is presently underway, which will allow the user to manually move the cursor on the TV monitor without the 4010 terminal. Upon completion and addition of this unit to TRACE the above discussion on moving the cursor becomes obsolete.

3. VCON

TRACE is controlled through a series of programs under the control of VCON. This section is a guide for starting up and using VCON.

3.1 Start Up

All power for TRACE is switched on by the master power switch at the bottom of the rack. After turning on the power, turn on the high intensity lamp and mount the photograph. Remove the lens cover from the camera lens and adjust the lens to photograph distance until the trace almost fills the monitor. Next, focus the camera by turning the lens. Sometimes, it may be necessary to use the beam focus on the camera controller, but usually not. The photograph alignment should be "eyeballed" as close as possible.

To activate VCON depress the CONTROL INTERRUPT button located on top of either 4010 terminal. The word "READY" will appear on the crt screen. The user has approximately ten seconds to give the command "GO TRA." If the user fails to give a command within the specified time limit "\\\" will appear on the 4010 terminal's display screen. The user must then depress the CONTROL INTERRUPT button again to reestablish contact with the computer.

An auxiliary method to activate VCON is to depress the CONSOLE INTERRUPT button located on top of the console 4010 terminal and type the following:

```
/TRA/ACT, 11, LMT
```

When VCON is ready the word "READY" and the character "&" will appear on the 4010 terminal. The system will be ready for use as described in the following sections.

3.2 Program Commands and General Functions

Once VCON has been initiated, it calls the subroutine COMINT. COMINT begins by writing "READY" "&" to the 4010 terminal. Any command may be given in any order. It is up to the user to issue commands in a logical

order (see examples). If the user types in an uninterpretable command, COMINT will write "COMMAND ERROR"; and the user should then type in a correct command. The following are valid commands for TRACE (for more details see descriptions of each subroutine):

<u>COMMAND</u>	<u>EXPLANATION</u>
BAS A	Calls BASLIN for automatic baseline removal.
BAS M	Calls VBASE for manual baseline removal procedure including virtual baselines.
BAS R	Performs baseline removal operation and plots results.
ALI	Calls VALIGN and initiates alignment procedure.
WIN	Calls VWIND and initiates windowing procedure.
CAL	Calls VCRBT and initiates calibration procedure.
CAL DF	Defaults cal. pts. to window limits.
DIG "threshold" (NO)	Digitize with intensity threshold level between 0 and 256. The option NO will cause raw array to not be plotted.
*SEP HI	Calls SEPRAT which separates the higher trace from two traces and places in raw array.
*SEP LO	Separates the lower trace and stores in raw array.
ENH	Calls ENHANS subroutine to add or delete points to raw array.
NOR	Calls NORMRW and calibrates, normalizes, and plots.
PLO A	Calls EBPLOT which plots normalized array.
PLO RA	Calls PLOTBW which plots the raw array.
DWR "record number"	Write normalized array to disc file 22. "Record number" is the record from 1 and 40.

DRE "record number"	Reads normalized array from disc file 22, (see above).
TWR	Writes raw array to logical unit 4 (presently 4 is assigned to disc partition AG3).
TRE	Reads raw array from logical unit 4.
GO ST	Starts program from beginning.
GO EX	Ends program.
GO FA	Activates FAWTEK.

*Note: When using SEPRAT tape write the raw array containing both traces or it will be lost. There is only one raw array in the program at a time and it will contain the raw array (2 traces), raw array (higher trace), or raw array (lower trace).

4. Subroutine and Section Descriptions

4.1 VALIGN

This subroutine is called by typing "ALI" which is interpreted by COMINT as a valid command. VALIGN has no effect on the digitizing process. It only moves the cursor and prints out the x and y coordinate of the cursor. When VALIGN is called it writes "TYPE E TO ERASE, S TO STOP, ANY OTHER CHAR TO MOVE CURS" also a grid is drawn and the cursor is activated.

Moving the cursor with "E" erases the screen, with "S" ends the module. The cursor can be moved with any other character and the x and y coordinates will be printed out on the 4010 terminal.

When the module is ended by typing "S", control is returned to VCON; and COMINT is "READY" to interpret the next valid command.

4.2 VWIND

The subroutine VWIND begins by writing "READY TO SET WINDOW LIMITS TYPE T, B, R, L -- S STOPS"; also a grid is drawn and the cursor activated.

Moving the cursor with the following character causes the following action:

T - causes the location of the horizontal cursor to be used as a top limit for the effective digitizing area.

B - causes the location of the horizontal cursor to be used as a bottom limit for the effective digitizing area.

R - causes the location of the vertical cursor to be used as a right limit for the effective digitizing area.

L - causes the location of the vertical cursor to be used as a left limit for the effective digitizing area.

S - causes termination of the module and control returned to VCON.

The T, B, R, L commands may repeat as many times as necessary. The last value for each limit is the one used when windowing.

4.3 VCBRT

If the command 'CAL DF' was typed in the main program VCON, the T, B, R, L window limits set in VWIND will become the T, B, R, L cal. points in VCBRT and control would skip the setting of cal. pts. in VCBRT.

If the command 'CAL' was typed in VCON, VCBRT will write "READY TO SET CAL POINTS TYPE T, B, R, L -- S STOPS" along with a grid. In exactly the same fashion as in VWIND the top, bottom, left, and right calibration points are set. After receiving "S", COMINT is called by VCBRT and writes "READY" "?". The user may then type one of the following:

<u>COMMAND</u>	<u>EXPLANATION</u>
HCAL "horizontal distance"	Horizontal distance is the number of units between horizontal cal. pts.
HCAL DF	DF defaults HCAL to a value of one to be used when time/address doesn't matter.

VCAL "vertical distance"	Vertical distance is the number of units between vertical cal. pts.
VCAL DF	DF defaults VCAL to a value of one to be used when vert. units/address doesn't matter.
GO ST	Goes to beginning of VCBRT.
GO EX	Ends VCBRT and control is returned to VCON.

Upon assigning VCAL and HCAL a value or defaulting them, the Time/Address value and the Vert. Units/Address value are printed out and VCBRT terminates.

4.4 VBASE

This subroutine begins by writing;

"TYPE T, B TO INDICATE BASELINE LOCATION--S STOPS
TYPE V TO INDICATE VIRTUAL BASELINE."

If there is a baseline trace the user should use the letters "T" and "B" to move the cursor and indicate the approximate locations of the top and bottom of the baseline trace. These points should be slightly above and below the baseline respectively. An "S" will cause points to be flashed

Fig. 4.1 Cursor Location for Baseline Removal

across the screen at the computed center of the baseline. The baseline should be manually aligned with these points. This baseline will be removed from the trace.

If one wishes to indicate a virtual baseline, i.e., a baseline level with no trace present, he should use any letter but "V" to move the cursor to this level and then type a "V" (return). As above dots will be flashed across the screen for alignment.

This virtual baseline level will be used as the zero level during calibration.

After either the "T, B, S" sequence or the "V" sequence is finished and dots are flashing on the screen at the baseline level, the module may be ended by typing and returning any character.

Control is returned to VCON.

4.5 ENHANS

ENHANS is a subroutine used to enhance the raw array by adding or deleting points. ENHANS is called by VCON when ENH is entered as a command. The following are valid commands for ENHANS:

<u>COMMAND</u>	<u>EXPLANATION</u>
DEL Q "quadrant"	"Quadrant" should be equal to 1, 2, 3, or 4. The cursor is enabled and all points in specified Cartesian quadrant will be removed when cursor position returned.
DEL A "n"	Data points within box with sides "n" x 1/10 inch square around returned crosshairs position will be deleted.
NEW	Allows user to position cursor where a new point will be added.
PLO	Plots raw array.
GO	Exits ENHANS, control returned to VCON.

4.6 Digitizing Section

The command DIG "intensity threshold level" (NO) brings us to the digitizing section of VCON. The intensity threshold level should be between 0 and 256. It allows the user to choose what level of intensity should be required for a point on the photograph to be considered a data point.

For example, if the trace is overlaid by an alignment graticule of extremely low intensity (as it should be) the graticule will not be digitized if the threshold is set between the graticule level and the trace level. The appropriate level can be guessed by observing the TV monitor display between the black and white levels. The aperture control on the camera regulates the overall image brightness.

After receiving the command 'DIG' with an appropriate intensity threshold level the program immediately begins digitizing the trace photograph. When digitizing is completed (approximately 17 sec) the raw array is plotted with windowing if the (NO) option was omitted from the command. The raw array is the untouched digitized image. If an error occurs during digitizing this message is printed:

"ERROR * DIG, CLUE = # _____, UNIT _____".

The UNIT number should be ignored. The user is only concerned with the most significant digit of the hexadecimal CLUE number. If the CLUE number begins with a C an overflow situation in the raw array exists. To remedy this situation the trace photograph should be redigitized with a higher intensity threshold level. This will reduce the number of points stored in the raw array and avoid the overflow condition. It may be necessary to touch up the photograph if excessive noise exists on it. The second digitizing error possible is the too slow condition indicated by a CLUE number beginning with an A. This condition will occur if two users are on the computer at the same time. The digitizing process is stopped or halted by the second user 'running' while the cursor is sweeping and digitizing. The solution to this problem is to have the second user wait for 17 seconds while the digitizing is taking place before he resumes 'running'.

Appendix A

Examples

The following examples illustrate a few typical photographs TRACE deals with. A usual sequence of commands is given along with a brief description. Keep in mind that the order of commands given is not fixed. Any command may be given at any time, but commands should be given in a logical order. For example, the user should remove the baseline and calibrate the raw array before normalizing. Many types of photographs may be digitized. The major limitations are the imagination of the user and the familiarity of the user with TRACE.

Examples

Example 1

Fig. A.1 Single trace with virtual baseline.

<u>Typical Sequence of Commands:</u>	<u>Explanation</u>
ALT	Align trace.
BAS M	Manually set baseline with a "V" (see VBASE).
CAL	Calibrate vertical and horizontal axis.
WIN	Set window limits if you chose.
DIG "intensity threshold level"	Digitize photograph. Redigitize if not satisfied.
ENH	Add or delete points as needed.
NOR	Gives calibrated and normalized plot.
DWR "record number"	Write array to disc if satisfied.
GO ST	Go to Start of program for next photograph.
GO EX	Go Exit if finished with TRACE.

Example 2

Fig. A.2 Single trace with baseline.

Typical Sequence of Commands		<u>Explanation</u>
ALI		Align trace.
WIN		Set window limits if necessary.
CAL		Calibrate.
The user has the option of using BAS A or BAS M.	BAS M	Remove baseline manually.
	BAS A	Automatic baseline removal, best method.
DIG "intensity threshold level"		Digitize.
ENH		Enhance if necessary.
BAS R		Plots trace with baseline removed.
ENH		Enhance if necessary.
NOR		Plots normalized and calibrated array.

DWR "record number"	Write array to disc.
Go ST	Go start for next photograph.
GO EX	Go exit if finished.

Example 3

Virtual Baseline
←
Level

Fig. A.3

Fringe data and beam intensity traces with virtual baseline (used in VISAR program) that do not touch or crossover each other. It is possible to digitize two traces each with a baseline if a mask of black paper is cut out to cover one of the traces while the other is being digitized. Actually, example 2 has two traces each with a baseline, but the lower trace has been masked with black paper for purposes of digitizing.

<u>Typical Sequence of Commands</u>	<u>Explanation</u>
ALI	Align.
WIN	Window.
CAL	Calibrate.
DIG "intensity threshold level"	Digitize.
ENH	Enhance if necessary.
TWR	Writes raw array to logical unit 4.

SEP HI	Separate high trace.
PLO RA	Plot raw array.
ENH	Enhance if necessary
NOR	Normalize.
DWR "record number"	Disc write.
TRE	Read Raw array with both traces.
SEP LO	Separates lower trace.
PLO RA	Plot raw array.
ENH	Enhance if necessary.
NOR	Normalize.
DWR "record number"	Disc Write.
GO ST	Go start for next photo- graph.
GO EX	Go exit if finished-
GO FA	Activates FAWTEK.

When "READY" "*" appears FAWTEK is ready to accept your commands. The first command should be to read the normalized arrays into array A, B, C, or D.

Appendix B

FAWTEK

(Partial Listing)

<u>COMMAND</u>	<u>EXPLANATION</u>
CHA, *array, element	Changes given element of array.
CUR	Enables cursor and prints out coordinates.
PLO, array, (NO)	Plots 'array' versus time.
DWF, array, record no., (22)	Writes array to disc with specified record no. usually direct access file 23 unless 22 option selected. File 22, 1-40; file 23, 1-80.
DRE, array, record no., (22)	Disc read (see above).
ENH	Enhance.
INT, array	Array mathematically integrated and placed back in original array.
DIF, array	Array mathematically differentiated and placed back in original array.
ADD, array, n	Number n is added to every data point in the array.
SUB, array, n	Number n subtracted from every point in array.
MUL, array, n	$n \times \text{array} = \text{array}.$
DIV, array, n	$\text{array} \div n = \text{array}.$

* Valid arrays for FAWTEK are A, B, C, and D.

ADD, A, array	$A + \text{array} = A.$
SUB, A, array	$A - \text{array} = A.$
MUL, A, array	$A \times \text{array} = A.$
DIV, A, array	$A \div \text{array} = A.$
AVE, array, (element 1, element 2)	Average value of array is computed from element 1 to element 2.
MAX, array, (element 1, element 2)	Maximum value of array found and printed between element 1 and element 2.
COM, A, B, $\begin{smallmatrix} \text{BA} \\ \text{BS} \end{smallmatrix}$	Least squares comparison of A and B. Takes A as known array and adjusts ampli- tude and time shift of B so that the total squared difference between the two is the optional BA or BS. BA causes array B to have amplitude of baseline adjusted to optimize fit. BS causes baseline slope to also be adjusted. The 2 arrays are plotted with A solid and B with dots. Final scale factor, time shift, base- line shift printed to left of graph. Standard deviation, normal standard devia- tion, and status word printed out.
PRI, array	Prints out array on terminal.
XFR, array 1, array 2	Transfers elements of array 1 to array 2.
CAB, array, compensator	Array convolved with array read from disc file of cable compensation curves.
FFT, array, window	Fourier transform of array performed. The magnitude is placed in the array. The frequency step is placed in element 2.

	Window: 0-no windowing, 1-trailing and leading edge windowed, 2-trailing edge windowed, 3-leading edge windowed.
TSH, array, time	Shifts array in time. Negative value shifts to left. Positive value shifts to right.
LOG, array	Array (I) = ALOGIO (array (I)).
SQR, array	Array (I) = SQRT (array (I))
TRE, RA, (REWIND)	Tape Read Raw array from logical unit 4. Rewind file optional.
TRE, array (REWIND)	Tape Read normalized array into array from logical unit 4. Rewind file optional.
TWR, array, (REWIND) (EWD)	Tape write array to logical unit 4.
TWR, RA, (REWIND) (EWD)	Tape write raw array to logical unit 4.

The preceding list of Commands is incomplete. It is added to give the user some idea of possible data manipulation through FAWTEK.

Appendix C

Flowcharts

Flowcharting Symbols

Statement Number

Decision

Arithmetic Operation

Subroutine Call

Program Name

Data Transfer Function

Return/Stop

Note: Simple output messages to the 4010 terminal are not flowcharted because they do not affect program operation.

SYSTEM FLOWCHART

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