THE CUPAD SYSTEM*: REAL TIME HANDLING OF RANDOMLY ACQUIRED

CLINICAL ULTRASOUND DATA

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The CUPAD system described in the previous paper includes a
custom designed hardware interface between a Picker EV-6 Scanner
and a Digital Equipment Corporation PDP-15 computer, and a sup-
porting software package. This paper will describe in greater
detail the structure and operation of the hardware and the soft-
ware.

1. The Hardware Interface

The hardware interface was designed as part of a research
system, with maximum flexibility and reasonable cost as essential
criteria. These criteria indicated a sampling data acquisition
technique, which eliminates the need for costly very high speed
analog/digital converters, and provides for a moderate rate of
such acquisition, allowing the computer time to engage in real
time processing and display of the acquired data.

The random motion of the transducer on the skin surface in a
B-scan presents problems of correct digital echo registration and
normalization. The interface hardware was designed to eliminate
these problems.

A Picker EV-6 scanner is slightly modified to allow the ex-
ternal use of the X and Y deflection position signals. In addition
the standard video and sync outputs are used (Figure 1). The X and
Y position signals are fed into two 8 bit tracking analog/digital
converters, which continuously convert the analog inputs into
digital address codes. The sampling logic generates one sampling
pulse for each received echo wave train. Successive sampling

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Figure 1
Hardware Interface Block Diagram

Bold arrows indicate digital data flow. Intermediate arrows indicate analog data flow. Thin arrows are control signals.
pulses are delayed such that they sample consecutive resolution cells (see Figures 2, 3). The occurrence of a sampling pulse causes the X and Y address registers to hold the current digital output of the tracking converter. The leading edge of the sampling pulse triggers the sweep generator and integrator circuits. The sweep generator produces a voltage which is proportional to the duration of the sampling pulse, while the integrator produces a voltage which is proportional to the total area under the video signal between the time it is triggered and the time it is stopped by the trailing edge of the sampling pulse. The integrator output is then divided by the sweep generator output, using an analog divider.

Analytically, if the sampling pulse starts at time \( t_A \) and stops at time \( t_B \), the output of the sweep generator after time \( t_B \) is held at \( k(t_B - t_A) \) volts, where \( k \) is a constant. The integrator produces the time integral of the video signal, \( v(t) \), or,

\[
k \int_{t_A}^{t_B} v(t) dt.
\]

These two outputs are divided such that the result is

\[
\frac{1}{t_B - t_A} \int_{t_A}^{t_B} v(t) dt.
\]

This corresponds to the average video signal during the sampling period.

After the division, the quotient voltage is digitized into 6 bits. Upon the completion of this digitization, and while the digitized address is held in the X and Y address registers, a flag is raised and an I/O program interrupt is requested. At this point the software assumes control of the I/O data transfer from the interface output address/data multiplexer to the computer.

The correct X-Y address of the echo origin and the properly normalized video are therefore always obtained, independent of the position, angulation and motion of the transducer.

2. The Software

Data flow in the computer and all other software functions are controlled by the user program (Figure 4). This includes the control of the interface handler programs, the preliminary data storage, the preprocessing programs, the assembly of the data buffer as well as the preparation for display.
The patient's cross section is subdivided into a matrix of 128 X 128 resolution cells. Typical boundary crossings (A, B, C, etc.) are shown. Normalization for path length dependence is necessary because path AB ≠ path BC, etc.
Figure 3
Hardware Sampling Through Resolution Matrix.

Top graph shows a typical A-scan echo train. Other graphs show successive samples taken from this echo train and the measured area under them (shaded areas). First sample is taken after first transmission pulse, second sample after the second pulse, etc. The times \( t_A, t_B \) etc correspond to the boundary crossings A, B, etc in Fig. 2. Note that \( t_B - t_A \neq t_C - t_B \).
Figure 4
CUPAD Software Data Handling Scheme.

Bold arrows indicate major data flow paths. Broken arrows are alternative paths. Thin lines indicate software control by the user program.
The handler is the lowest level program which communicates directly with the hardware interface and facilitates the correct transfer of data into one of two 512 word line buffers. Upon command from the user program, the handler instructs the hardware multiplexer to first transfer the address and then the digitized video. These two pieces of data are stored in two successive computer words in the line buffer. The process is repeated until all the addresses and video samples from one echo wave train have been stored in one line buffer. The data from the next wave train will start to fill the second line buffer, while the data already stored in the first line buffer will be preprocessed by one of a number of preprocessing programs (such as maximum, averaging and TGC correction programs) and stored in the appropriate computer word in a 16K image buffer. The switching of line buffers enables the computer to synchronize the acquisition and preprocessing such that all incoming data is properly handled. Since the data in the line buffers is stored in a sequence corresponding to its distance from the transducer, it lends itself to software TGC corrections. These corrections are made by identifying a standard reflector, calculating the attenuation coefficient and then correcting for attenuation.

The data in the line buffers can then be processed by averaging or maximum programs. In the 16K data buffer, the averaging program keeps and updates the running sum and a count of the number of times each resolution cell was interrogated. The maximum program compares each data word in the line buffers with the corresponding word already stored in the 16K data buffer, and keeps only the largest. Thus no overwrite problems are encountered.

The data flow from the interface is periodically halted to allow the computer to process the contents of the 16K buffer such that it will be ready for display (e.g. in the case of averaging it divides the running sum by the contents of the counter mentioned above). After appropriate computer word packing, the 16K data buffer is reduced to a 4K buffer and is dumped onto a Data Disc 5200 fixed head disc. The disc refreshes black and white and color monitors directly.

The resulting image can be erased, stored temporarily or saved permanently on a RP-02 disc pack for later retrieval and post-processing.