Developments in laboratory equipment

Equipment for linking the AutoAnalyzer to an off-line computer

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The increasing demand for laboratory investigation of patients has created many new problems for the pathologist, not least of which is the difficulty of handling all the data involved. Manual data processing systems are still operating satisfactorily at present but there are sound reasons for considering the use of automatic data processing in the future (Flynn, 1966).

To enable data to be handled entirely by mechanical or electronic means a language is required which can be written, recognized and reproduced without the aid of the human eye. In the punched hole language which is commonly used for this purpose there are only two symbols, a hole or no hole, and different numbers and combinations of these symbols are used to represent each 'character', that is each letter, digit, or sign. The machines detect where holes are present and convert the information into electrical impulses.

Getting information into suitable form for machine handling represents one of the major obstacles to the use of automatic data processing systems. Of the two steps that are involved, namely, the collection of significant data and the coding of such data, the second presents the greater difficulty and is often dependent on specially trained personnel. Because a high proportion of our analyses are now performed with the Technicon AutoAnalyzer, we have concentrated in the first instance on devising equipment which will automatically collect data from these instruments in machine-readable form. We have collaborated in designing a suitable analogue-to-digital converter which when attached to the AutoAnalyzer recorders automatically finds the peaks during the run of analyses and records their height on punched paper-tape ready for direct computer entry. In this paper we describe the equipment and report on our experience with it; preliminary accounts have already been published (Flynn, 1965a and b). Details of how a computer has been programmed to process the data captured by the analogue-to-digital converter will be described elsewhere.

DESIGN CONSIDERATIONS

The basic requirement of the analogue-to-digital converter equipment is that it should automatically select, code, and store for subsequent computer processing the significant part of the analogue information presented on the AutoAnalyzer recorder. The equipment therefore incorporates facilities for recognizing the peaks, quantitating their heights, converting the values to binary form, and punching the coded information on to paper-tape.

It is not possible to select peak values by a timing device because the intervals between them are not quite constant for a given rate of sampling of specimens, and therefore peaks have to be recognized in some way. This could be done electronically by monitoring the magnitude of the voltage signal to the recorder, or mechanically by following the direction of rotation of the potentiometer shaft. The latter method has been selected because of its relative simplicity. The existence of background noise on the recording complicates the recognition of peaks, so provision has been made to prevent it triggering extraneous readings. Occasional gross chemical carryover between adjacent specimens complicates the recognition of peaks and provision has been made to ensure that a reading is taken from a poorly described peak which has been virtually swamped by a preceding high one. Because temporary absence of peaks is not uncommon, due for instance to small clots blocking the tubing of the sampling line, provision has also been made for the taking of readings to correspond with these non-existent peaks. Because readings taken in such circumstances are not valid for the calculation of results by the computer they require distinction from true peak readings and consequently they are coded differently. Baseline readings are sometimes required and provision has been made for them to be taken at will. Variables in AutoAnalyzer operation which have to be taken into account are alteration in sampling rate and changes in the analytical procedure which make it necessary to read inverse peaks, or troughs, rather than peaks. As laboratories with large work loads inevitably use several AutoAnalyzers the equipment has been designed so that data can be collected on to a single punched paper-tape from up to eight channels operating simultaneously but independently. In view of the amount of data that might accumulate from such multiplexing it has been decided that the equipment should take only one reading from each peak; the amount of data for storage and processing is thus kept to a minimum. It has also been decided that the existing record of pen movement should be preserved so that (a) results of urgent tests can be assessed visually during a run of analyses by comparing the height of the appropriate standard and unknown peaks; (b) faults are

FIG. 1. Diagram showing the main components of the equipment required for automatically recording peak heights from six AutoAnalyzer channels on punched paper-tape.

FIG. 2. View of the cabinets which house all the electronic components other than those attached to the recorders.

immediately apparent as irregularities on the pen tracing; and (c) the tracing is available for manual processing in the event of breakdown of the equipment or of the computer.

DESCRIPTION OF THE APPARATUS AND ITS FUNCTIONS

The main components of the equipment required for recording peak heights from six AutoAnalyzer channels on a single punched paper-tape are shown in diagrammatic form in Figure 1. Most of these items, together with the transformer which is required for providing the power supplies to the various parts of the system, are mounted in cabinets at a distance from the Auto-Analyzers (Fig. 2). These cabinets are provided with air-tight doors to protect the contacts on the various switches from the laboratory atmosphere.

The attachment of the apparatus to the AutoAnalyzer requires some additional fittings in the recorder, as shown in Figure 3. These comprise (a) a device for detecting peaks; (b) an encoder for registering the position of the potentiometer shaft; (c) two event-indicator pens; (d) three extra switches.

THE PEAK OR TROUGH DETECTING DEVICE This consists of two microswitches and an arm which is attached via a clutch to the recorder potentiometer shaft. The arm follows the rotation of the potentiometer shaft except when stopped from moving further by striking the actuator of one or other micro-switch; rotation of the shaft beyond this point is accompanied by slip occurring at the clutch. One of the micro-switches is closed by the

FIG. 3a

FIG. 3. Views of the AutoAnalyzer recorder showing the extra fittings required for the analogue-to-digital converter equipment: (a) view from the front with door opened; (b) rear view from inside.

FIG. 3b

arm moving a predetermined amount in a clockwise direction, corresponding to a right-to-left movement of the recorder pen across the chart, and the other by a similar movement of the arm in the opposite direction, corresponding to a left-to-right movement of the pen. The sequential closing of one circuit and then the other in a defined order causes a reading of shaft position to be taken immediately after a peak has been described on the chart tracing. To prevent small irrelevant movements of the potentiometer shaft, due to searching chatter by the potentiometer drive or minor irregularities in the chemical reaction, from triggering false readings, the rotation of the shaft required to move the arm from one micro-switch actuator to the other must be set to be greater than that expected from such background 'noise'. On the other hand the setting must not be so great as to exclude the recognition of the smallest peaks likely to be encountered. One of the micro-switches is mounted on a bracket with slots so that the distance between the two switches can be readily adjusted; by altering this setting the shaft movement required to initiate a peak reading can easily be changed. Our usual setting corresponds to a pen movement of approximately 1.3% of full-scale deflection. It should be noted here that the method of triggering a peak reading is such that the reading will not be taken at the top of the peak: this is of no consequence, however, as all peaks, including those corresponding to chemical standards, will be read a constant distance from their zenith. The amount of backlash

required to trigger peak readings must be accurately known when baseline readings are required for the calculation of results, as a corresponding correction has to be made by the computer.

THE SHAFT-POSITION ENCODER This follows the rotation of the recorder potentiometer at all times, and when a small current is sent through it the angular rotation of the shaft at that instant is noted in electrical form according to which unique combination of 12 possible circuits becomes live through its commutator. Within the encoder, brushes ride over the photo-etched contacts of the coding commutator; according to which circuits become live or remain inactive, shaft position is indicated linearly in a special code to the nearest 1/1000th part of the angle of 336° which is spanned by the commutator. As rotation of the shaft through an angle of 336° is required to move the pen from one extreme position on the recorder chart to the other, the coded signals also indicate pen position to the nearest 1/1000th part of full-scale deflection giving a thousand possible readings from 000 to 999. A combination of four circuits is used to define each of the three digits, the hundreds, the tens, and the units. Current may be caused to pass through the encoder by closure of the peak-detecting circuit, by use of the push-button switch on the front of the recorder or by closure of the circuit by a time switch. Before power is applied through the encoder its movement is momentarily stopped by interrupting the recorder servo motor.

THE EVENT INDICATOR PENS These continuously write on the edge of the recorder chart in the same horizontal plane as the recorder pen. They are caused to make a momentary $\frac{1}{8}$ in. excursion towards the recorder pen when a current is triggered through an attached solenoid. One registers whenever a peak reading is taken and the other records the occurrence of readings triggered either by the time switch or the manual press button switch. Their function is to supply the AutoAnalyzer operator with information as to which specimens will require repeat analysis and as to when any extraneous reading has been taken.

SWITCHES ADDED TO EACH RECORDER The three switches added to each recorder have the following functions. The toggle switch on the front is for connecting the recorder to the analogue-to-digital converter system; when it is in the off position the recorder can be used in an ordinary way. The press button switch on the front is used at the commencement of each run to start the time clock and activate the system to take readings. A reading of pen position is taken whenever it is pressed and it can be used therefore to obtain a baseline reading if this is required. The switch at the back is used to change from a peak-detecting to a trough-detecting operation according to whether the chemical reaction concerned results in production or loss of colour; for example, it is turned to peak picking for urea determinations and to trough picking for bicarbonate estimations. This switch changes over the circuits to which the two micro-switches are connected and therefore alters the direction of pen movement required to close the peak-reading circuit.

TRANSLATOR UNIT A translator unit consists of groups of relays designed to translate the special coded signals from the encoder into decimal contact closures, which are used ultimately to operate the punching of the readings. The relays are equipped with hold-coils so that the digital signals can be stored until the programmer unit is ready to receive the information. As soon as the translator unit receives signals via the encoder it sends a signal to the programmer unit calling it to punch the data.

TIMER UNIT A timer unit is equipped with a time switch which will automatically close the circuit through the encoder if a peak reading fails to be triggered within a predetermined time interval. The time clock is reset to zero each time a reading is taken. The purpose of this timed reading is to ensure that a reading is taken to correspond with each specimen that has or should have been sampled; this is essential as readings are related to particular specimens purely by their sequential position. Figure 4 shows how the timer unit ensures that a reading is taken from a low peak which follows an extra high one; carry over has prevented the usual drop of the pen between peaks so that the peak-detecting circuit is not reset and consequently no peak reading is taken. Figure 5 shows how sequence is similarly maintained when a break in sampling occurs, due, for example, to a clot blocking the sampling tube. By the time the absence of peaks is noted on the recorder tracing and remedial action taken,

FIG. 4. Recorder chart showing how a timed reading is taken from a small peak which has been swamped by a preceding high one.

the sampler unit has failed to aspirate several specimens; however, when sampling is resumed and peaks reappear readings will be correctly related to specimens on the sampler plate because the time switch has operated once for each missing peak. The timing interval can be adjusted to permit the employment of different sampling rates on the AutoAnalyzer and to allow for minor fluctuations in the intervals between peaks. When 40 specimens are being sampled per hour we have found that the time interval between the triggering of successive peak readings may be up to 96 seconds and consequently it is necessary to set the time switch to operate at greater intervals than this. When very small peaks are encountered, of the order of 3 to 5% of full-scale deflection, the flatter shape of these peaks leads to still further time delay in the triggering of peak readings. However, if the timer is set to operate at 97 seconds only very small valid peaks fail to trigger a peak reading in the time available. At a sampling rate of 40 per hour peaks should occur at 90-second intervals, but if they fail to appear for a considerable period and timed readings continue to be taken at 97-second intervals, readings will eventually become out of step with sampling. In practice, at this rate of sampling, the relationship of readings to samples is only maintained for just over a quarter of an hour.

FIG. 5. Recorder chart showing how timed readings maintain the one-for-one relationship between readings and sampling when peaks are absent for a limited period.

AutoAnalyzer failures which lead to the absence of peaks for periods greater than this must be regarded as major breakdowns and the specimens affected will have to be re-run with a new set of calibration standards. When it is desirable to set the timer to operate at more than 97-second intervals, as on the urea channel where very small peaks are regularly encountered, loss of sequence would occur with less than a quarter of an hour's absence of peaks. To cover this situation extra circuits have been added to the timer unit which cause the time switch to operate on a long-setting, *e.g.*, 110 seconds, for the first two cycles of each new series of time readings, and thereafter on a shorter interval corresponding exactly to the rate of sampling of specimens, *e.g.*, 90 seconds. With this arrangement, provided the sampler unit is never halted, correspondence between the sequence of readings and the sequence of sampling is never lost however long peaks are absent. Each time the time clock is reset to zero the peak-reading circuit through the encoder is inhibited so that it cannot be operated for a short but adjustable interval until another time switch closes. The purpose of this second time switch, which we have set to operate at 5 seconds, is to prevent the possibility of data from a second reading arriving at the translator unit before there has been time for information on the first reading to be transferred to the punch.

PROGRAMMER UNIT The programmer unit organizes the punching of the readings on paper-tape for computer input. Its operation is controlled by two stepping switches which are capable of scanning a series of contacts at a maximum speed of 50 steps per second. They advance in a fixed direction from one set of contacts to another only when they receive a signal calling them to do so. One of the stepping switches immediately 'homes' on to whichever translator unit is calling for data to be punched, thereby linking the data lines of that translator to the programmer. By a contact closure it then calls the other stepping switch to organize the punching operation. The second stepping switch links the punch solenoids, in turn, to circuits which hold in coded form the various items of information which comprise a reading. It first connects circuits which produce signals indicating the start of a new reading, then those indicating the channel that the reading is coming from, and eventually those indicating the method by which the reading was taken and its value. The second stepping switch also restores the translator unit concerned to a 'cleared' state by releasing its hold-coils after transferring the data to the punch. Because the programmer unit connects with the first translator to have data available, the blocks of characters representing single readings are transferred to the paper-tape in random order. When the programmer receives calls from more than one translator unit at any instant, it 'homes' on the one nearest to the present position of the stepping switch before jumping to the others. If six translators called simultaneously for attention, all could be cleared of their information in four seconds. In order to verify correct performance of the punch it is possible to cause the programmer unit to organize a repetitive sequence of seven test characters; this operation is set in motion by pressing a switch on the front of the cabinet housing this unit.

TAPE PUNCH The tape punch uses electrical impulses from the programmer unit to cause holes to be punched on paper-tape. It is capable of punching 28 characters, or rows of holes, per second. It holds two reels of $\frac{3}{8}$ in. wide tape, each 1,020 ft. long and because it is extremely noisy we have had a sound-deadening box made for it. Information is punched in a five-bit alpha-numeric code, *i.e.*, combinations of holes in five possible positions are used to represent single figures, letters, or signs. The small hole punched near the middle of each row is not a code hole but is used by a sprocket feed device to advance the tape mechanically. Each reading is punched in a standard format of seven consecutive characters as shown in Figure 6. The function of each character is as follows:—

1st character	=	code to indicate start of new reading
2nd character	=	code to indicate AutoAnalyzer channel from which reading originated
3rd character	=	code to indicate start of result data
4th character	=	code to indicate whether the reading is a peak-reading, or a timed or manual reading
5th } characters	=	codes indicating reading value: the 5th, 6th, and 7th characters represent the hundreds, ten and units respectively
6th }		
7th }		

EXPERIENCE WITH THE APPARATUS

Routine operational experience with the full equipment

FIG. 6. Examples of punched tape readings produced by the equipment. That on the left was a timed reading of 123 taken from channel A, and that on the right a peak reading of 456 taken from channel B.

now extends over 12 months and before that we spent six months experimenting with a prototype of the apparatus linked to one AutoAnalyzer recorder. From this experience we believe the equipment to be adequate and well suited to its function of automatically collecting and coding significant data from several independent AutoAnalyzer channels. It has not proved necessary to modify existing AutoAnalyzer procedures to use the equipment satisfactorily but we have had to raise the standard of our operations, for example, by renewing the pump tubing of the manifold more frequently, especially when small peaks are liable to be encountered. The functional flexibility of the equipment has overcome problems arising from background noise on the recordings, from variation in peak arrival time or duration, from swamping of low peaks by preceding high ones, and from temporary interruptions of peak formation. From time to time chemical irregularities cause the analogue-to-digital converter to punch extra or incorrect peak values. For example, a very brief and temporary blockage of the sampling line by particulate matter in a specimen may cause a bifid peak and then two peak readings may be taken from one sample; again, passage of an air bubble or of a speck of solid matter through the colorimeter flow-cell may trigger an extraneous or incorrect peak-reading. Faults such as these seem to be almost inevitable accompaniments of AutoAnalyzer operations under routine conditions and because they may cause serious error in the results calculated by computer, we have incorporated facilities in the computer programme which make it possible to make appropriate corrections of the raw data after they have been transferred into the computer store. The faults responsible for incorrect or

extraneous readings are visible to the AutoAnalyzer operator on the chart record, and lack of uniformity in the spacing of the marks made by the event pen registering peak readings makes it an easy matter to detect where they have occurred.

The accuracy of the readings taken by the equipment has been investigated by comparing the values recorded on the punched paper-tape with those obtained by visual assessment. The comparison was carried out when the prototype apparatus was in use and when the point at which a reading was taken was being directly marked on the analogue trace itself; consequently the visual readings were greatly facilitated. Comparisons were made during the reading of 1,000 peaks covering all parts of the recorder scale and as can be seen from Table I there was excellent agreement. Because the thickness of the ink-line amounts to 0.2% of full-scale deflection across the recorder chart, it is reasonable to attribute the small differences noted to inaccuracies of the visual assessment of pen position. Automatic readings are probably accurate therefore to 0.2% of full scale deflection, which is more than adequate for their purpose.

TABLE I

DIFFERENCE BETWEEN VISUAL ASSESSMENT OF PEN POSITION AND VALUE PUNCHED BY THE ANALOGUE-TO-DIGITAL CONVERTER DURING THE READING OF 1,000 PEAKS

Difference	Number of Readings
None	184
1/1000th of full scale deflection	451
2/1000th of full scale deflection	262
3/1000th of full scale deflection	94
4/1000th of full scale deflection	9

Regarding reliability of the equipment, breakdowns are far more frequently attributable to failures of the AutoAnalyzer procedure than to malfunction of components of the analogue-to-digital converter. However, breakdowns of the equipment have occurred and in the course of 12 months' full use, five diodes, three relays, one synchronous electric motor, one condenser, one drive solenoid, and the shaft drive of the punch have all had to be replaced. Where component failure was gradual and produced an intermittent fault, tracing of the trouble proved very time-consuming. The punch proved liable after several hours' inactivity to mispunch a character by omitting a hole, but the introduction of the test programme has successfully eliminated trouble from this source. In any event the computer has been programmed to carry out certain checks on the codes as the data are fed into it. The punch requires periodic adjustment and routine maintenance of this component is essential.

DISCUSSION

The escalation of work loads and the shortage of trained staff seem likely to hasten the introduction of machines for assisting laboratory data processing and already a few papers and preliminary communications describing

their use have appeared in the literature. Most experience has been gained with mechanical systems for handling punch cards (Peacock, Bunting, Brewer, Cotlove, and Williams, 1965; Whitehead, 1965; Lindberg, 1965; Sobota, Brewer, Cummings, Feld, and Williams, 1965) but some, notably Constandse (1965) and Lamson (1965), have described the use of off-line computer facilities. We are also aware that on-line data acquisition systems are in use in Sweden and the United States. While considerable benefits have been derived from the use of mechanical data processing systems, there can be no doubt that much more extensive and comprehensive data processing becomes possible with systems which make use of a general purpose electronic computer.

The equipment described in this paper has been designed to form a part of a computer-orientated data processing system for the laboratory. It has been designed for use with an off-line computer because on-line facilities seem unlikely to become available for a considerable time to come. Punched paper-tape was chosen as the data storage medium rather than punch cards for a variety of reasons. Thus, equipment required to produce punched paper-tape is far less expensive than that required to punch 80 column cards, and paper-tape provides cheaper and more compact storage than cards. Further, paper-tape is well suited to the storage of a large amount of data in sequential order and is compatible with the transmission of data to a remote computer via a G.P.O. Telex installation.

In the laboratory data processing systems described in the literature, final test result data have been entered manually on a Hollerith-type card by operating a keyboard punch or by marking appropriate areas with a special pencil. The great advantage of the data acquisition equipment reported here is that analytical data are collected and prepared for direct computer entry virtually without manual intervention. Moreover as the system collects raw analytical data the task of processing this information to produce final test results can be delegated to the computer, with an appreciable saving in time and elimination of human errors which inevitably creep in at this stage.

The equipment described here has been specifically designed for collecting data from the AutoAnalyzer and it appears to be well suited to this function. It could easily be used, however, for collecting raw analytical data from other laboratory instruments. Any instrument producing a voltage signal which was suitable for monitoring by a 10 millivolt recorder could be linked to the system. By simply slackening a locking nut the peak-detecting device can be disconnected and digitised readings could then be taken solely on a time basis. If readings at timed intervals were not appropriate it would be a simple matter to disconnect the timing mechanism and take readings at will by operating the manual press-button switch on the front of the recorder whenever significant data were to be noted.

The cost of the equipment described is considerable. The cost per channel decreases as the number of channels

increases because one programmer unit and punch are required regardless of whether the system is operated for a single channel or for eight. The cost of the total equipment, including the cost of modifying the standard recorder, approximates £1,500 for the first channel and £1,000 for each subsequent channel up to the eighth¹. Considering that this equipment is preparing data for direct computer entry and therefore for processing in an infinite number of ways, these costs compare favourably with that of available equipment which merely provides a simple print-out of results. Moreover results produced with the latter type of equipment are often of limited accuracy because drift correction is ignored.

SUMMARY

A detailed description is given of equipment which has been designed to collect data automatically from the AutoAnalyzer and prepare it for computer entry. The equipment detects the peaks, quantitates their height, converts their value to binary form and punches the coded information on to paper-tape. It can punch on a single paper-tape data collected from eight AutoAnalyzer channels operating simultaneously but independently.

Experience with the equipment is reported. It is shown to take highly accurate readings, to be reasonably reliable, and to have sufficient flexibility to enable it to cope with all the usual variables and difficulties encountered during routine AutoAnalyzer operation.

The basic engineering plan of the equipment described was conceived by Mr. J. H. Aird of Elliott Medical Automation Ltd., and we wish to acknowledge his important contribution to this work. The equipment was purchased from research funds granted to University College Hospital by the Ministry of Health and we wish to thank the Ministry for their support in our project of exploring the use of a computer by a clinical chemistry service.

We also wish to thank Mr. V. K. Asta for the diagrams and Mr. A. C. Lees for the photographs.

¹The equipment is available from Medical Equipments Division, Elliott Medical Automation Ltd., 97 Maidstone Road, Rochester, Kent.

REFERENCES

- Constandse, W. J. (1965). In *Symposium on Computer-assisted Pathology*, p. 26. College of American Pathologists, Chicago.
- Flynn, F. V. (1965a). *Proc. Ass. clin. Biochem.*, 3, 272.
- (1965b). In *Progress in Medical Computing*, p. 46. Elliott Medical Automation Ltd., London.
- (1966). *Proc. roy. Soc. Med.*, 59, 779.
- Lamson, B. G. (1965). In *Computers in Biomedical Research*, vol. 1, p. 353. Edited by R. W. Stacy and B. Waxman. Academic Press, New York and London.
- Lindberg, D. A. B. (1965). *Missouri Med.*, 62, 296.
- Peacock, A. C., Bunting, S. L., Brewer, D., Cotlove, E., and Williams, G. Z. (1965). *Clin. Chem.*, 11, 595.
- Sobotta, J. T., Brewer, D., Cummings, M. E., Feld, M., and Williams, G. Z. (1965) *Amer. J. clin. Path.*, 44, 502.
- Whitehead, T. P. (1965) In *Progress in Medical Computing*, p. 52. Elliott Medical Automation Ltd., London.