S-100/Z80 microprocessor-based scanning microdensitometer and signal processing system

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A S-100/Z80 8-bit microprocessor-based system which is used to digitize, reduce, and smooth picosecond data is described. Utilizing real-time signal sampling combined with a software-controlled signal averaging, the system uses, to the maximum extent, all of the information obtainable from the microdensitometer. The versatility of the system, in terms of both the hardware and software, minimized the need for extensive in-house interfacing and makes it possible to scan a film containing six spectra (6×40K raw data points) in 16 min. The use of a LS1 stepping motor controller chip is described.

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INTRODUCTION

In picosecond absorption spectroscopy and other applications such as gel electrophoresis, a system is required to digitize the analog film data, reduce grain and other noise, and carry out data processing (to account for characteristics of the film and of the particular experiment) before the information can be used. Because of the massive amount of information contained in films, a compromise is usually made in the amount of information which is extracted due either to time constraint or to the complexity and cost of the system required. In our specific application to process film data from picosecond spectroscopic experiments, we required a microcomputer and recording system capable of driving an existing (obsolete but mechanically sound) microdensitometer, acquiring an amplified photomultiplier tube signal, and carrying out fast Fourier signal processing and data reduction. We further required that the maximum possible available information be acquired in the shortest time possible (scan limited only by mechanical considerations), a minimum of in-house interfacing, a minimum of expense, and rapid postsignal processing. In this article, we describe a particular hardware/software configuration based on real-time sampling and signal averaging which meets our objectives.

We chose an S-100 bus based Z80 microprocessor system[1] with CP/M[2] operating system, assembly, and FORTRAN language capabilities. Our choice was based on the need for hardware versatility afforded by a standardized bus system, and a compiler-based language such as assembly or FORTRAN for speed (interpreter-based BASIC is too slow to be useful). Use of a standardized bus system which can directly accept plug-in interface and fast A/D converter boards from any number of manufacturers greatly simplified the need for in-house interfacing. In addition, the availability of a large number of scientific and mathematical programs greatly facilitated implementation of the overall system.

The system functions as a computer-controlled microdensitometer with real-time signal sampling and averaging capabilities. An amplified photomultiplier signal detecting a 240 Hz chopped light beam is digitized by an A/D converter at the chopping frequency. The digital buffer on the A/D converter board is, therefore, being continually updated. The current value stored in the A/D converter buffer is read by the microprocessor at the stepping motor frequency. Providing that the chopping frequency is greater than or equal to the stepping frequency, real-time sampling is realized. Averaging of the data is carried out by the microprocessor after sampling (i.e., under software control) and is, therefore, independent of the hardware. This technique differs from that using a conventional tuned ac amplifier with a dc output. Because the dc output is obtained by rectifying and filtering the signal, the time constant of the output severely limits the scan rate. For this reason, we bypassed the original electronics on the microdensitometer (Baird-Atomic model RC-2) and sampled the (amplified) chopped photomultiplier signal directly. The maximum scan rate is presently limited by mechanical considerations to 2.7 min./scan (7.5 times faster than before). For a total scan of 40 960 steps (at 2.1 μm/step), 1024 averaged sampling points are derived and stored on a 8-in. floppy disc. The increased scan speed also means that the reliability of the results is less dependent on the long-term stability of the electronics.

I. DESCRIPTION

The system block diagram is shown in Fig. 1. Two functional modules can be seen: (1) a stepping motor controller which provides the microdensitometer scan, and (2) an interrupt-driven data-acquisition system which records the analog signal from the microdensitometer.

ASCII instructions are transferred from the microprocessor to the stepping motor controller by a handshake sequence. The instructions specify the number of steps, rate, direction, ramp rate at the beginning and end, and when to start. On each step, the stepper controller outputs a pulse which is used as an interrupt for the micropro-

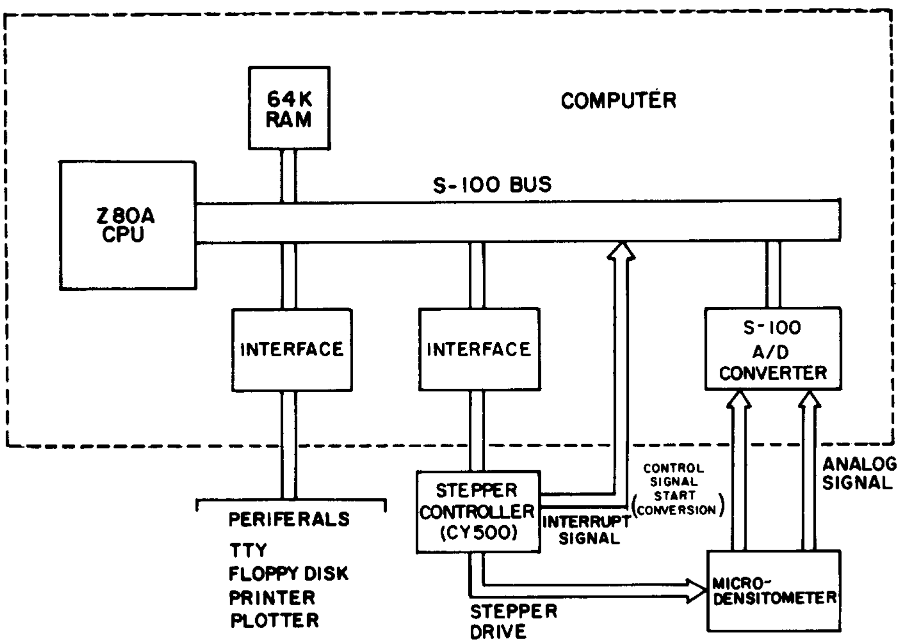

FIG. 1. Block diagram of the microprocessor-based scanning microdensitometer system.

cessor. Digital data held in the A/D converter buffer is transferred to the microprocessor memory on each interrupt by an interrupt service routine (in assembly language). The circuit diagram of the stepper motor controller is shown in Fig. 2. The heart of the module is a 40 pin LSI chip, the CY500.[3] Signal to (data out) and from the CY500 (data in) can be grouped into three sets of 8-bit signals: (1) data out (ASCII program instruction for the CY500), (2) control signals out to the CY500 (stepper command), and (3) data into the microprocessor (status information about the CY500). The three sets of signal lines are connected to the parallel ports of an S-100 plug-in interface board ("Interfacer II," Godbout Electronics, Oakland, California). The latter two sets of signals provide the necessary control for the CY500 and the handshake sequence for data transfer between the microprocessor and the CY500. The positive "pulse" signal (pin 35 on the CY500, see Fig. 2), generated on each step, triggers the 74LS123 on the negative edge and provides the negative pulse ($\overline{\text{PINT}}$) for the microprocessor interrupt.

Several aspects of circuit shown in Fig. 2 require comment. Pins number 28–30 in the CY500 for external hardware start/stop control were not used. The stepping motor on the microdensitometer, a 3V SLO-SYN HS-50 (Superior Electric, Connecticut), requires a drive circuit with transistors having low turn-on voltages. A higher input voltage stepping motor is preferable. The 74LS08 connected to the input and ouput pins of the CY500 were used, in our case, to protect the CY500 against damage from transients and accidental connections rather than for added drive. Depending on the interface, the 74LS08 can probably be safely omitted. We have not, however, tested the reliability of the CY500 under these conditions.

The signal from the microdensitometer is derived from a 240-Hz chopped optical beam which is detected by a photomultiplier and amplified. A negative pulse (sync pulse) synchronous with the signal pulse from the microdensitometer is used to start conversion on the A/D converter. The digital data in the A/D buffer is, therefore, updated at the chopping frequency. The A/D converter

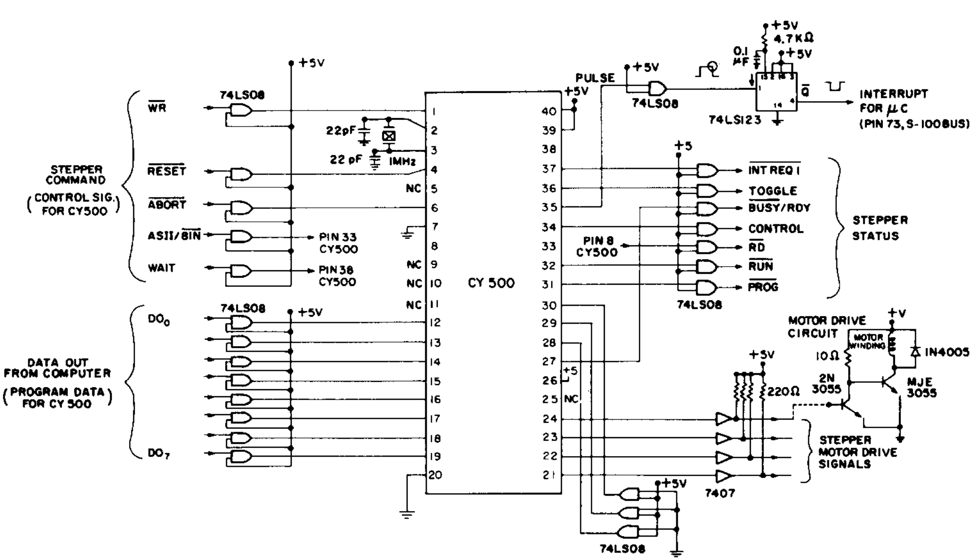

FIG. 2. Stepping motor controller.

(California Data Corp., Newbury Park, California, AD-100-4) plugs directly into the microcomputer S-100 bus. It has 12-bit resolution, software programmable gain of up to 1024, and a gain dependent settling time of 40–400 μs. The sync pulse line from the microdensitometer, an open-collector TTL ouput, is directly connected to the trigger input of the convert register on the A/D converter board. The Z80 assembly language subroutine for the CY500 stepping motor controller was obtained commercially.[4]

A typical "raw data" spectrum consisting of 1024 sampled microdensitometer readings, with each reading representing an average of 40 values, is shown in Fig. 3. Following acquisition, the raw data for a complete set of five transient absorption spectra is smoothed by means of a FORTRAN module which is automatically loaded and executed. The smoothing process consists of a simple low-frequency-pass step truncation of the Fourier spectrum in which the Fourier coefficients above a cut-off frequency are set to zero. The Fourier coefficients were computed using the IBM Scientific Subroutine "HARM" which is based on the fast Fourier Transform (FFT) algorithm due to Cooley and Tukey.[5] The result for the data of Fig. 3 using a cut-off frequency of ~0.20 of the maximum Fourier spatial frequency is shown in Fig. 4(A). The figure shows that the high-frequency "noise" originally present in the film transmission is eliminated by this filtering whereas the overall envelope of the spectrum, the low-frequency component, is undistorted. There remained in the low-pass filtered spectrum, a constant-frequency modulation associated with the laser-generated "continuum"[6] probe beam. This modulation was attenuated by FTT-based convolution,[7,8] that is, by multiplying the data Fourier cos and sin coefficients A_K and B_K with those for a rectangular, unit area 'slit' function (width ΔK) according to:

$$A'_K = A_K C_K - B_K D_K\,,$$

$$B'_K = A_K D_K + B_K C_K\,,$$

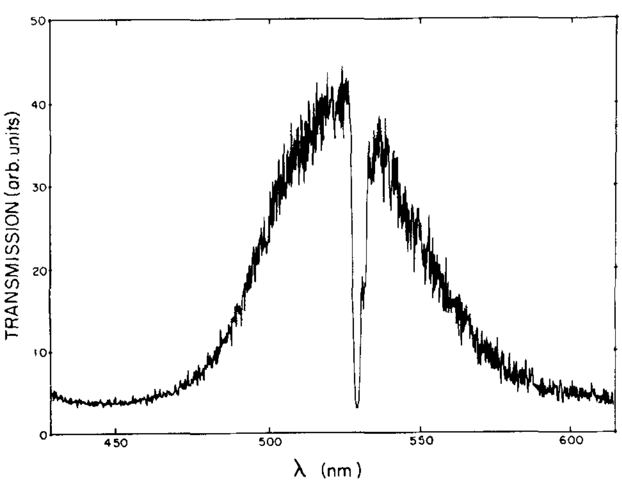

FIG. 3. A raw data spectrum of the absorption of the Reinecke's salt $[KCr(NH_3)_2(NCS)_4]$ in ethylene glycol. The calibration line (530 nm) is due to scattered laser pump light.

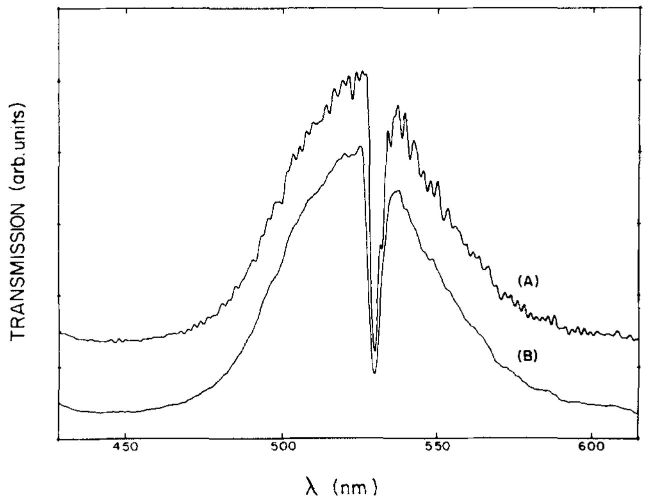

FIG. 4. Data smoothing by low-frequency-pass truncation of the raw data fast Fourier transform spectrum: (A) without convolution and, (B), with convolution (slit-function width = 20 sample points).

where

$$C_K = \cos\left((3 - \Delta K)\frac{\pi K}{2N}\right)\left(\frac{\sin\left(\Delta K \frac{\pi K}{2N}\right)}{\Delta K\left(\sin\frac{\pi K}{2N}\right)}\right),$$

$$D_K = \sin\left((3 - \Delta K)\frac{\pi K}{2N}\right)\left(\frac{\sin\left(\Delta K \frac{\pi K}{2N}\right)}{\Delta K\left(\sin\frac{\pi K}{2N}\right)}\right).$$

Note that the coefficients C_K and D_K include, in addition to the convolution, a shift by $\Delta K/2$ points of the data set to lower wavelengths to eliminate the effect of partial averaging of the first and last $\Delta K/2$ data points. The result with $\Delta K = 20$ is shown in Fig. 4B. Further postdata reduction unique to picosecond transient absorption spectroscopy will be reported in a separate publication.

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[1] A number of Z80/S-100 systems are available on the market. The particular one we happen to use is the Ithaca Intersystems Model DPS1.
[2] Digital Research, Pacific Grove, California.
[3] Cybernetic Microsystems, Los Altos, California.
[4] Datacap Ltd., 220 Laurier Ave. W., Ottawa, Canada.
[5] J. W. Cooley and J. W. Tukey, Math. Comput. **19**, 297 (1965).
[6] D. K. Sharma and R. W. Yip, Opt. Commun. 113 (1979).
[7] R. W. Bracewell, *The Fourier Transform and its Applications*, 2nd ed. (McGraw-Hill, New York, 1978).
[8] E. O. Brigham, *The Fast Fourier Transform* (Prentice-Hall, New Jersey, 1974).