A COMPUTER-CONTROLLED DATA ACQUISITION SYSTEM
FOR AUTOMATED AMINO-ACID ANALYSIS*

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Abstract

A computer-oriented continuous signal sampling and recording system is described for amino acid analysis in ion-exchange chromatography. The system employs synchronous tape drives for multiplexed data storage from four amino acid analyzer colorimeter outputs. Each amino acid analyzer provides three colorimeter outputs. All twelve continuous signals are digitized through voltage-to-frequency to count conversion. The PDP-8/L computer controls the data acquisition system, buffers data to magnetic tape and also provides for concurrent transfer of tape data via the BROOKNET II data link to a CDC6600 computer for data reduction.

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NOTES TO THE READER:

This report contains both a summary of the hardware and programming details and a description of the method of usage. In the sections devoted to explanations of the program structure, a copy of the program listing is useful. This is available on request from one of the authors (C.P.H.).

A convention is employed here in denoting multi-digit octal (base 8) numbers: Any number preceded by a letter "O" or zero ("0") is assumed to be octal; decimal numbers are written in the normal manner.

Label names in the program rather than addresses are given in the program description for the sake of generality. A cross-reference table at the end of the program listing will enable the reader to determine the location of each subroutine called or referenced.

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1. System Description

A system is described for data acquisition in amino acid analysis employing synchronous magnetic tape drives for multiplexed storage of 4 amino acid analyzer outputs, plus direct data analysis via the BROOKNET II link (Campbell, Fuchel and Padwa, 1972; Friedman and Padwa, 1970) to the Brookhaven National Laboratory Central Scientific Computation Facility (CSCF) CDC6600 computer.

A high-quality computer-based data acquisition system is employed here with two 6600-compatible synchronous tape drives specified for best system reliability. A control computer of the PDP-8/L type, with 8K of core memory, is employed to initiate and control the data acquisition system, buffer data to the magnetic tape systems, and control the BROOKNET data transfers.

The magnetic tapes provide the primary record storage for each experiment. A selectable program option permits transmission of tapes to the CDC6600 via BROOKNET simultaneously with the data recording on a second tape. The data tapes may also be taken directly to the CSCF for experiment analysis.

The major components of this system are illustrated in the accompanying block diagrams, Fig. 1. Each of the 4 amino acid analyzers is provided with a buffer amplifier for its 3 colorimeter photocells, including a provision for 3 outputs to the existing 5 mV full-scale recorder channels.

Voltage-to-frequency conversion at the photocell outputs provides higher reliability transmission than analog voltage or digital

data transmission, and freedom from ground-loop problems as isolated (transformer) coupling may be employed. This technique also tends to cancel out the effects of noise at the photocell when integrating type frequency-to-digital converters (scalers) are employed at the computer interface. A separate gated 12-bit scaler is provided for each colorimeter photocell of each analyzer at the computer data acquisition interface. The scaler integrates between each computer sampling. A real-time clock generates the sample rate and timing pulses so that each analyzer (3 colorimeters) is served in a cyclic manner every 2-16 seconds as selected by a 4 position switch. An 8 second data acquisition cycle time was determined to be best for use with the current analysis program and the ion-exchange chromatographs in use (Beale, 1972).

The PDP-8/L computer acts as a data accumulation facility for several low data rate sources. The data is then formed into data blocks for transfer one of two a local magnetic tapes. The PDP-8/L also controls the BROOKNET link to the CDC6600, and performs a number of reporting, tape and data management, and diagnostic functions selected by the use of option switches.

Data input is performed on an interrupt basis; in the Interrupt Program tape recording and transmission to the central computer is organized on cycle-stealing (data break) basis; checking of the status of transfers is done in the Background Program.

There are two buffers in a "ping-pong" arrangement. These occupy most of the upper 4K of core memory. One buffer (BUFIN), accepting

new data from the experiment, the other (BUFOUT), is employed for outputting data to the tape and BROOKNET. When the first buffer is full, the timer interrupt will call a subroutine to switch the buffer assignments and set flags for recording on magnetic tape. This will be described in detail later.

There is always a possibility that a data block transfer to BROOKNET or the magnetic tape will fail or contain errors requiring it to be repeated, or that a failure of the I/O device will render it permanently busy or inoperative. The control program is designed to permit continuation of the experiment and acceptance of new input data as long as either of the magnetic tape units are operable and to automatically abort BROOKNET and/or any other user or operator options in favor of the tape data acquisition process when ever a conflict situation arises. The two possible conflict situations which arise in this program, that of use of the magnetic tape subsystems (writing new data on one tape, reading the other tape during BROOKNET transfer, in the alternate data buffer) and that of an indefinite wait on keyboard input of parameters, have been resolved to meet this criteria.

2. Selectable Program Options

Capacity for up to 037 (octal) program options has been provided. Options 032-037 are currently not programmed; selection of these options are ignored by the PDP-8/L. Options are selected by placing the octal option number in the right most 5 switches (switches 7-11) of the PDP-8/L Switch Register (1 = up, 0 = down) and then lifting switch 0, (the left most switch) and depressing it again. This will cause selection of the subroutine corresponding to that octal option number.

These options are divided into three categories. These are catalogued by type in Table I.

1. User Options: Basic reporting on the system status.
2. Operator Options: Run number and starting time initiation and update, control of the data acquisition, tape unit selection and End-Of-File mark creation, and transfer of tapes to BROOKNET.
3. Diagnostic Options: Reading tables of flags and variables, examining data and status histories, and testing and manipulation of magnetic tapes through the program. All tape operations are interlocked from accidental selection by the user, as their untimely selection could destroy the data tape. The PDP-8/L must be halted and a memory location (AINTLK) altered to permit their activation.

In certain diagnostic (only) options, a parameter is required. The parameter is entered by setting switches 1-11 to the 11-bit parameter value while switch 0 is up. The option number is selected when switch 0 is up. The option number is selected when switch 0 is raised; the parameter entered when switch 0 is depressed. The parameter value is ignored in all the user and operator options listed in Table I.

It is recommended that all 12th switches be set to the 0 state (all down) after selection of each option, to prevent accidental selection of an operator option by a user, etc. Option 0 is the user status reporting option, and in no way affects the functioning of the data acquisition and tape recording processor and other options (like BROOKNET transmissions) which may be active. The User Status Message typed out by selection of Option 0 is shown as part of Fig. 12.

3. Digitizers for the Amino Acid Analyzer Colorimeters

The current from each of the three photocells of the ninhydrin-developed column effluent colorimeters of each of the four analyzer systems is converted to a train of pulses whose frequency is directly proportional to the current. This is illustrated in Fig. 2. The train of pulses is later applied to a gated scaler where the pulses are counted for a specific length of time. This digital information then may be fed to the computer. ^A

The output of the photocells is in the 30 to 50 μ ampere range. The input amplifier is a current amplifier whose feedback resistor is adjusted to give a five volt full-scale output voltage. Negative voltages appear at the output where it is attenuated by a factor of 1000 to supply a 5 mv. output for the chart recorder. The unattenuated output feeds the voltage-to-frequency converter. A trim pot enables one to set the output voltage to zero with zero input current.

The voltage-to-frequency converter consists of an integrator, a discriminator and a charge dumping circuit. The integrator integrates the negative input voltage from the photocell amplifier. When the integrator output voltage reaches the threshold of the discriminator, a univibrator is then triggered which causes a constant current of opposite polarity to the signal current to be injected at the summing point. This current flows for the duration of the oneshot and causes the charge on the capacitor to be removed. The charge placed on the capacitor is directly related to the input current, and therefore the number of discriminator firings per second and the output frequency

of the voltage-to-frequency converter is proportional to the photocell current, and the time duration for which it is applied. The stability of the converter is limited by that of the constant current dump; the stability of the capacitor and the discriminator threshold are not important. An amplifier trim is included for the integrator. It is normally adjusted such that a few pulses per second are generated with no input signal.

A pulse from the discriminator gates a constant current output transistor. The 40 ma. collector current pulse flows through the primary of a pulse transformer. The transformer secondary winding is terminated at both the transmitting and receiving end of a twisted pair in the typical 130Ω characteristic impedance of such lines. The pulse transformer provides DC isolation between the voltage-to-frequency converter and digital computer interfaces, preventing ground loops which might affect the low-level analog signals from the colorimeter photocells.

4. The Data Acquisition Interface

The pulse trains from the 12 voltage-to-frequency converters are counted for a fixed time period in 12 separate scalers. The interface is divided into 4 stations (one for each amino acid analyzer), each having three inputs and three scalers which have been denoted in the program as Red, Blue, and Green for convenience.*

The data acquisition operation is cyclic and controlled by the clock obtained from the 60 Hz line frequency. Figure 3 shows the timing diagram of the data input. The timing generator generates 5 intervals, called a Timer, Station 1, Station 2, Station 3, and Station 4. During each interval, three pulses are generated and are called Transfer (TR); Reset (RS); and Set Flag (SF) in Fig. 3, bottom trace. The pulses are gated with the 5 time intervals and in this way, during each interval, only a selected station receives pulses TR, RS, and SF.

There is a two-bit counter in the interface which can be in one of the 4 states: Time, Red, Blue, Green - see Fig. 3, second trace. The data acquisition interface holds the counter in the time state when the timer interrupt is honored and, in this way, provides time pulse T, which gates the Status Word onto the computer input data lines (Fig. 4). The instruction IOT 6304 is used to strobe the input data lines into the Accumulator of the PDP-8/L.

The TR pulse is used to transfer Red, Blue, and Green counters of a selected station into common Red, Blue, and Green buffer registers as shown in Fig. 4.

*This denotation bears no relation to the actual absorption wavelength employed in the colorimeters themselves.

The RS pulse resets three scalars of the selected station and new sampling of the colorimeter signals of that analyzer is initialized. The SF pulse sets the flag flip-flop of a given station.

Flag flip-flops are connected to the interrupt and skip lines of the PDP-8 computer. The device selection addresses of the timer and 4 analyzers are 030, 031, 032, 033, and 034, respectively.

Upon recognition of the timer interrupt (IOT 6301), the computer clears the timer flag (IOT 6302) and reads in the Status Word. The Status Word is composed of 12 bits set directly by mechanical switches or remotely by the amino acid analyzer control programmer. The first 4 bits are used to identify which of the 4 analyzers are on or off. Users can employ the other 8 bits to record additional information about the analyzer state. Currently, 3 of the 4 ion exchange chromatographs are being employed as two-column amino acid analyzers, with a "short" column for the amino acids and a "long" column for the amino acids. The selection of the column bits in the status word is remotely controlled by the same Singer tape programmer employed for control of the sample injection and chromatograph operations of each amino acid analyzer.

Upon recognition of an interrupt from, say Analyzer 1, (IOT 6311), the computer clears flag 1, (IOT 6312) and reads in the colorimeter data of this analyzer. The sequence of I/O commands is shown in Fig. 3. The command IOT 6302 is used to advance the two-bit counter through the counter buffer register sequence Red (R), Blue (B), Green (G). In this way, the three buffer registers are sequentially connected and strobed onto the computer input data lines. The command

IOT 6304 is used to strobe this data into accumulator. The data are then stored into the input core buffer, BUFIN.

5. The Magnetic Tape Data Recording System

The PDP-8/L computer also acts as a tape controller and is employed here for buffering during inter-record gap, tape formatting and time reference mark generation and data compression.

The continuous acquisition of data on magnetic tape raises two problems:

- 1) Either amino acid analyzers must spill over one tape onto a second reel, or a period must be set near the end of each reel in which a new analysis run cannot be initiated. This latter restriction appeared to put a serious constraint on the research activity and was unacceptable. More than one tape may, therefore, be required to store a given analyzer run. These data tapes may be taken directly to the CDC6600 or sent there via BROOKNET where a file processing routine employed in the analysis sorts these tapes into discrete experiments, and writes an output tape of sorted experiments identical to that of the processed experiments (Beale, 1972). Then all data of each analyzer run is stored contiguously on a Master Tape.
- 2) Tape drives and the tape surfaces themselves are orders of magnitude poorer in reliability than the solid-state electronics. Furthermore, the effects of tape drive failures and errors, unlike parity errors, will usually not be apparent until the tape data is processed by the CDC6600. Thus, the data collecting system may be operating improperly

for 24 hours or more before the failure is even detected.

The total system reliability is limited by the period between putting on a new tape and the 6600 processing of it. Short cycle times between acquisition and analysis gives better system reliability, but requires more tapes and manual tape changing. Longer periods requires less manual intervention (which contribute to tape handling errors), but increase the length of time during which bad tapes may be written undetected. and thus decreases the total system reliability.

To achieve the maximum system reliability, with a moderate tape length, 7-channel 12.5 ips synchronous magnetic tape drives with read-after-write parity error detection operating at 200/556 BPI with a 600' reel capacity were selected. In a typical operating situation at an 8 second cycle time for all 12 colorimeters and 556 BPI tape density, one block of 12 x 150 points plus 4 20-word word header (1780 tape characters), as shown in Figs. 5 and 6, is written every 20 minutes. This requires approximately 8 inches of tape including the 3/4" inter-record gap. This permits approximately 900 blocks on a 600' tape. At this top data rate, (3 blocks/hr.) then, one tape will suffice for up to 10 days. Higher data rates (up to 12/hr.) and/or use of low-density (200 BPI) recording increase the tape changing frequency proportionally.

Examination of the magnetic tape system controller status word upon receipt of a magnetic tape controller interrupt after termination of a tape operation results in the determination of one of four situations. Each of these situations require a special action on the part

of the PDP-8/L control program.

- 1) The last tape-write operation performed was completed correctly.

In this case, a code is written in the header block for the next data buffer, to indicate that the previously written block on the tape was valid.

- 2) A parity error has occurred in the last tape operation. This is usually due to a local bad spot on the tape itself. This is detected through the read-after-write feature of the particular tape drives (PEC, with Datum, Inc. Controller) employed. The test subroutine will then reinitialize the tape-write operation: the tape will be backspaced, and rewritten. Up to 3 attempts will be made to rewrite a data block. If the error still occurs, then the system will advance to the next segment on the tape and restart the tape write trials, resulting in an extra (but hopefully correct) block of this data being written on the tape. (Since all blocks are numbered sequentially, the CDC6600 data analysis program treats the case of duplicate block numbers by assuming that only the last read copy of that numbered block is correct.)
- 3) If this new attempt to write the data on to tape again results in a tape error, then the tape unit itself will be assumed to have failed. The other tape drive will then be employed for data acquisition (if available), or else the tape recording of the data blocks will be terminated until a new tape is placed on either tape unit, and so signaled to the operator by use of the switch register subroutine.

- 4) An End-Of-Tape (EOT) mark is encountered. The program will find which tape unit is in use, write End-Of-File (EOF) mark and back-space the tape off of the End-Of-Tape mark. It will also set flags LIGHT1 or LIGHT2. The Main Loop of the program will then send I/O instruction to turn on the proper light on the console to remind the operator to change tapes. The operator should now rewind the tape, load new tape, and turn off the light by use of switch option.

6. The Background Program

The Background Program is composed of a Main Loop for the checking of different task flags and the execution of the branch subroutines if a particular task request flag is set, as illustrated in Fig. 7.

The first branch, MAN2, permits optional manual selection of subroutines by use of the switch register on the computer console. The rightmost 5 switches of the switch register are used to select, from an address table, one of a variety of subroutines for data collection, data formatting, magnetic tape diagnostics, BROOKNET transfer, asking the computer to type messages or data, etc. This subroutine is then executed, or if a complex task such as the BROOKNET data transfer, it is initiated here and allowed to continue under control of the Main Loop in a multi-programmed manner.

The next branch, DRT2, processes requests for the recording of data on magnetic tape. When the timer interrupt subroutine finds that input data buffer is full, it sets the flag DRT0. The Main Loop then checks if the tape controller is ready and if the last tape operation is finished. It also checks the flag OPEN. If a tape unit is ready for recording, this flag will have been set by the operator by a switch register option.

The magnetic tape handler sends a command to the tape interface signifying tape unit, format, and the desired tape operation. It also utilizes the three-cycle data break: a (negative) word count and the buffer starting address are stored in the memory locations 32 and 33, which are assigned to the magnetic tape data break facility.

The next branch, TES2, is a subroutine for testing the last magnetic tape operation performed. Completion or in-process termination of a tape-written operation is signaled by the magnetic tape interrupt. This subroutine will read the magnetic tape status from tape controller and will set the flag, TES0. Certain other tape operations will not produce interrupts. The end of these operations can be found through the skip on controller ready IOT 6711. In these cases, the IOT 6706 is also used to read the magnetic tape controller status in a similar manner.

The next branch, EXC2, is the exchange tape units program. This program will backspace the current tape unit and change the driver tape command in subroutine DRT2, to switch to the second tape unit. It will also set flag BELL to signify that the tape is not available for further recording until changed by the operator.

While the second unit is used for data recording, the operator should reload the previous unit, reset the change tape light by execution of a subroutine through the switch register commands. This subroutine will also reset the flag BELL. If the operator forgets to reload the tape, next time, when the end of the second tape is reached, the EXC2 subroutine will find the flag BELL set. The program will then reset the flag OPEN and this will stop the recording of data on the tapes. Other operations will continue, including any transmission of data from a tape over BROOKNET.

The next branch is the BROOKNET data transmission task. Two flags, BNACTV and BNTRDY, are employed in a staged manner to cause

reentry into an appropriate location BNTnn in the BROOKNET task by means of an indirect address ABNTSK. The flag, BNACTV, is set when the BROOKNET option is selected. BNTRDY is set as an interrupt end-action to the various tape and BROOKNET wait states, by the interrupt routines. It is also set at certain points to cause reentry to the BROOKNET task on each pass through the Main Loop to check certain tape flags. In this latter flag usage, one may visualize the main loop as extended by an extra subroutine, not shown in Fig. 7, but within the BROOKNET task (Fig. 9) itself. Normally, however, this flag BNTRDY is interrupt driven in a manner similar to the other flags in the Main Loop.

Two flags, LIGHT1 and LIGHT2, are tested next in the Main Loop. If set, these signal the completion of the magnetic tape on tape units 1 and 2, respectively. An IOT is issued in this case to cause Lights 1 or 2 on the interface panel to flash, signalling the operator to remove the completed tape and place a fresh tape on the corresponding tape unit. The restoration of each tape unit is signaled by his selection of options 1 and 2, respectively, on the switch register. These options reset the flags LIGHT1 and LIGHT2 and cause the flags OPEN and BELL (discussed above) to be appropriately updated.

The flag, TTY0, when set, indicates that the teleprinter is ready to accept the next character of an output message. The routine TPR0 unpacks and converts to ASCII the 6-bit characters in the message buffer (PBUFFR), and initiates their output. This cycle will

continue until a terminating JMP I APRTN instruction is found in PBUFFR.

The message processing subroutine GETMSG, accepts messages for the teletype from all other subroutines and enters them in PBUFFR. Messages consist of JMS <subroutine> instructions followed by packed sixbit strings. GETMSG handles multiple teleprinter messages, and queues them for output. A JMP I APRTN instruction is pushed down to the end of the message queue. The flag TTYMSG is set by GETMSG if the teleprinter was inactive when the message was placed in PBUFFR, as signalled by the state of the flag PRNTNG. The flag TTYMSG in the Main Loop, cause initiation of teleprinter output, done via the subroutine at TTYØ. Execution of the end action jump at the end of PBUFFR cause all appropriate flags to be reset, and the endaction jump to be placed at the beginning of PBUFFR. This method of handling queued teleprinter messages permits very simple message entry and multi-programming of teleprinter output.

The teletype keyboard is similarly multi-programmed. Each input character causes a keyboard interrupt, and the subroutine KBINT processes the characters. Only numeric characters and the letter Y (assigned a numeric value of 011) are accepted, all other printing characters are treated as a numeric value of 0. A subroutine DGTACC accumulates the binary value of each input string, until the terminating carriage return is encountered. Then, KBDRDY is set, and the subroutines requesting keyboard input (via a JMS I AKBCAL) is reentered the crossover KBINPT/KBCALL. Upon completion of this subroutine, the Main Program Loop is reentered and this flag testing cycle begins at LOOP.

7. The Interrupt Program

The interrupt program contains not only the interrupt-driven I/O control routines but also the subroutines required to sense the start and stop of each run, log each run, assign run numbers, and start and terminate the data acquisition from the four amino acid analyzers.

The interrupt program (at INTER) is composed of a main tree and branches. This is shown in Fig. 8. The main tree sends I/O test instructions to different possible sources of interrupt, which include BROOKNET and the magnetic tapes, and through a skip line finds which device is interrupting.

When an interrupt occurs, the Link and Accumulator bits are first saved. Then the flag IOSW is tested to see if data acquisition is enabled. If not, then all the device flags for the data acquisition interface are cleared before testing at label DACLR.

If a tape interrupt has occurred, the MGTAPE handler is re-entered and the status of the tape operation decoded as described in Section 4 and a retry set up when a recoverable error detected.

The power failure flag is next checked. If the onset of a power failure is detected, the interrupt return address in location Ø is saved, and this location loaded with the address of the power failure recovery routine, PFRCVY. The computer then is halted. Upon power restoration, the power fail recovery routine PFRCVY is immediately entered.* This routine determines what operations were taking place

*Note: The power switch on the front panel must be in the PANEL LOCK position for automatic power failure recovery.

at the time of the power failure and automatically restores a proper operating state to the program, teletype, data acquisition interface and BROOKNET coupler. An operator message is printed giving the time of the power failure, along with instructions for restoration of the tape unit if the power failure occurred during a tape operation. After an 8 second delay, the interrupt routine is restored and reentered at DACLR. This permits a minimum of 16 seconds to elapse before a timer interrupt is honored, allowing the chromatograph controllers an opportunity to settle before the sampling status.

When a timer interrupt is detected, the status of all 4 chromatographs is examined to see if a status change has occurred during the last 8 seconds. If an amino acid analyzer has started a run, then the subroutine BEGIN is called to assign a run number, update all appropriate data block headers and flags, and print a RUN BEGINS message on the teletype. The FINISH subroutine performs a similar but complementary operation for analyzers which have completed their runs. If all 4 amino acid analyzers are then idle, the PDP-8/L enters PAUSE mode.

In PAUSE mode, the data acquisition process is halted, and the current data buffer immediately written to tape. No further data recording takes place until a new run begins. This avoids several problems:

1. Unnecessary delay in the writing of the final data block on tape;
2. writing dummy blocks on tape if all amino acid analyzers are idle;
3. unnecessary delay in the initiation of BROOKNET transmissions.

In the TIMER subroutine the data buffer count is also tested to see if the current buffer is full. If so, then several operations take place if data acquisition continues:

1. Any BROOKNET operation, other than the wait on initialization of a transmission, is aborted.
2. The input and output buffers are exchanged.
3. The data and tape headers for the new buffer are initiated.
4. Flags for the Main Loop to initiate a tape write of the output buffer are set.

When a teleprinter interrupt is received, the flag TTYØ for the Main Loop is merely set. The keyboard interrupt, however, requires an extensive subroutine KBINT for its processing which causes the input character to be echoed, and its numeric value accumulated. (Recall that only the characters Ø-9 and "Y" have non-zero numeric values.) When a carriage return character is received, the flag KBDRDY in the Main Loop is also set to permit reentry there to the task or subroutine requesting parameter input.

The BROOKNET interrupt flag is then tested. The subroutine BNTINT checks the Central Status Word associated with the BROOKNET interrupt and ignores it if a status parity error condition exists. In case of a status parity error, the BROOKNET system automatically detects the parity error and reissues the interrupt request to the PDP-8/L. A reentry to the BROOKNET task at the appropriate preset point, via the Main Loop, is set up by setting the BNTRDY flag if a BROOKNET

abort has not been set.

At this point, RESTOR, the Accumulator and Link bits are restored, interrupts reenabled, and the interrupt program exits to the interrupted point in the background program.

8. The BROOKNET Communications Link and Its Operation

A link to the CDC6600 at the BNL Central Scientific Computation Facility is provided via a connection to the Laboratory-wide BROOKNET II System. This permits optional transmission of data tapes of any number of records to the CDC6600 disc storage units. These data files can then be accessed by a program executed on the CDC6600 for analysis of the recorded chromatograph data and detailed analysis of the amino acid composition of the analyzed sample. Such a program has been prepared by Beale (1972), and later modified by Thompson (1972) to accept BROOKNET files.

The BROOKNET data transfer task is selected by operator option 5. It runs to completion in a multipli-programmed manner under control of the Main Loop, but may be aborted in process due to unrecovered errors, operator action (option 031), or a conflict of tape unit usage with the data acquisition process.

The data acquisition and BROOKNET tasks run concurrently, with no effect on the collection of data from the analyzers and/or the starting up of new analyzer runs. A slight modification does exist in the data acquisition task in the run termination procedure when the last active run ends, so that PAUSE mode is entered, the last tape write which normally takes place immediately upon entry into PAUSE mode is delayed until the entire BROOKNET transfer operation is completed (if successful) or aborted.

As both the data acquisition and BROOKNET tasks employ (separate) tape units, a method of shared access to the magnetic tape system had to be devised for the two concurrent programs. One such method is

to queue tape requests. This, however, requires an extremely complicated tape handler. A serious problem also exists in terms of buffer storage space: There are only two core buffers available which are large enough to hold 1 tape block. Thus, usage of the core buffers by the BROOKNET task must be synchronized with their usage by the data acquisition task, so that a second core buffer is always available for the data acquisition task to continue data collection once a tape write operation has been initiated for the filled first core buffer.

With a data acquisition cycle time of 8 seconds, one tape block is written every 20 minutes. This process generally takes less than 5 seconds, even with retries. Thus, considerable time is generally available for usage of the tape units by the BROOKNET task between tape writes by the data acquisition task. As only 10 minutes is required to read an entire 600' magnetic tape, and the transfer of each data block over BROOKNET generally only requires a few milliseconds, the entire tape transfer can be performed within the available 20 minute interval. Therefore, it was determined that the BROOKNET data transfer could be restricted to being completed entirely between successive tape write operations of the data acquisition program, and thus the two tasks could alternate control of the magnetic tape system rather than share it, resulting in a considerable programming simplification.

In the actual BROOKNET task, a flow chart of which is shown in Fig. 9, selection of option 5 by the operator initiates the program

and causes a message for a tape unit number (1 or 2) assignment to be printed. This dialogue is shown in Fig. 10. Generally, the tape data acquisition is performed on tape 1, although operator options can select either tape unit 1 or 2 for this function. The other tape unit is then available for BROOKNET. These tape select options permit easy operation of the system, as a data tape can be completed on one unit, say unit 1, an EOF mark written on unit one (option 015), data acquisition switched to a new tape on unit 2 (option 002) and a BROOKNET transfer (option 5) immediately started from tape unit 1.

Typing in of the tape unit number reactivates the suspended BROOKNET task and a request for the tape number ("N" followed by 5 digits) is typed out if no tape assignment conflict (both data acquisition and BROOKNET assigned to same tape unit) exists. In the case of an assignment conflict, the BROOKNET program is aborted, and a message typed indicating this fact and an abort location* and the BROOKNET Central Status Word at the time of the abort. Response to an input tape number address consists of typing in the 5 digit tape number xxxxx following the "N" of the tape to be sent, plus a carriage return. This is shown in Fig. 10. A BROOKNET permanent file name BNxxxxx is formed from this typed-in number.

The next phase of the BROOKNET task is to determine whether sufficient time is available to complete the BROOKNET operation before the next data acquisition task tape write operation. A criteria of

*These refer to the location in the PDP-8/L control program from which the BROOKNET abort was called.

15 minutes is used here, 50% more than the maximum full tape read time of 10 minutes. The system is just checked to see if it is in PAUSE mode (no analyzers active). If it is, then even if a new analyzer run were to start instantly, no tape write would be required by the data acquisition task for 20 minutes. If data acquisition is, however, active, then the data buffer index is checked to determine if at least 15 minutes are available before the next tape write. If neither condition is met, then a "WAIT" message is typed out on the console, and the BROOKNET task goes into a suspended state, rechecking this status on each passage through the Main Loop until one of these conditions is met.

When either the PAUSE mode or 15+ minutes available conditions exists, the BROOKNET task at BNT02 checks to determine whether a successful tape write of the last data block has taken place. Once any retries are complete, the data acquisition task does not require the tape unit until completion of the next data buffer. The BROOKNET task types out the "PROCEED" message and initiates a rewind of the BROOKNET tape unit, waiting at BNT04 until this is completed. Upon completion, the BROOKNET transmission dialogue is initiated at BNT10.

If returned error message is encountered when the PDP-8/L attempts to initiate a BROOKNET transmission, the message is read and typed out on the teletype and the BROOKNET task aborted. If normal initiation occurs, a create BNxxxxx permanent file message is sent to BROOKNET. In the case of a duplicate file name error, a message is typed on the teletype informing the operator and asking if this existing file is to be overwritten and giving him the option of entering a new file name. This is an important feature in practice, as a BROOKNET abort for any

reason may leave a partial data file on the CDC6600 disc which must be overwritten by a later BROOKNET transfer of the same data tape. The actual file overwrite (if selected) is performed by deleting the existing file and then creating a new file of the same BNxxxxxx name.

Once the BROOKNET data file is created, a tape read operation is set up at BNT20 and the BROOKNET task suspended until a successful tape read performed. In case of a recurrent tape read error, after 9 tries the tape operation and the BROOKNET task are aborted. At BNT30, the successfully-read tape data block is transferred to BROOKNET in an End of Record (EOR) write operation using the data break facility under control of registers 030 and 031. This may be repeated once if a transmission error occurs during data transfer. After a successful block transfer, the BROOKNET task loops to BNT20 to read the next tape data block.

If an EOF mark is encountered during the tape read, the program closes, rewinds and returns the BROOKNET file to the CSCF catalog in a subroutine starting at BNT22. A message telling of the successful BROOKNET transfer is printed on the teletype, and the BROOKNET system decoupled and the BROOKNET task deactivated at BNTEND. Control is then transferred back to the Main Loop with its flags BNACTV and BNTRDY to the reset.

9. Loading and Operation of the PDP-8/L Computer

The PDP-8/L control program is supplied as a binary paper tape which is loaded through the paper tape reader on the ASR-33 teletype. This program is loaded by use of the PDP-8 Binary Loader program.

To load the program tape, the PDP-8 RIM bootstrap loader and the PDP-8 Binary Loader only need be present in the PDP-8/L. The RIM loader is loaded at 7756 in the lower 4K of core memory (data and instruction field switches on the computer console in the down position). The instructions for loading the RIM and Binary Loaders can be formed in the Appendices of any DEC Small Computer Handbook which refers to the PDP-8, PDP-8/L, PDP-8/I or PDP-8/e. The Teletype Bypass Switch (on front of the black box on the left side of the Teletype) should be in the "On" position during all paper tape operations and program initiation.

The computer is then halted and is now ready for loading the program tape version with a date corresponding to the version of the printout labeled "Amino Acid Analyzer with PDP-8 Computer -- BROOKNET Version" (usually found in a brown binder near the computer). This paper tape is placed in the teletype tape reader in a manner identical to the Binary Loader paper tape. The octal number 7777 is placed on the console switch register and the switches "Load Address" and "Start" depressed in order. If (or when) the teletype paper tape reader switch is placed in the "start" position, paper tape reading will commence and after about 10 minutes will halt automatically at the end of information on the program tape.

The Accumulator Lights on the PDP-8/L console should next be checked. If any of the 12 positions are lighted, then parity errors have occurred during the reading of the program paper tape. This tape should be reloaded in the same manner described above.

Initiation:

When a successful (error-free) program tape read-in has been performed, the program may be initiated by placing the octal number 0200 on the console switch register and depressing the "Halt", "Load Address" and "Start" switches in order.

The time and run number update is now generally performed. The last completed run number on each analyzer A,B,C, and D is determined from the analyzer log books. If any of the analyzers are executing runs at the time of update, then the run number of the last runs previous to the runs in process must be used, otherwise the run numbering on the tape will be 1 more than the log books indicate.

Selection of Operator Option 030 is performed to initiate the run number and time Update. An example of this is shown in Fig. 11. User type-ins have been underlined. Run numbers are typed in as 6-digit numbers with sufficient leading zeroes in the order requested by the computer. Time of year is input as a 3-digit day number, 2-digit hour number, and 2-digit minute number rounded to the nearest 2 minutes from 0-58. (This is because the 8-second cycle-timing does not divide into 1 minute evenly.)

If an odd number of minutes is typed in, the computer will repeat the request for the minutes typed in until correctly performed.

Data acquisition is started by first verifying that a write enable tape is mounted and the unit in the "On-Line" and "Write Enabled" states as shown by the indicator lights on the tape unit. If this is a new tape, the "Load" lights should also be on. The tape unit to be used for data acquisition is signaled to the program by use of Operator Options 021 or 022 to select tape units 1 or 2, respectively. The four column switches and the four recorder switches on the interface should all be in the "Auto" (up) position. Data acquisition is then started by selecting Operator Option 4. The Teletype Bypass Switch may now be placed in the "off" position, to automatically turn off the Teletype 10 seconds after each logging operation.

Logging Messages:

Typical logging messages are shown in Fig. 12. As the first character sent out by the computer turns on the teletype motor, some "garbage" may be typed out along the left margin of the page until the motor comes up to the rated speed. These spurious characters should be ignored. The teletype automatically turns off 10 seconds after the last character of a message is sent out by the computer.

Each starting run is logged separately. The letter "S" or "L" indicates the ion-exchange column in use on that analyzer run.

More than one run may be logged in the run ending message. As part of each run ending message, the User Option 0 Status Message is automatically typed to show the current analyzer status. This message can be typed at any other time by selection of User Option 0. The

The current active analyzer runs are given and other analyzers not in the data collection phase are denoted as "idle."

Power Messages and Recovery Procedures:

Power Failures are logged automatically. When power is restored, a power failure message, followed by a User Status Message, reflecting the state of the analyzers at the time of power failure is printed out. Operator action may be required if the tape units are not in the proper state, as these units will ^{lose} drop tape tension and lose their state and tape position after about 500 ms of no power. In such a case, a tape unit which is in the middle of a tape should be restored by pushing the "On-Off" switch to the "On" position and the pressing of the "Load" switch once to set tape tension. Since tape position may have been lost, the write EOF Mark option (Operator Option 15 or 16, respectively for units 1 or 2) should then be selected several times for the unit. This will generally preserve all the data acquired on the tape up to the time of power failure.

There is one rare case, however, in which the last tape block may be destroyed - that is when the tape was actually being written when the power failure occurred. In this case, a message informing the operator and telling him: "Tape Operation Failed. Set SW27 when ready" is typed out. If the tape unit has not lost tension, then the tape operation can generally be recovered by mere selection of Operator Option 027. If it has lost tension, then the restoration and write EOF mark procedure described above should be performed before selection of Option 27. Then the tape may be changed.

Data Acquisition Tape Messages:

Other miscellaneous messages are occasionally typed out regarding data acquisition tape status.

1. "NO TAPE AVAILABLE"

Neither tape unit is available for data acquisition.

A new tape must be mounted and Operator Options 1 or 2 and 021 or 022 selected to inform the computer of which tape unit is ready and selected for data acquisition.

2. "TAPE ERROR -- RETRY"

A parity error occurred during tape write. This is logged for diagnostic purposes only. An automatic retry is performed by the program. No operation action is required.

3. "RETRY FAILED -- TAPE ADVANCED"

After 3 unsuccessful attempts to write an error-free block on the tape, the tape is automatically advanced and a new copy of the block written. A bad spot on the tape is logged by this message. The tape should probably be shortened past this point or discarded in the near future.

4. "TAPE OPN FAILED"

This is part of the power failure recovery messages described above, and indicates that a tape operation was actually underway at the time of power failure. Operator action for this condition is described above.

The Change Tape Lights:

Two flashing white lights are provided on the data acquisition interface to indicate when a tape has reached the physical End of Tape mark during a tape write operation. If this occurs, after completion of the data write and End of File mark will be automatic-ally written by the control program, and the tape backspaced on record (set ahead of the EOT mark). This procedure is required to prevent the tape controller from "hanging" in the End of Tape condition. The corresponding "Change Tape" light will be flashed until the unit is reloaded with a new tape and Operator Option 1 or 2 selected (corresponding to tape unit 1 or 2, respectively) to tell the program that the tape unit is ready.

Do not, under any circumstances, write an EOF mark (Operator Option 15 or 16) on a tape unit which has the change tape light on and is near the end of the tape. This operation is redundant, and will result in an extra EOF mark being written ahead of the one already written by the computer, and on top of the last data block. The last data block on the tape will thus be lost.

When a unit reaches the physical EOT mark, the assignment of the data acquisition tape unit will also automatically be changed over to the other tape unit if and only if that unit has been previously signaled as ready by selection of Operator Option 1 or 2. If upon reaching the end of tape and completing the EOF write and backspace, the program does not find the other tape unit ready, then the "Tape not available" message will be printed and no further tape data acquisition will be performed until at least 1 tape unit is signaled as ready and selected by the operator.

REFERENCES

1. Beale, S. I. (1972) Unpublished Report.
2. Campbell, G., K. Fuchel, and L. Padwa. "BROOKNET 2: Brookhaven On-Line Computer Network." BNL 17054, (July 1972).
3. Digital Equipment Corporation Small Computer Handbook (any version referring to the PDP-8 Computer).
4. Friedman, J. and L. Padwa. "BROOKNET Brookhaven On-Line Remote Network" BNL 50262 (December 1970).
5. Thompson, K. (1972) Private Communication.

Table I

Optional Functions Available for Manual Selection

Switch register value, octal	Symbolic name	Parameter	Operation
<u>1. User Options:</u>			
0	TIME	-	Types correct time and status information, in- cluding run numbers and columns selected, of all 4 analyzers. See Fig. 12.
<u>2. Operator Options:</u>			
1	OFLIT1	-	The operator can not- ify computer that tape unit 1 is prepared.
2	OFLIT2	-	The operator can notify computer that tape unit 2 is prepared.
4	GO	-	Start the data acqui- sition process.
5	BRKNET	-	Initiate a transfer of data from the tape unit not currently employed for data acquisition to a BROOKENT file at the CDC6600. An extensive dialog with PDP-8/L en- sues. See Fig. 10.
10	STOP	-	Stop data acquisition process.
15	MARK1	-	Write End of File mark on tape 1.
16	MARK2	-	Write End of File mark on tape 2.

Table I (cont'd.)

Optional Functions Available for Manual Selection

Switch register value, octal	Symbolic name	Parameter	Operation
<u>2. Operator Options:</u> (cont'd.)			
21	SEL1	-	Select tape unit 1 for data acquisition.
22	SEL2	-	Select tape unit 2 for data acquisition.
27	TAPRDY	-	Tell computer tapes now ready after a power failure occurred. This is done only in response to a typed message on the console once power is restored, and the operator has manually reinitiated the magnetic tapes.
30	SETUP	-	Enter last completed run number for each analyzer and current time of year (dialog). See Fig. 11.
31	GIVEUP	-	Abort BROOKNET operations.
<u>3. Diagnostic Options:</u> (a * indicates that this option is interlocked from accidental selection)			
3*	BUFF	Buffer Address	Reads from console switches starting address of buffer and initialize all magnetic tape sub- routines.

Table I (cont'd.)

Optional Functions Available for Manual Selection

Switch register value, octal	Symbolic name	Parameter	Operation
<u>3. Diagnostic Options:</u> (cont'd.)			
6*	REW1	-	Rewind magnetic tape unit 1
7*	REW2	-	Rewind magnetic tape unit 2
11*	READ1	-	Read one record from tape 1
12*	READ2	-	Read one record from tape 2
13*	WRT1	-	Write one record on tape 1
14*	WRT2	-	Write one record on tape 2
17	STAT	-	Read tape status. It has 4 halt ad- dresses, depending on the tape status: error exit, re-try exit; ok exit and not ready exit.
20	TYPEM	-	Teletype will type last 14 time status pairs of the experiment.
23*	BACK1	no. of records	Reads from console switches number of records, and backspace tape 1.
24*	BACK2	no. of records	Reads from console switches number of records, and backspace tape 2.
25	CLEAR	-	Clear selected buffer in core memory.

Table I (cont'd.)

Optional Functions Available for Manual Selection

Switch register value, octal	Symbolic name	Parameter	Operation
<hr/>			
3. <u>Diagnostic Options:</u> (cont'd.)			
26	TYPE1	Starting Address	Reads from console switches the start- ing address and types contents of the next 14 memory locations (octal)
32 - 37	NOOP	-	Do nothing.

Figure 1. Block Diagram of Amino Acid Analyzer Data Acquisition System

Figure 3. Internal Timing in the Data Acquisition Interface

RELATIVE WORD ADDRESS:

TAPE HEADER FORMAT

Figure 5. Magnetic Tape Data Block Format

DATA BLOCK HEADER FORMAT		
Relative Word Address	0	Not Used
	1	24-Bit Tape
	2	Block Number
	3	48-Bit Block Data
	4	
	5	
	6	Acquisition Starting Time
	7	3 Spare Words
	8	
	9	
	011	
	012	24-Bit Current/ (U12 bits)
	013	Ending Run Number (L12 bits)
	014	Ending Status Word
	015	Ending Data Index
	016	Spare
	017	24-Bit Starting (U12 bits)
	020	Run Number (L12 bits)
	021	Starting Status Word
	022	Starting Data Index
	023	Spare

All locations have same values as in tape header.

CURRENT/ENDING RUN PACKET

=0 if no run active on block initiation

if not ending, status at block initiation

=7777 if current run continues over block, or none active

STARTING RUN PACKET

=0 if no new run starts during this block

undefined if no run starting

=7777 if no new run starting

Figure 6. Data Block Header Format
for Each Amino Acid Analyzer

SUBROUTINES:

FLAG SET BY:

BNTnn : SET UP
NEXT BROOKNET
OPERATION

nn: 00-37

BNACTX : BRKNET

BNTRDY: MAG TAPE
(READ) OR BROOKNET
INTERRUPT SR.

REMIND OPERATOR TO PREPARE
TAPE 1

TES2 ROUTINE

REMIND OPERATOR TO PREPARE
TAPE 2

TES2 ROUTINE

TPR0: OUTPUT NEXT
TELETYPE CHARACTER

TELEPRINTER
INTERRUPT

PRINT: INITIATE TELETYPE
OUTPUT

GETMSG

KBINTP: REENTER TASK
REQUESTING INPUT
PARAMETER

KBINT UPON RECEIPT OF A
CARRIAGE RETURN

KBCALL: WAIT ON INPUT
PARAMETER TYPE IN BY USER

Figure 7. (Continued)

INPUT KEYBOARD CHARACTER ECHO,
PUT IN INPUT CHARACTER BUFFER.
SET FLAG "KBDRDY" UPON RECEIPT
OF A CARRIAGE RETURN.

TEST VALID CENTRAL STATUS
WORD RECEIVED, SET FLAG
"BNTRDY" FOR MAIN LOOP ON
VALID STATUS AND NON-ABORT
CONDITION.

Figure 8. (Continued)

Figure 9. The BROOKNET Control Task

Figure 9. (Continued)

Figure 9. (Continued)

Example 1: Both Data Acquisition and Brooknet Assigned to
Same Tape Unit

BROOKNET TAPE TRANSFER OPERATION:

TAPE UNIT TO SEND: 1 ← Tape Unit 1 or 2 typed in

TAPE ASSIGNMENT CONFLICT

BROOKNET TRANSMISSION FAILED AT ADDR. 5423 CS=0000 (Diagnostic
Message)

Example 2: Normal Transmission over Brooknet

BROOKNET TAPE TRANSFER OPERATION:

TAPE UNIT TO SEND: 2 ← Tape Unit typed in

INPUT TAPE NO- N27701 ← Five-digit tape number typed in

PROCEED

BROOKNET TRANSMISSION SUCCESSFUL

Example 3: Retransmission of a File

BROOKNET TAPE TRANSFER OPERATION:

TAPE UNIT TO SEND: 2 ← Tape Unit

INPUT TAPE NO- N27701 ← Tape Number

PROCEED

BROOKNET MSG NO:0033 AT ADDR: 5645

DUPLICATE FILE NAME

--DELETE OLD FILE (Y OR N)?: Y { "Y" deletes old file copy,
sends tape creating a new
file of the same file name.

PROCEED

BROOKNET TRANSMISSION SUCCESSFUL

Figure 10: Brooknet Tape Transfer Dialogue
(Operator type-ins are underlined)

RUN NUMBER & TIME UPDATE:

ANALYZER A LAST COMPLETED RUN NUMBER:	<u>001078</u> ,	} Type in 6 digit run numbers
ANALYZER B LAST COMPLETED RUN NUMBER:	<u>000342</u> ,	
ANALYZER C LAST COMPLETED RUN NUMBER:	<u>001742</u> ,	
ANALYZER D LAST COMPLETED RUN NUMBER:	<u>001896</u> ,	

CURRENT TIME

DAY <u>318</u> ,	} Type in time of year (to nearest 2 minutes)
HOUR <u>11</u> ,	
MIN <u>02</u> ,	

Figure 11: Operator Option 30. Dialogue
for Update of Run Numbers and Current Time

ANALYZER B S RUN 000336 BEGINS TIME 307: 11: 48	} Separate Run Starting Messages
ANALYZER C S RUN 001722 BEGINS TIME 307: 11: 48	
ANALYZER D L RUN 001871 BEGINS TIME 307: 11: 50	

ANALYZER CS RUN ENDS AT TIME 307: 11: 53	} Option 0 User Status Message	} Run Ending Message, Includes User Status Message
ANALYZER STATUS		
A IDLE		
B 000336S		
C IDLE		
D 001871L		

Figure 12: Logging and Status Typeouts