A DATA ACQUISITION, PROCESSING, AND DISPLAY SYSTEM FOR EXPERIMENTAL WORK IN VETERINARY MEDICINE

by

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CHAPTER I

INTRODUCTION

The success of most experimental work lies in the collection of data and the display of that data in a useful way. With the increase in computer technology, especially in the area of microcomputers, it has become desirable to use computers to facilitate data acquisition and display. This is certainly true in the area of veterinary medicine since computers are becoming an integral part of the medical environment. Microcomputers are being used in the monitoring of physiological signals [1] and in a variety of instrumentation devices [2,3]. Much work has also been involved with the use of a computer system for dedicated experimental applications. Examples are a microcomputer-based system for CO_2 rebreathing studies [4], a computer system for the measurement of transient temperature <u>in vivo</u> [5], and a computer system for recording physiological data from conditioning experiments on dogs [6]. An obvious advantage of these systems is that many changes can be made by simply modifying the computer programs.

Once the decision to use a computer has been made, it becomes very important to select the appropriate computer system for the environment in which it will be used. Parameters which must be given major consideration for a computer system to be used in experimental work in veterinary medicine include data collection capability, data display capability, expansion capability, and cost. The system should be chosen for the parcicular applications for which it is to be used but should allow for expansion in case additional capabilities are needed in the future.

In order to fully determine the parameters for a computer system to be used for experimental work in veterinary medicine, an experimental computer system was used to collect, process, and display data from veterinary medicine experiments. The experimental system consists of an Intecolor 8001 microcomputer [7,8] and peripherals. The Intecolor 8001 system was chosen because it possesses many of the characteristics needed for experimental work and was available for use in veterinary medicine experiments. A description of the experimental computer system is given in Chapter 2. Chapter 3 describes how the experimental system was used to collect experimental data and discusses computer system parameters such as memory size and sampling frequency which are important to data acquisition. Chapter 4 deals with the processing of experimental data by a computer system in a veterinary medicine environment. Chapter 5 then discusses the ways in which data was displayed on the experimental computer system and the desired features of a computer system which is to be used for data display in an experimental environment. In Chapter 6 the results of the previous chapters are used to determine possible computer systems for experimental work in veterinary medicine. The capabilities and approximate costs of each system are compared. Finally, conclusions are presented in Chapter 7.

CHAPTER II

EXPERIMENTAL SYSTEM

The experimental computer system used in the evaluation of a data acquisition, data processing, and data display system for experimental work in veterinary medicine was an Intecolor 8001 microcomputer made by Intelligent Systems Corporation. A block diagram of this experimental system is shown in Fig. 1. The Intecolor 8001 has color graphics capabilities and may be used as either a general purpose microcomputer system or a display terminal. The basic system components are a central processing unit, memory, input/output circuits, keyboard, and CRT display. Peripherals in the experimental system are a printer, a dual mini-floppy disk unit, and an analog-to-digital converter system. The Intecolor 8001 software includes a CRT operating system, a CPU operating system, a file control system, and BASIC 8001. Programming the Intecolor can be done with either BASIC, machine language, or a combination of both. The Intecolor 8001 used as an experimental system is described in more detail in the following paragraphs.

The central processing unit for the Intecolor 8001 is an 8080 8-bit microprocessor [9] driven by a two-phase 2 MHz clock. Addresses from the 8080 are transmitted over a 16-bit 3-state address bus. Similarly, data is transmitted and received over an 8-bit bidirectional 3-state data bus. Interrupts to the 8080 are initiated by simply driving the interrupt line high. Five different types of instructions are included in the 8080 instruction set. These instruction types will be discussed later in the paragraph discussing machine language programming.

Memory in the Intecolor 8001 can be divided into two sections. The

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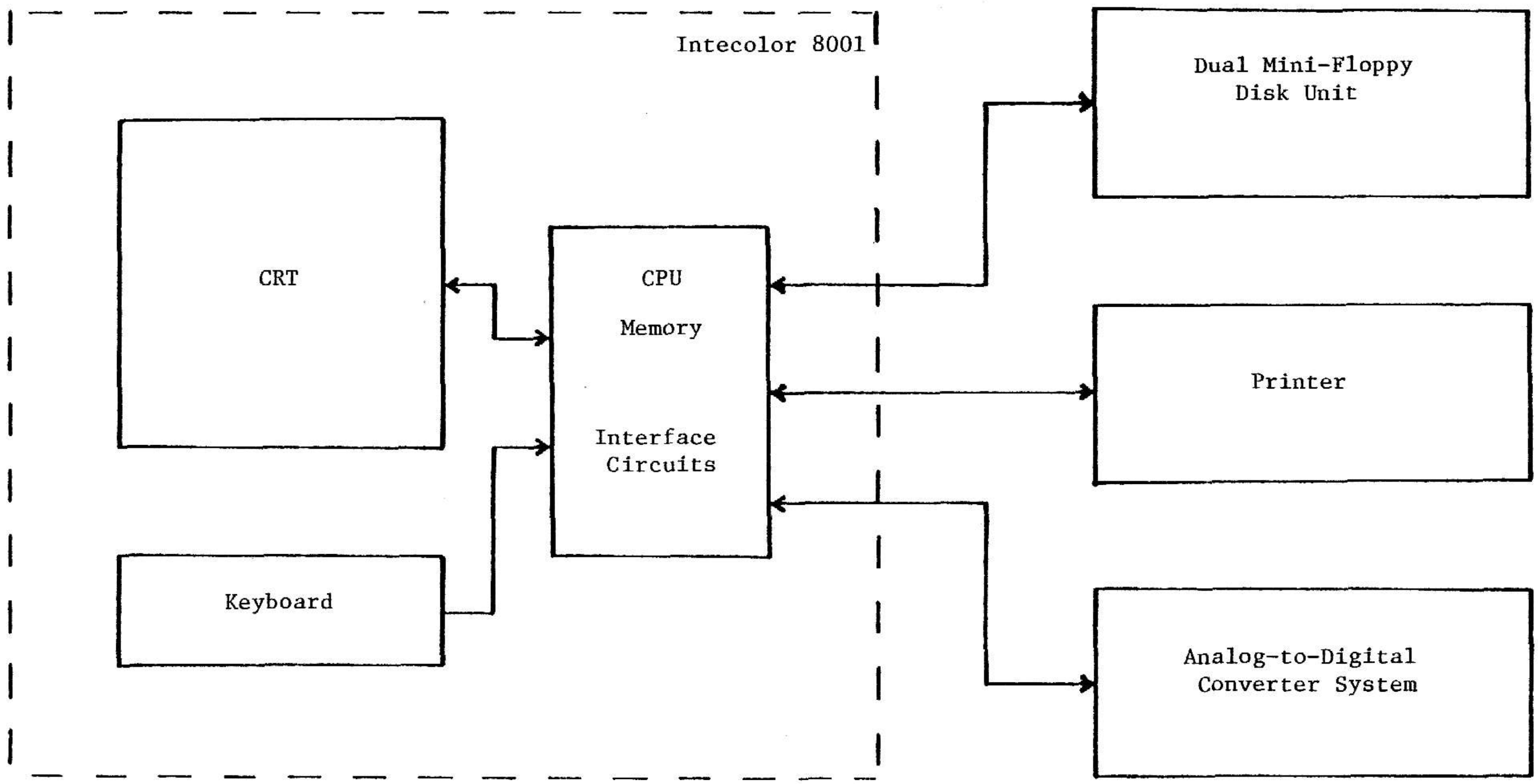

Fig. 1. Block Diagram of Experimental System

first section is located in the lower 32K of addressable locations and is comprised of ROM, PROM, and EPROM. This section of memory contains the system operating programs. The location of each program in the experimental system is shown in Fig. 2. As can be seen in the figure, many of the lower 32K addresses are not used. These locations can be used to add more system software such as better editing capability and an assembler. They can also be used to store user programs which are frequently needed and now require RAM memory which could be better utilized for data storage.

The second section of memory is located in the upper 32K of addressable locations and is comprised entirely of RAM. The RAM is divided as shown in Fig. 3. Refresh RAM for the CRT is located between 8000_{16} and $9DFF_{16}$. This RAM is addressed by the display generator as well as the central processing unit. Locations between 40K and 64K may be used for either program or data storage. BASIC programs must begin at $A0B2_{16}$ whereas the programmer may decide where to store machine language programs and data. Precautions must be taken, though, to assure that programs do not overlap.

One of the most important features of a microcomputer system for experimental work is its display capability. The Intecolor 8001 has a CRT with excellent color graphics. The CRT can be set to display either 25 or 48 lines of 80 characters each on a 12" wide by 10" high screen. There are eight possible color levels for both foreground and background which may be individually selected for each character. The Intecolor also has the capability of plotting on a 160 x 192 screen grid. Other features include automatic plotting of X and Y bar graphs by defining end points, automatic incremental point movements, and individual point addressing. The CRT display is stored in the previously mentioned refresh

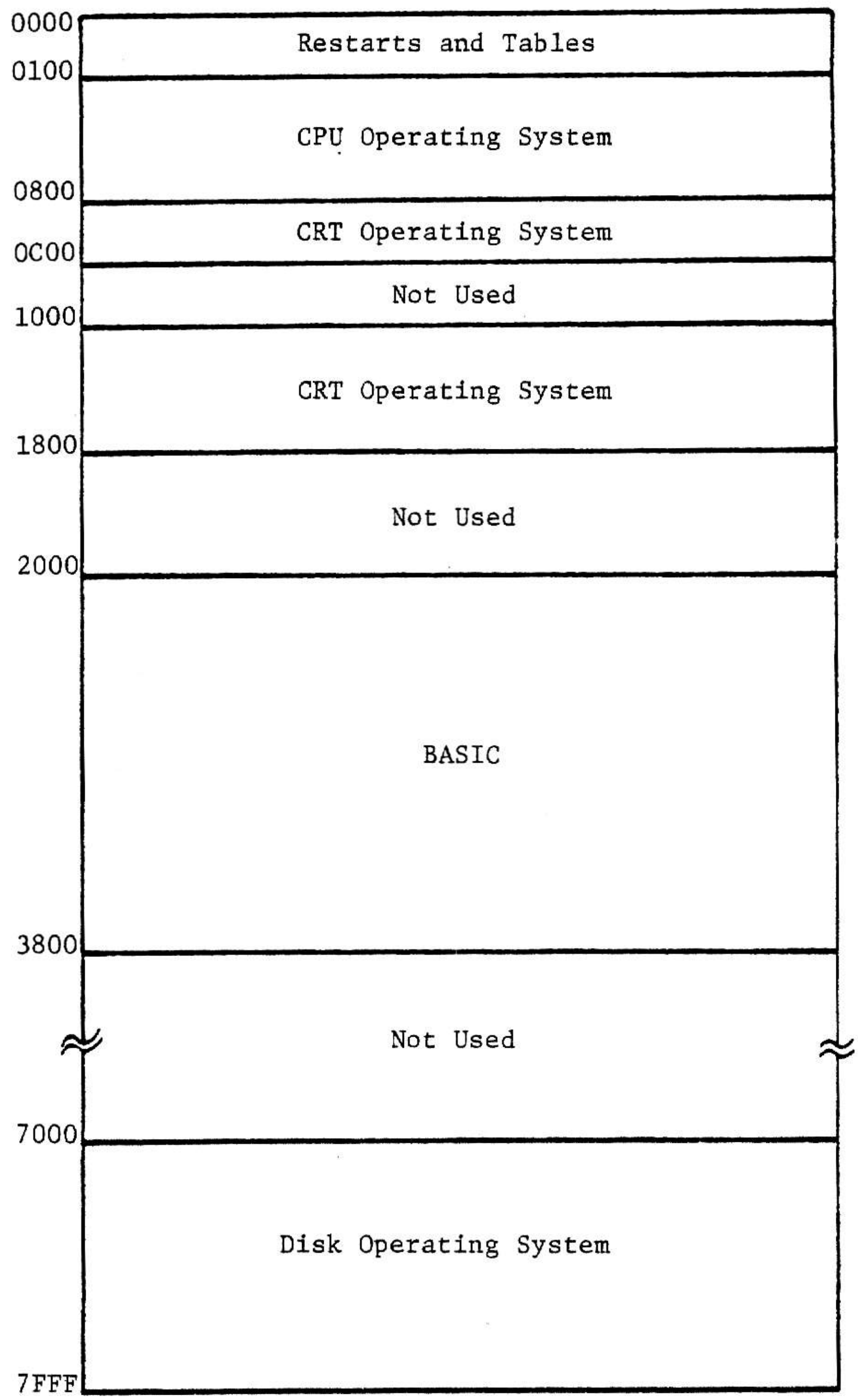

Fig. 2. Intecolor 8001 Memory (ROM, PROM, EPROM)

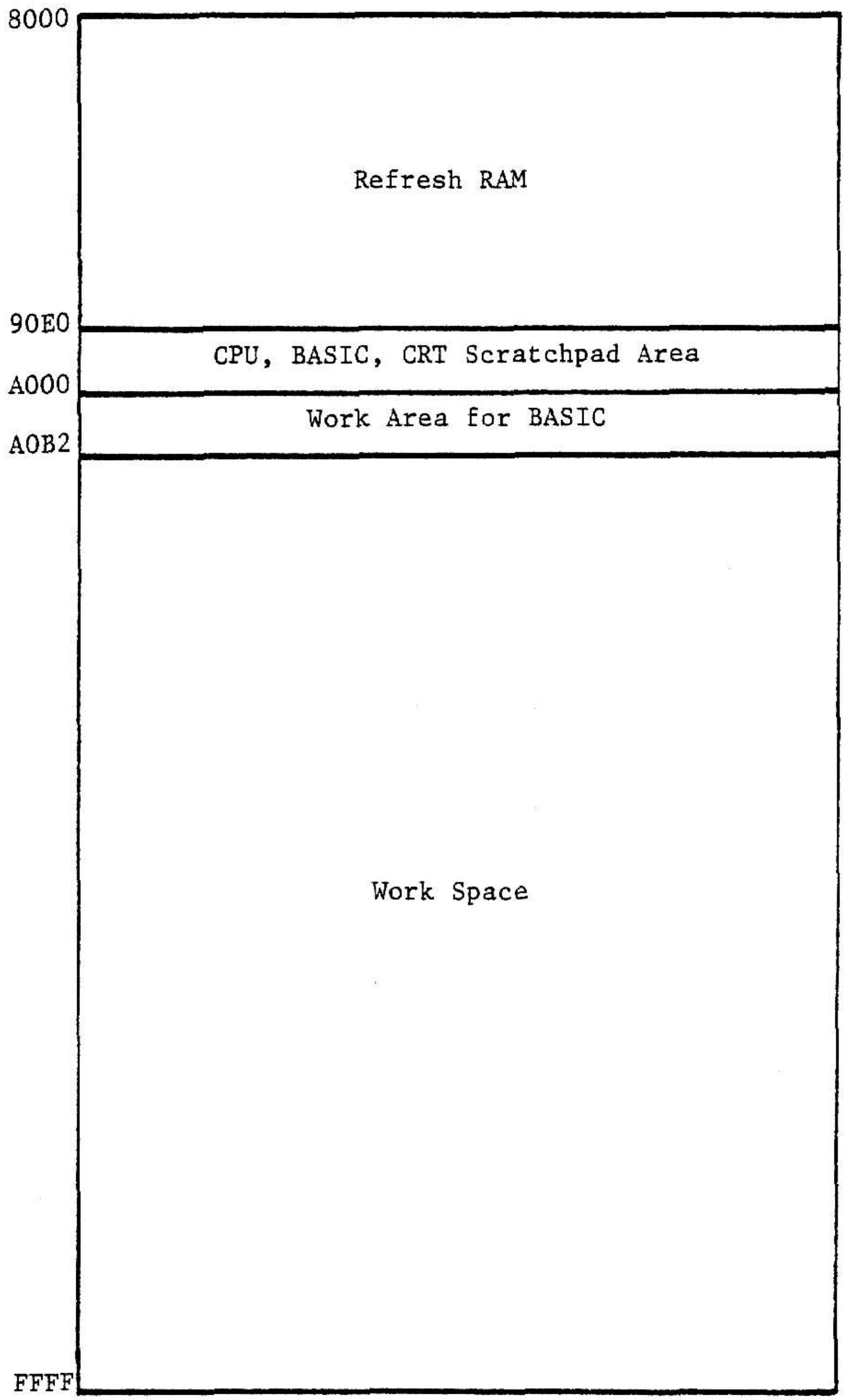

Fig. 3. Intecolor 8001 Memory (RAM)

RAM and is accessed at a rate of 60 Hz. CRT circuitry performs deflection and video drive functions, memory accessing, and character generation.

Another important feature of a computer system is its interface circuitry as the interface circuits control the number and variety of peripherals the computer may control. In the case of this particular Intecolor 8001, there are four interface circuits. They are two 5501 multifunction input/output circuits, an 8255 programmable peripheral interface, and an FD1771B floppy disk formatter/controller. A brief discription of each interface and its application in this Intecolor 8001 is given below.

The 5501 multifunction input/output circuit provides an 8080-based computer system with a communication interface, data input/output buffers, interrupt control logic, and five interval timers. The communication interface supplies an asynchronous transmitter and receiver for serial communications. The baud rate is programmable and can be set at 110, 150, 300, 1200, 2400, 4800, or 9800 baud. The data buffers provide an 8-bit parallel interface and the timers can supply intervals from 64 to 16,320 microseconds. In the experimental system, the communications interface transmits data to a line printer and the parallel interface allows data to be received from the keyboard. Interrupts from the 5501 are used for both printer and keyboard communications. A second 5501 provides an additional RS-232 interface which is not used in the experimental system.

Another interface in the Intecolor 8001 is an 8255 programmable peripheral interface chip. The 8255 is a general purpose I/O device. The functions of its three 8-bit ports (A,B, and C) are determined by software. The three operating modes which may be selected are basic input/output, strobed input/output, and strobed bidirectional bus I/O. Each mode may be selected using a single instruction which allows the 8255 to service more than one peripheral with a single software routine. In this experimental system, the 8255 was used in the basic I/O mode as the interface for the analog-to-digital converter system. More detail will be given in the chapter on collecting data using the experimental system.

The final interface of importance in the Intecolor 8001 experimental system is an FD11771B. This device is a floppy disk controller/ formatter. The experimental system uses the FD11771B as the interface for a dual mini-floppy disk unit.

Also important in a computer system description is the available system software. Software in the Intecolor 8001 used as an experimental system includes a CRT operating system, a CPU operating system, a file control system, and BASIC 8001. The Intecolor is in the CRT operating system after power up and any time the CRT reset key has been pushed. The CRT operating system initializes the system and allows keyboard entries. The CPU operating system allows the keyboard operator to display the 8080 registers and memory contents as well as modify the 8080 registers and RAM memory contents. It also allows the execution of machine language programs and the setting of breakpoints to aid in the debugging of these programs. Also included in the system software is a file control system which allows the keyboard operator to display listings of programs on disk and load these programs to and from the dual mini-floppy disk unit. Finally, the BASIC 8001 system software permits the entering and execution of BASIC programs.

As stated earlier, programming the Intecolor 8001 can be accomplished in one of two ways, BASIC or machine language. BASIC is a simple computer language to learn and can be very powerful and versatile. In the Intecolor 8001, immediate translation and storage of user programs is provided by an incremental compiler which decreases execution time. Included in BASIC 8001 are program, editing, and command statements, mathematical and string functions, and error messages. In addition, provisions in BASIC 8001 allow the BASIC program to provide graphic functions, change background and foreground colors on the CRT, access data through the file control system, and in general, perform any operation a keyboard operator could perform.

Although BASIC programs can handle most applications for the experimental system, machine language programs were sometimes needed to decrease execution times. In that case programs were written in 8080 assembly language and then assembled using tables since there was no assembler in the experimental system software. Five different types of instructions are included in the 8080 instruction set. They are data transfer instructions, arithmetic instructions, logical instructions, branch instructions, and stack, I/O, and machine control instructions. Machine language may be used to write entire programs but a more common application would be their use as subroutines to BASIC programs.

CHAPTER III

DATA ACQUISITION

The acquisition of experimental data is an essential feature for a computer system in veterinary medicine. The computer system must be able to collect experimental data with the desired accuracy and store this data in a form which can be analyzed and displayed. This, of course, requires an analog-to-digital converter system. Many types of analog signals are encountered in the veterinary medicine environment. These analog signals vary both in magnitude and bandwidth. The differences in magnitude can be handled by running the analog signals through instrumentation amplifiers so that they are all approximately the same size and can then be digitized using the same A/D converter system. In addition, the sampling frequency should be programmable so that the analog signal can be sampled at a rate which assures that information is not lost. A sampling rate faster than necessary, however, will use up memory for data storage and limit the length of experimental data which may be continuously collected. In order to get a good idea of the computer system parameters necessary for the acquisition of data, an A/D converter system was designed for the experimental computer system described in the previous chapter. Also, computer programs were written to control the A/D converter system in the collection of data from a mass spectrometer.

A/D Converter System

The A/D converter system was designed to interface with the experimental computer system through the 8255 programmable interface chip. A block diagram of the A/D converter system is shown in Fig. 4. The system consists of two main sections, an ADC0816CCN single chip data acquisition

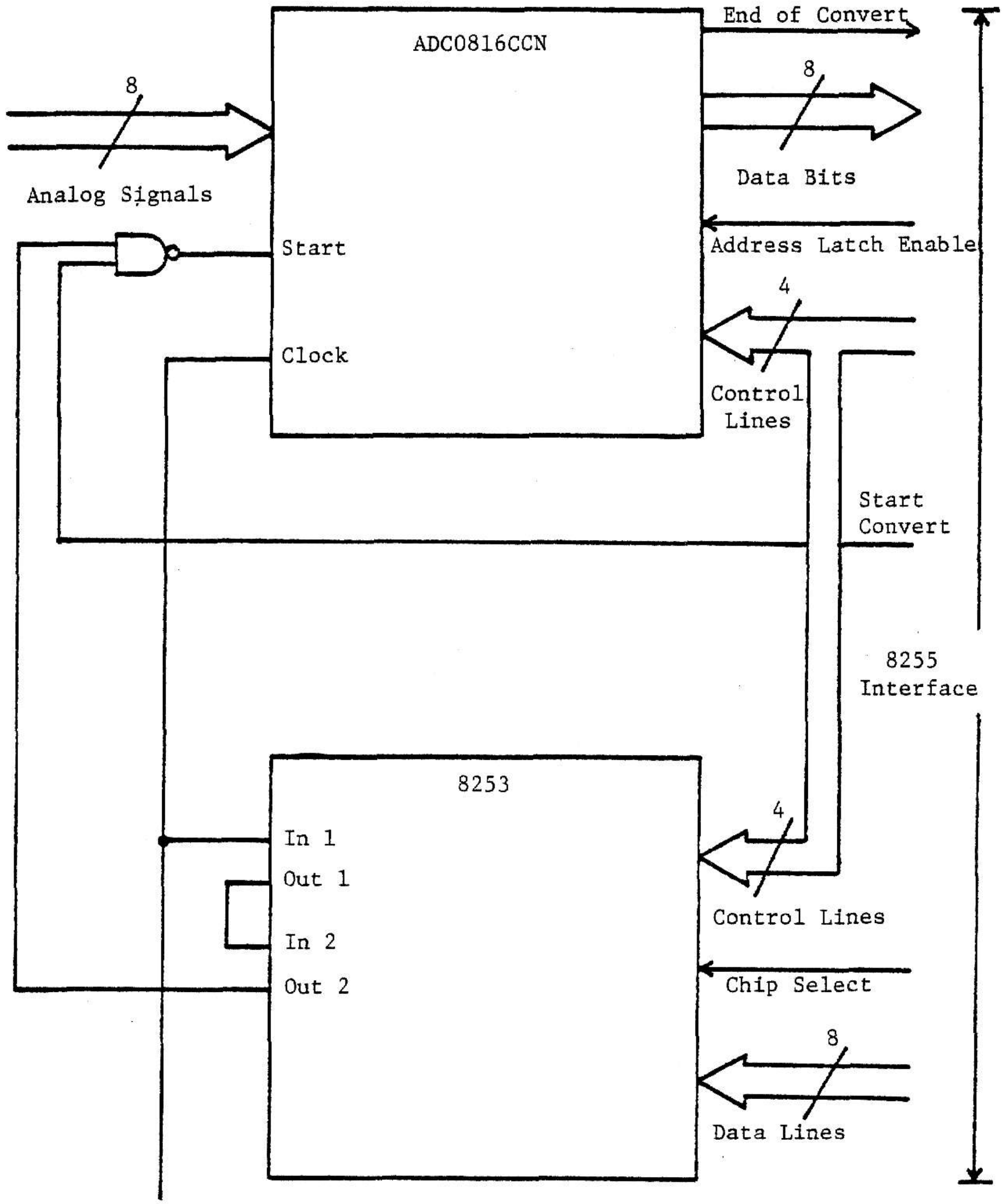

Fig. 4. Block Diagram of A/D Converter System

system and an 8253 programmable interval timer. The ADC0816CCN consists of an 8-bit analog-to-digital converter, a 16-channel multiplexer, and control logic. The 8253 programmable interval timer has three timers, each of which can be programmed separately. The system also includes a crystal which provides a 895 kHz clock for both the first interval timer and A/D converter. The basic operation of the system is described in the following paragraph.

The A/D converter system is completely under software control. By writing to and reading from the appropriate port of the 8255 programmable interface chip, the 8080 microprocessor in the experimental computer system can set the sampling frequency through port B, select the channel or channels to be sampled through port C, and read the digital data through port A. The sampling frequency is selected by writing the proper count values into the first two timers. Since the first timer uses the 895 kHz clock, the first two timers are cascaded in order to get sampling frequencies of less than 10 Hz. The output of the second timer is sent to the start pin of the A/D which then starts a conversion of the selected channel. Next, the microprocessor must send out the appropriate control signals to select the first channel to be sampled. The microprocessor then waits to receive the signal that the A/D has finished the conversion so that it may read the 8 bits of data. If more than one channel is being sampled, the microprocessor then immediately selects the next channel, sends out another start signal to the A/D, waits for the end of convert signal, and reads the 8 bits of data. The system may handle eight channels in this way. Although each channel is not sampled simultaneously, they may be treated as such because each channel is sampled within 100 μsec of the previous channel. This is very small compared with the interval between samples of the same channel which is greater than 10 msec for sampling frequencies of less than 100 Hz. After all channels have been sampled the microprocessor selects the first channel and waits for an end of convert signal from the A/D. Again, the sequence is initiated by a start signal from the second timer whose rate is determined by the sampling frequency. This sequence continues until the required number of samples has been taken. A flow chart of the program used for this collection of data is shown in Fig. 5. Also, after each data point is read it is stored in binary form in successive memory locations.

The program for the collection of data was written as a combination of BASIC and machine language. BASIC was used for as much of the program as possible because BASIC is easily understood by a person with little or no programming experience. The execution time of BASIC statements can be a limitation, though, so BASIC was used only for routines where speed was not critical. Execution time of the program is critical when data is being read from the A/D converter. This routine must be executed in the shortest period of time possible so that data read from different channels may be treated as being simultaneously taken which may be important in certain types of experiments. Therefore, the actual reading of data was written as a machine language subroutine to the BASIC program.

Computer System Parameters

The acquisition of experimental data using a computer system results, of course, in an approximation of the original signal. This can not be avoided as a continuous signal is being stored as a set of discrete points. The set of points becomes a closer approximation as either the resolution or sampling frequency of the A/D converter system is increased. Of course, as either of these parameters is increased the amount of memory required in the computer system increases. The A/D converter used with the

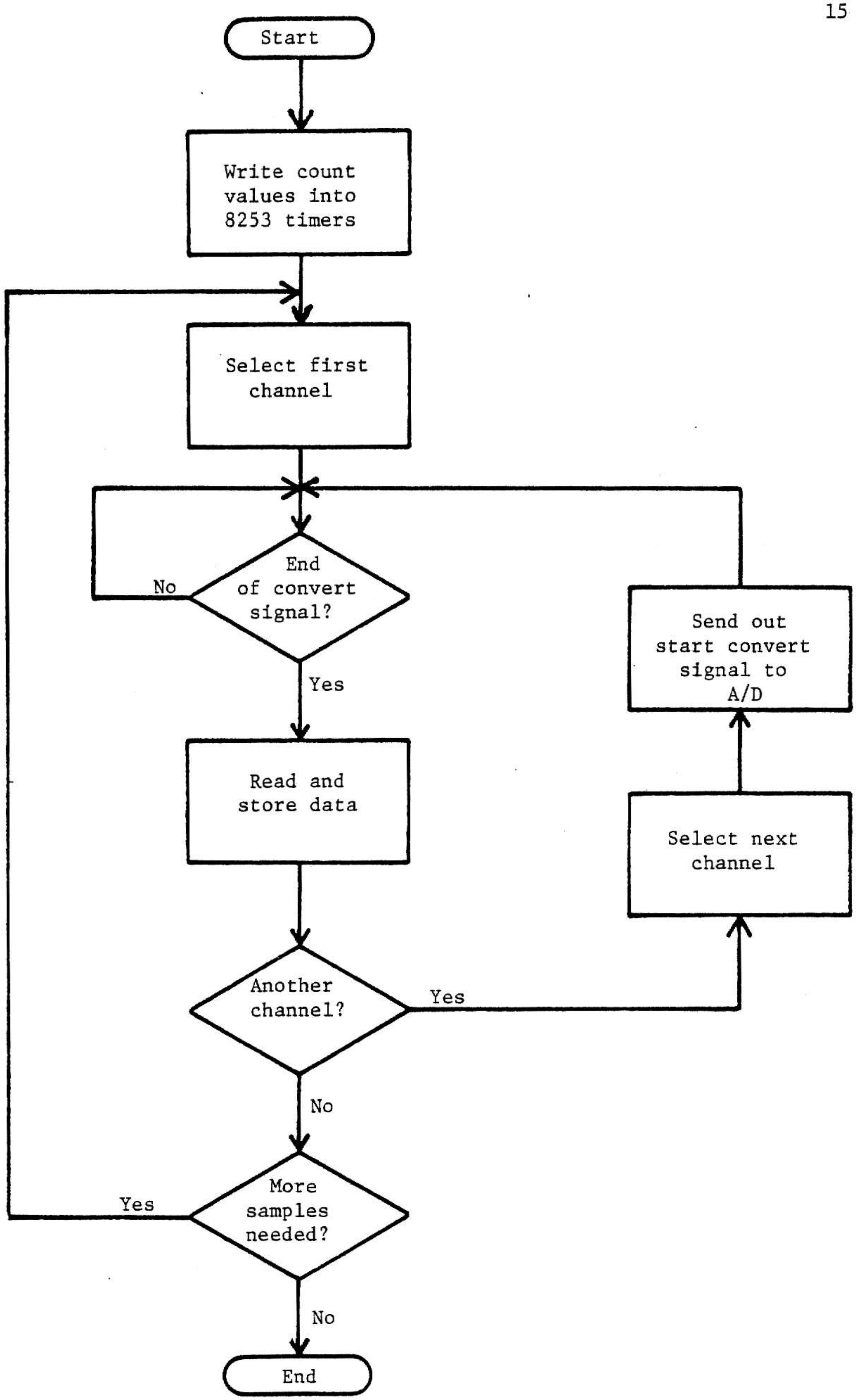

Fig. 5. Flow Chart for Data Acquisition

experimental system is an 8-bit converter which gives accuracy to within 0.4%. This is sufficient for most applications and is very convenient because one data value may be stored in one memory location. An A/D converter with 10-bit and 12-bit resolution may be used if the application requires the additional accuracy but each data point will require two memory locations and, therefore, twice the amount of memory. As mentioned earlier, the sampling frequency was programmable in the A/D converter system used with the experimental computer system. This is a very important feature of any acquisition system because sampling at a faster rate than is necessary requires additional memory. The necessary sampling frequency is determined by both the frequency of the signal and the information that is needed. For example, it would require a higher sampling frequency to completely describe a carbon dioxide signal during a respiratory cycle than it would to find a peak value of the cycle. This is because the carbon dioxide signal varies at a much slower rate during the time when the peak value occurs than it does during the transitions between inspiration and expiration.

The relationship between sampling frequency and memory size required for a five minute experiment is shown on the graph in Fig. 6. As is shown on the graph, the needed memory size increases at a rate equal to the increases in the sampling frequency. One channel may be sampled at a rate of 100 Hz for five minutes if 32K bytes of memory are provided for data storage. If eight channels are sampled, however, the sampling frequency must be lowered to about 12 Hz. In Fig. 7, a maximum area for data storage has been set at 20K bytes and the experiment length is varied. In this case a sampling frequency of 40 Hz for one channel limits the experiment to approximately 500 seconds. It should be noted that an 8-bit A/D converter is assumed in both Fig. 6 and Fig. 7.

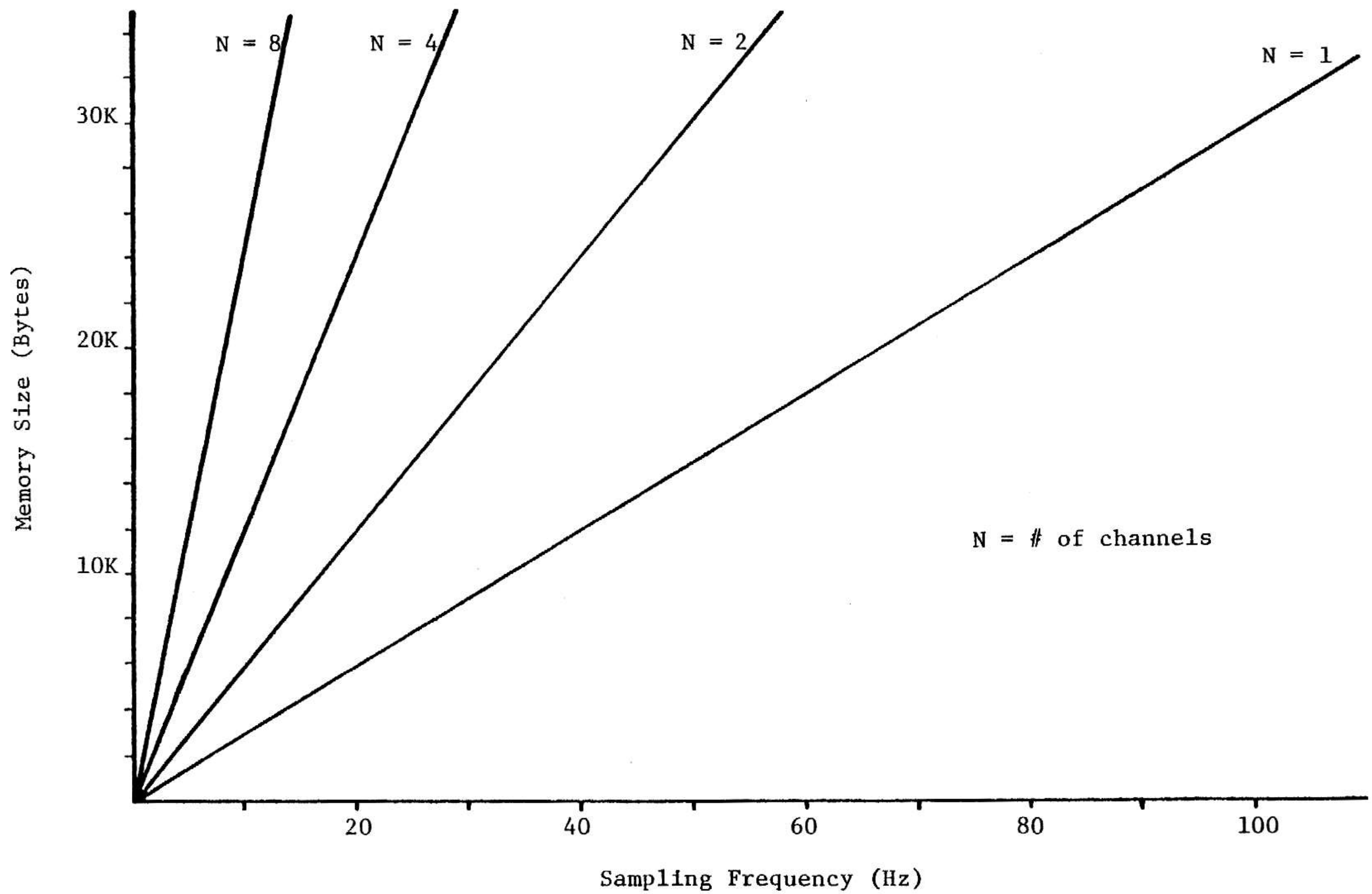

Fig. 6. Memory Size Vs. Sampling Frequency for a 5 Minute Experiment

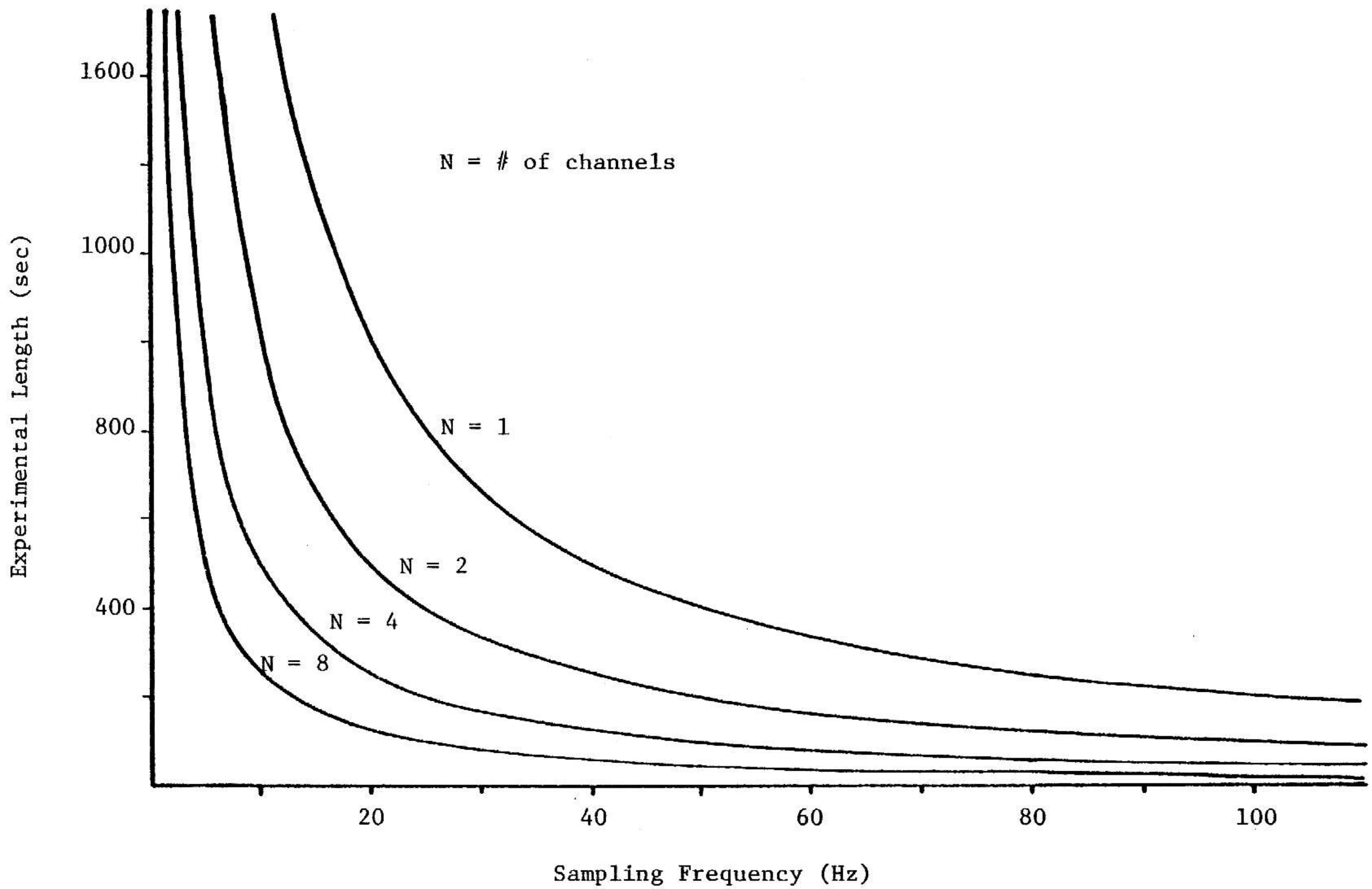

Fig. 7. Experimental Length Vs. Sampling Frequency for 20K Byte Memory Size

If a longer experiment length is needed and additional memory is not available for data storage it may be necessary to consider setting up two areas of memory for data storage. This would require additional software to handle the data transfer and to assure that all data is read from the A/D converter. The use of direct memory access (DMA) or interrupts can be very useful in this type of data transfer. DMA would allow data to be transferred to disks while the program is collecting data. If an interrupt system is used, the program can be transferring data except when an interrupt request is generated by a signal signifying that data is ready to be collected. The interrupt routine will read and store the data and then return to the main program. This allows the computer to be working on other tasks when data is not ready to be read from the A/D converter.

In all cases, not only the experiments where additional memory is required, it is desirable to store the acquired data on disks or tape. Many experiments can be stored on one disk or tape. This allows the experimenter to collect data, store it, and then process and display it at some later time. Also, it is sometimes desirable to store raw data even if it has been processed and displayed because at some later point in time additional information may be needed from the data.

CHAPTER IV

DATA PROCESSING

Another area of interest is the ability of a computer system in veterinary medicine to process the experimental data it has acquired. The complexity of the data processing involved may vary immensely between types of experiments. Data processing may range from simple scaling of the data values so that they may be displayed to complex equations requiring many data manipulations. Ideally the data processing would occur as the data is being acquired. This is not possible for most applications, though. Therefore, almost all processing of experimental data will occur after the experiment is completed and data has been stored in memory. Once again the experimental system described earlier was used as a means of determining parameters for a computer system to be used in an experimental setting in veterinary medicine.

In order to acquire data for processing, the experimental system was used to collect data from nitrogen washout experiments. In these experiments, an animal was switched from breathing room air to breathing 100% oxygen. The nitrogen being inhaled and exhaled by the animal was monitored by a mass spectrometer which does on-line gas analysis. The analog nitrogen signal from the mass spectrometer was then digitized and stored using the methods of the previous chapter. As the experiment progresses, the percentage of nitrogen being exhaled each breath should decrease as nitrogen is washed out of the animal's lungs. The information desired from the experiment is the breath by breath percentage of nitrogen being exhaled. Therefore, the data processing needed for this experimental data is the selection of the peak value of nitrogen for each breath. This would be an easy task for ideal data, but as is the case in all types of experiments, data may be far from ideal. This is certainly the case in this experimental setup. Uneven breathing by the animal may cause a peak value for a particular breath to be higher than the last one or lower by an amount much greater than expected. These peaks should not be included in the breath by breath analysis. It is fairly easy to recognize on a strip chart recording which peaks are valid but it is much harder for a program processing this data because there are no set rules for the inclusion or exclusion of data. Certain limits may be arbitrarily set, though, to aid in the selection of the desired peak values. Two possible restrictions are the length of time between successive peaks and the relative magnitudes of successive peaks. The latter is used in the program which was run on the experimental system. A flow chart of the program, which was written in BASIC, is shown in Fig. 8. The present peak value (PPV) is the largest value of nitrogen recorded during the present breath and the last peak value (LPV) is the largest value of nitrogen recorded during the preceeding breath. As can be seen from the flow chart, the program begins by initializing past and present peak values and reading the first byte of data. Next, the data byte is tested to see if it is larger than the present peak value in which case the data byte would replace the present peak value. If not, two tests are made to determine if a breath has been completed. If a breath has been completed the present peak value is checked to see if it should be included in the set of nitrogen peaks. The program continues to read the data and make the necessary tests until all data has been processed. This program requires approximately 4 1/2 minutes to run through approximately 6000 data points which include 50 peak values. This is only one possible program to determine peak values for

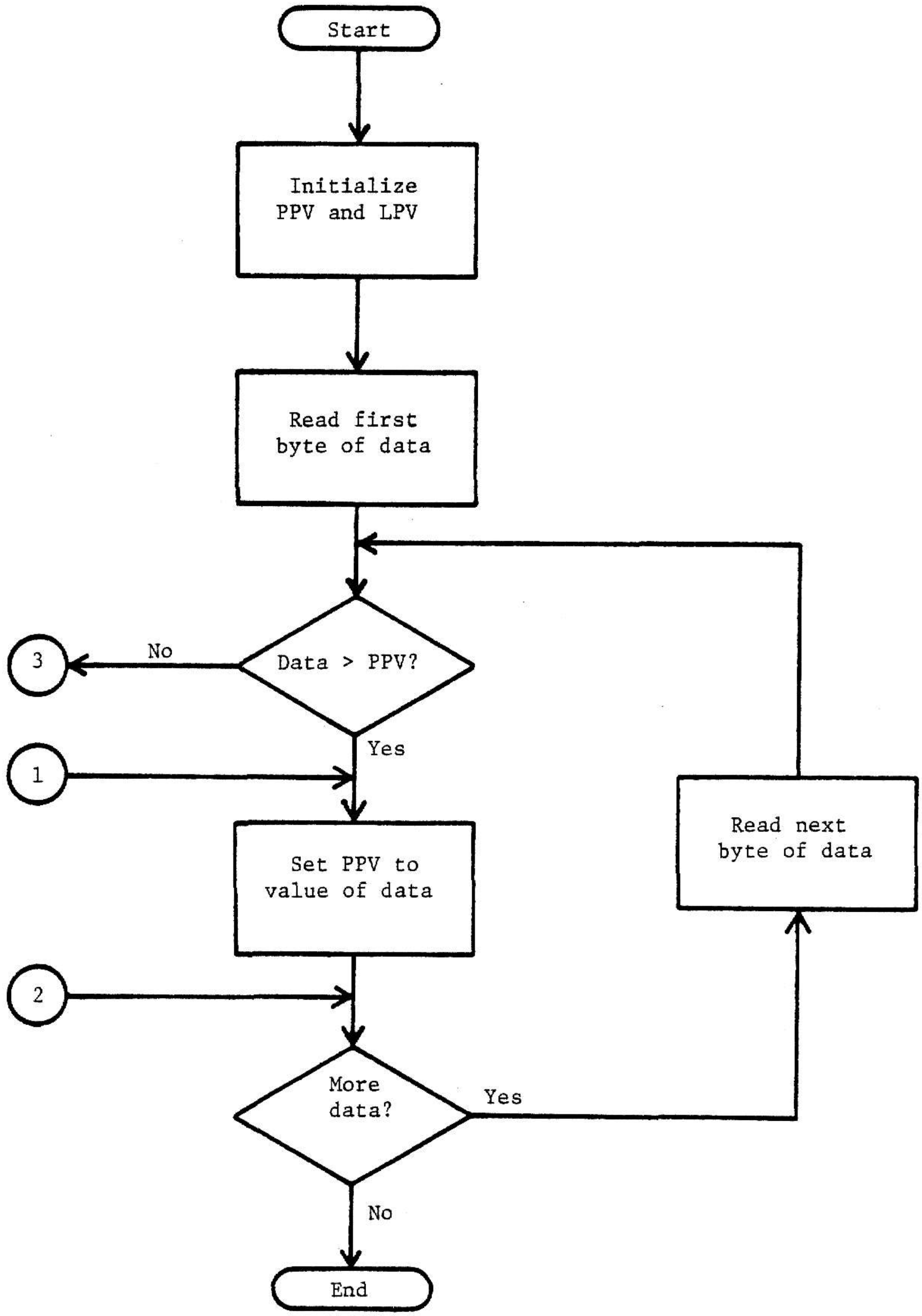

Fig. 8. Flow Chart for Finding Peak Values in Nitrogen Washout Data

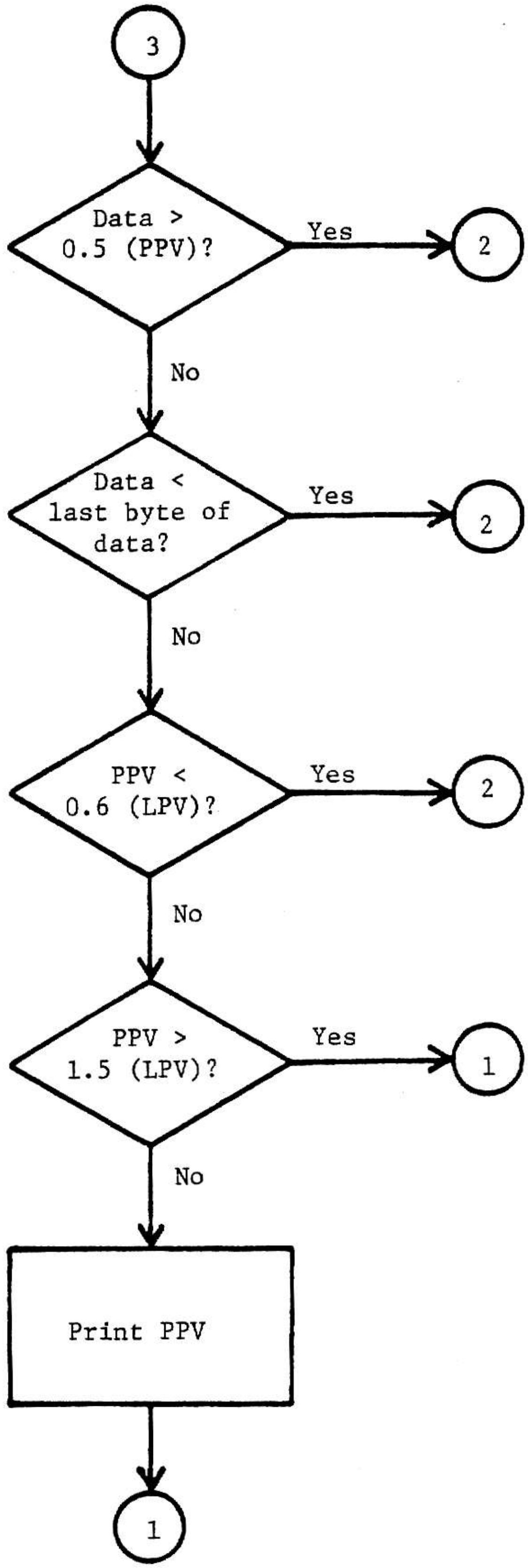
3
Data > 0.5 (PPV)?
Yes
2
No
Data < last byte of data?
Yes
2
No
PPV < 0.6 (LPV)?
Yes
2
No
PPV > 1.5 (LPV)?
Yes
1
No
Print PPV
1

Fig. 8. Cont.

nitrogen washout data. Each program may be best suited for a certain set of data and increasing the complexity of the program does not necessarily improve it. Additionally, the failure of a program to produce the peak values may be used as an indication of invalid data.

As can be seen from the preceeding example, data processing of experimental data can become more complicated than it first appears. This is one of the reasons that it is very difficult and many times impossible to process data as it is being collected. Even for simple data manipulations, the execution time of the processing might be too long to insure that it is completed in time to collect the next byte of data. Obviously, any processing to be executed by the experimental computer system as the data is being collected must be written as part of the data acquisition routine. Allowing for conversion time of the A/D converter and execution time of data acquisition and data storage at a 40 Hz rate as was the case for the nitrogen washout experiment still gives more than 20 msec for the processing of data. Since a typical machine language instruction requires less than 10 μsec, approximately 2000 instructions could be used for the processing of each data point. This seems like more than enough instructions to do most data processing but one must remember the type of instructions available. Each multiplication, for example, would take many instructions with the exact number of instructions determined by the length of the multiplier and multiplicand. This is not to say that routines couldn't be written to perform some data processing but that these routines would be very involved and complicated to write for someone with machine language programming experience. Interrupts can be be used in the same way as they were discussed in the previous chapter on data acquisition. An interrupt routine generated by the A/D converter when data is ready can be used to collect data. This allows the computer to use the remainder of time for data processing. This does not nessarily mean that data is processed immediately after it is collected, though, but at least some of the data processing can be done during an experiment.

As stated earlier, most processing of experimental data will occur after all data for the experiment has been collected. Therefore, these programs will probably be written in a higher level language such as BASIC as was the case for the nitrogen washout experiment. Execution time should still be minimized where possible, but it is not the critical factor it is for data acquisition. Machine language subroutines to the BASIC program can be written for some routines which are frequently used in order to minimize execution times. BASIC programs are desirable because they may be written by someone with little programming experience such as a physiologist. It must be pointed out, however, that the execution time and length of BASIC programs may become prohibitive for sophisticated data processing. Sophisticated data processing for microcomputers includes processing which involves many iterations, complex numbers, or large matrices. In those cases it would probably be best to transmit the data to a larger computer for processing. Also, the data could be stored on a disk or tape in a format which could be read by a larger computer. This is probably the best solution if there is a computer with excellent data processing capability available for use. A computer system in the laboratory should be concerned with the acquisition of data, display of the data, and some data processing. The additional expense of a larger computer system for complex data processing probably can not be justified.

In general, a computer system for use in experimental work in veterinary medicine should allow the use of a programming language which could be used by someone with little programming experience. Since the experimenter knows what information he needs from the experimental data, it would be desirable for him to be involved in the writing of the data processing program. Another parameter of interest is the execution time of the program which should be kept to a minimum. Memory size is again important as room must exist in the computer memory for the data processing program, the data to be processed, and the results. Additionally, there should be a means of storing data on disks or tapes so that it may be transferred to another computer for complex data processing.

CHAPTER V

DATA DISPLAY

An important part of an experiment is the display of the experimental data and results in a form which is both useful and easy to understand. In a computer system there are many devices which can be used for display of information such as CRTs, printers, and plotters. Information can be displayed on these devices in a wide variety of ways including lists, graphs, and color displays. In veterinary medicine it is sometimes desirable to produce displays which show general trends and relationships as well as the raw data and specific results. Color can play an important role in the display of such information. The experimental computer system described in Chapter 2 has color graphics capability, and thus, was an excellent system to use in the determination of parameters necessary for the display of information in an experimental environment in veterinary medicine.

As was mentioned in the previous chapter on data processing, the experimenter sometimes needs to see either the raw data or an intermediate result during an experiment. The results from the early stages of an experiment may determine the experimental procedure for the final stages. Also, it is desirable, though not necessary, to display the data or some intermediate result so that the experimenter may assure himself that the computer is actually acquiring data and that the experiment is proceeding as planned.

While the experimental system has excellent graphics capabilities, the execution times of the BASIC statements which provide graphics are too long to allow the plotting of each data point as it is collected.

Typical execution times are 5.5 msec for the plotting of a 100 element X bar graph and 34 msec for the plotting of an 100 element vector. The actual plotting of a single data point requires only approximately 1 msec but many milliseconds are required to take a data value and display it on the CRT. First, the data value must be read from memory. Then some scaling would probably have to be done so that the exact position of the point on the CRT may be determined. The scaling would likely involve multiplication and, therefore, require more time. The major problem occurs when the CRT has been filled with data and the screen must be cleared. Only 160 points may be plotted so the screen must be erased every few seconds. An erase of the screen using BASIC statements requires 30 msec. Thus, it is not possible to insure that all data is acquired from the A/D converter in this interval for typical sampling frequencies of 20 to 40 Hz.

A solution to the problem is to write the entire data acquisition and display program in machine language. As in data processing, though, the machine language program becomes long and complicated very quickly. The program does not have to display the data to show that data is being collected, however. The subroutine for the collection of data using the previously described A/D converter system was modified so that a clock was displayed in the upper right hand corner of the CRT. The program simply counts the number of samples being taken. After a number of samples equal to the sampling frequency has been collected a second is added to the clock. This does, of course, require an integer value for the sampling frequency. The clock numerals can be displayed by writing directly into the refresh RAM memory locations for the desired positions on the CRT. The clock actually serves two purposes. The experimenter is not only assured that data is being collected but also can make a record of times in the experiment which may be used for reference.

After the data has been collected and processed, all display of information can again be handled by programs written in BASIC. The experimental computer system has excellent graphics capabilities. The BASIC graphics software in the system allows XY point plots, XY incremental point plots, X bar graphs, Y bar graphs, vector plots, and incremental vector plots. In addition, there is a character plot mode which causes each dot matrix in the display to be divided into eight blocks. After entering the character plot mode, each block or combination of blocks in the matrix may be selected by setting the corresponding bits on the next byte.

The type of display to be used in each situation will depend on the kind of information desired. The simplest form of display is a listing. Raw data and results, for example, can be displayed on the CRT or printer as a list. Only headings are needed to complete the display. The software which must be added to a program for a list consists only of PRINT statements since the software interface for the display device is included in system software. An advantage of this kind of display is that all data and results can be displayed to their full accuracy.

Another common form of display is a graph of the data or results. This kind of display requires more software but is still fairly simple if graphics are included in the system software. The graph should include well labeled axes as well as the information to be plotted. A generalized flow chart of a BASIC program for graphing one channel of data on the CRT in the experimental system is shown in Fig. 9. This flow chart is then expanded in Fig. 10 for the case of two or more channels. The flow charts assume that all data has been collected and is stored in the computer memory. X bar graphs and Y bar graphs are handled similarly with bars

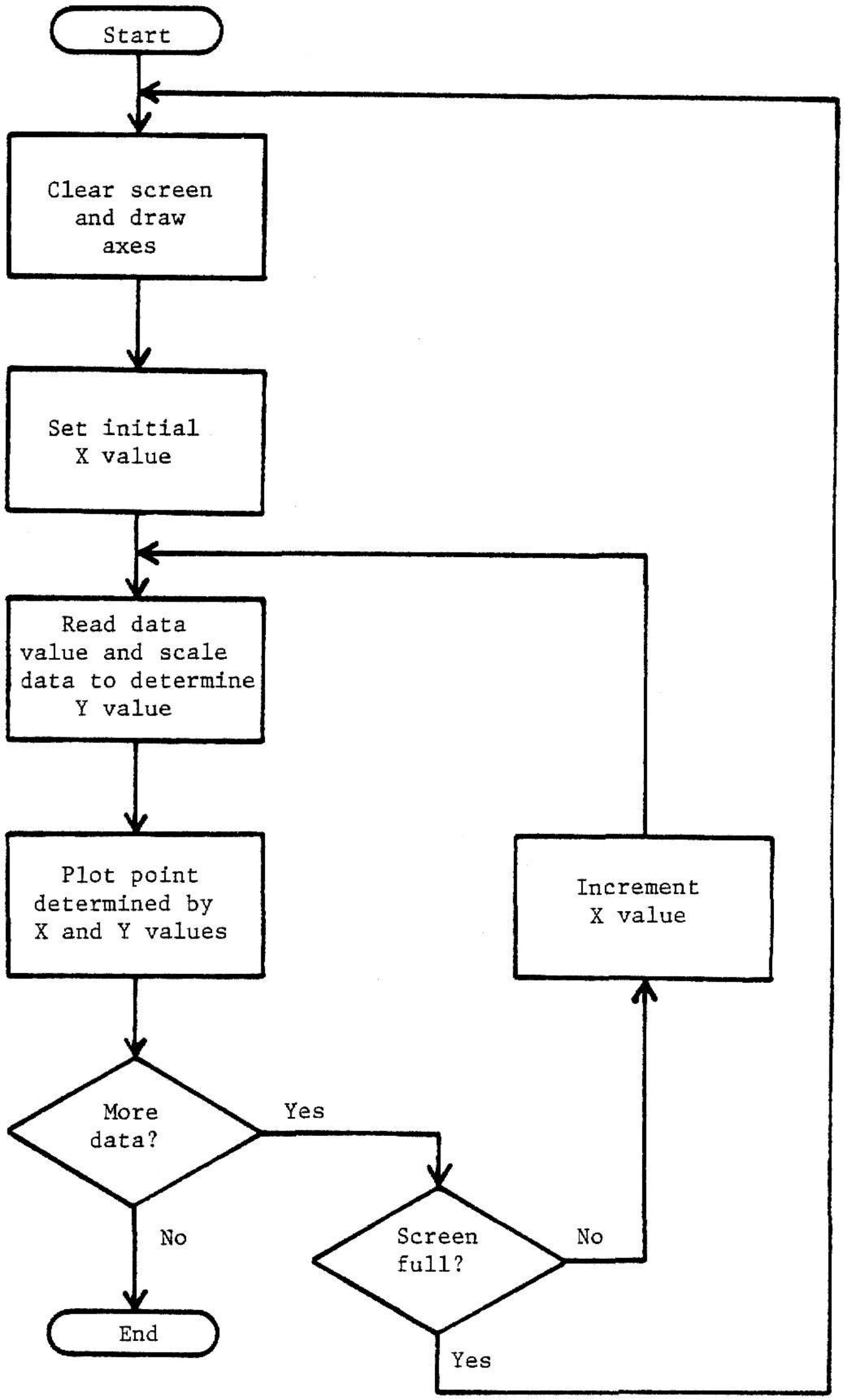

Fig. 9. Flow Chart for Graphing One Channel of Data on the Intecolor 8001

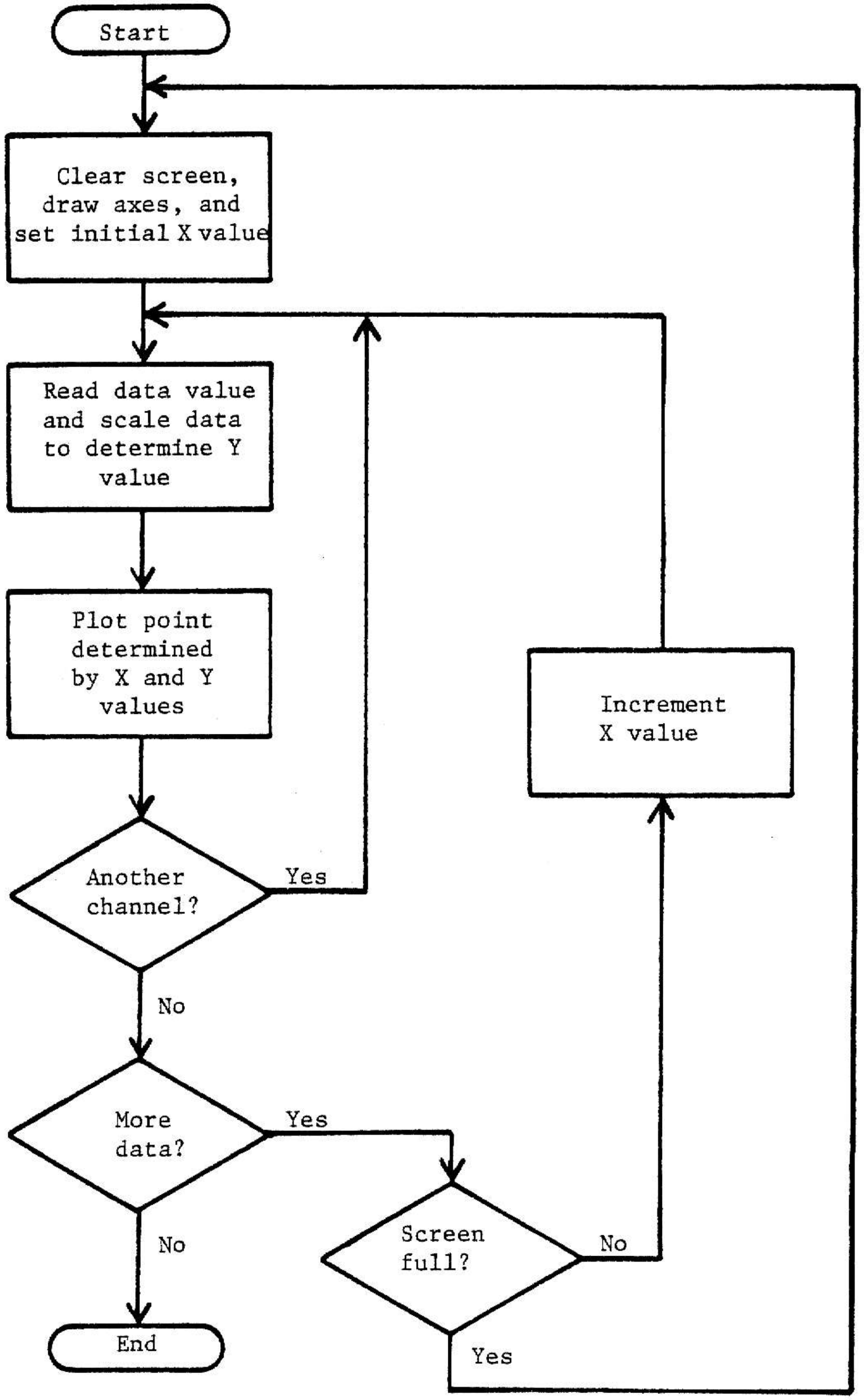

Fig. 10. Flow Chart for Graphing Two or More Channels of Data on the Intecolor 8001

being plotted between the data point and the appropriate axis. The vector plot mode may be used to draw lines between successive points if some sort of linear approximation is needed between data points. An advantage of a graphics display is that the relative magnitudes of the data points can be seen easily. Graphics displays can be used to spot trends in the data and also compare the data taken from each channel. One disadvantage of this type of display is that some approximation is often involved. In the case of the experimental system there are 160 possible X values and 196 possible Y values. Scaling can be used, of course, to plot the data or results in the allowed range but it may become impossible to see small differences as the range of values increases. Even for data received from the 8-bit A/D converter, there are 256 possible data values and some approximation would be required to plot the data on the CRT in the experimental system.

One feature which may be used to improve the display capability of a computer system is color. The use of color can be extremely helpful when comparing data. Also, a three-dimensional effect can be created by allowing the position on the CRT to represent two dimensions and the color to represent the third dimension. The experimental system was used to evaluate some possible color displays for experimental data and results. The experimental system has eight possible colors and allows the selection of both background and foreground colors.

A simple but effective way to use color is to plot more than one set of data on the same graph and use color to distinguish between them. An example of this is the plotting of data from two or more channels of the A/D converter which were sampled simultaneously. It may be very desirable to plot this data on the same graph with time as the X axis. This may, of course, be done without color but it may become confusing as to which set of data a particular data point belongs.

Another use of color is a three-dimensional display. In a display of this kind, two dimensions may be used to determine a point on a surface. The third dimension represents the measurement of some information of interest at that point such as temperature. A generalized flow chart for a display of this kind is shown in Fig. 11. As can be seen, very little software is required for this display if the computer has color graphics. A color is simply assigned to a range of values. Once a data value for a particular location is read, a color determined by that data value is assigned to that location. This color is then plotted on the CRT display. This color display cannot show small differences between regions but can give an easy to read generalized description of an area. The same form of display could be created using different characters or symbols for each range of values but each area would not be as easily distinguished.

There are, of course, many other types of displays. Sophisticated three-dimensional displays which permit the operator to change the viewing angle, for example, are available. Also, displays with much higher graphics resolution than the experimental system are available as a part of some systems. The display unit and software to create these displays can become expensive and are probably not practical for a computer system in an experimental setting in veterinary medicine. Once again, data should be stored so that it may be transferred to other computer displays if desired.

The displays mentioned in the preceeding paragraphs involved the use of a CRT. A CRT is an important part of a computer system because it allows the quick display of programs, data, and results. A printer may also be used for the display of information but will be much slower. A

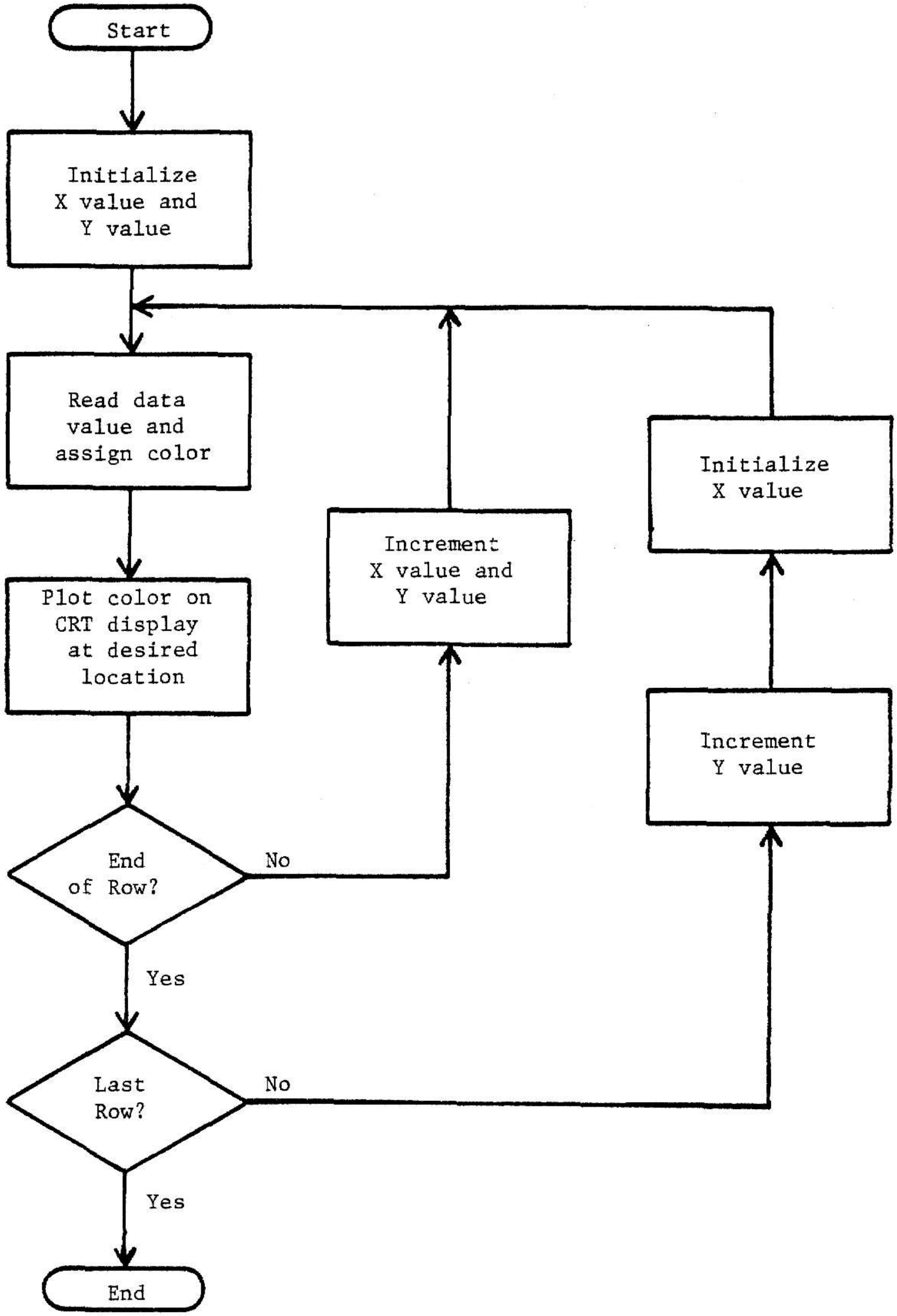

Fig. 11. Flow Chart for Three-Dimensional Display Using Color

printer will normally be used to provide a hard copy of program listings and CRT displays which are to be saved. CRT displays may be saved on disks or tapes but it is not practical to save all displays this way because of the storage required. Also, the computer would not always be available for use. A plotter is another way in which information may be displayed. Plotters can provide graphs of data and some also can provide multi-colored graphs. A plotter is a much more accurate way of acquiring hard copies of graphs than a printer. Plotters allow continuous lines to be drawn while printers generally print a square or circle to represent a point on the graph. Displays and printers will be treated in more detail in the following chapter.

CHAPTER VI

SYSTEM CONFIGURATIONS

The selection of a computer system for experimental work in veterinary medicine is dependent on many factors and the first step in choosing an appropriate computer system for this application is to select the necessary parameters. These parameters have been addressed in the previous chapters and include memory size, display capabilities, and programming capabilities. In this chapter, these parameters will be used as a guide in the selection of possible computer systems for experimental work in veterinary medicine.

As microcomputers have grown in performance, they have become applicable to many functions previously associated with minicomputers. Available memory size has increased, more I/O interfaces are available, and there are interrupt and direct memory controls. System software has also increased and now higher-level languages such as FORTRAN are available in some microcomputer systems. Microcomputer specifications which apply to a microcomputer in an experimental environment include memory size, I/O control, and software.

As mentioned earlier, memory size is extremely important for the storage of experimental data. As was discussed in the chapter on data acquisition, the exact size of RAM memory required is determined by the size of user programs and the amount of data storage required. A RAM memory area of 32K bytes should be considered a minimum size. More RAM may be needed if the experimenter envisions experimental lengths greater than 10 minutes or sampling frequencies greater than 100 Hz. In Fig. 12, memory size is again plotted against sampling frequency as in Fig. 6.

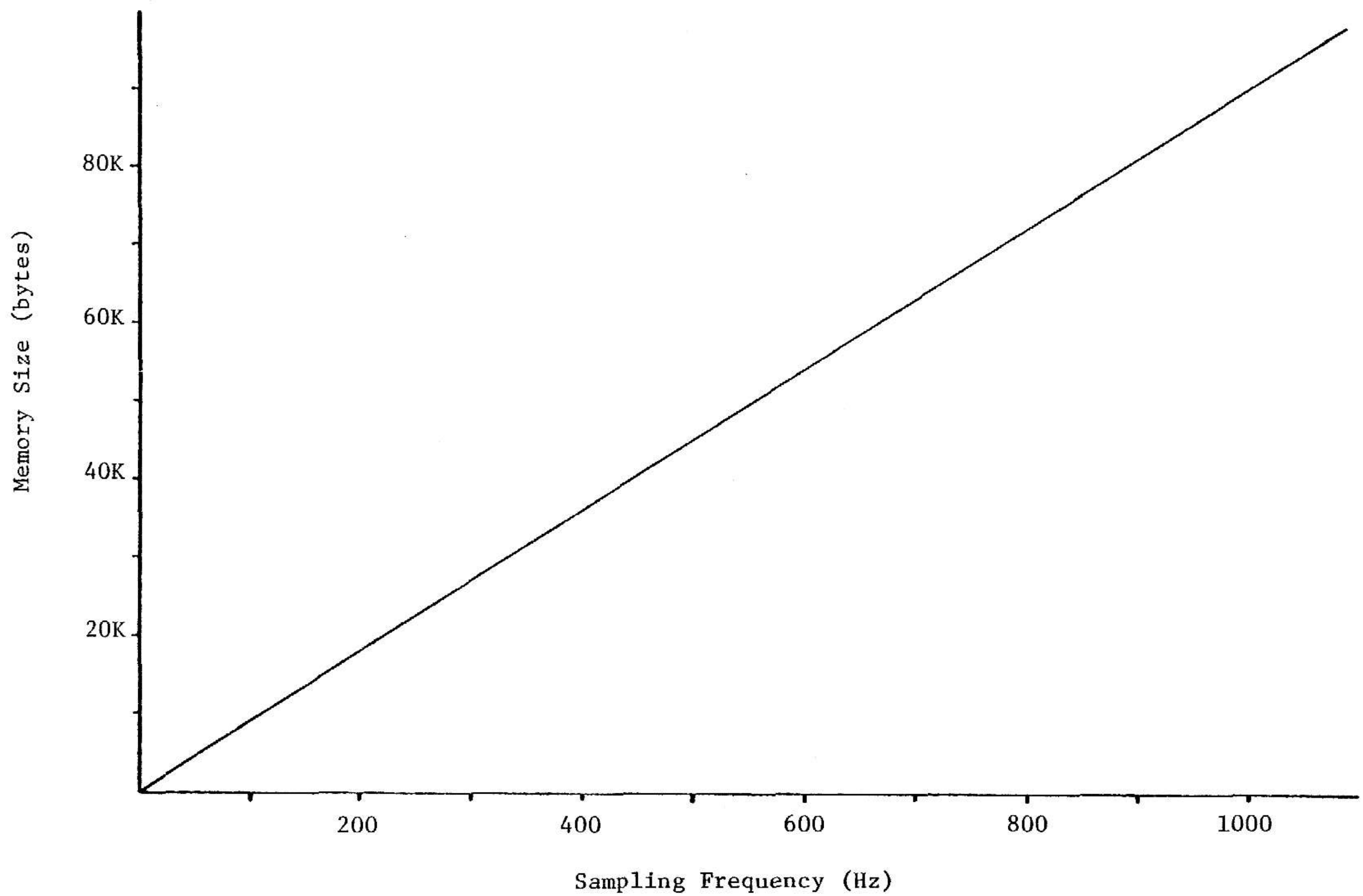

Fig. 12. Graph of Memory Size Vs. Sampling Frequency for a 15 Minute Experiment

In Fig. 12 though, the experimental time is 15 minutes and a wider range of sampling frequencies is considered. In Fig. 13, memory size is plotted against experimental length for a sampling frequency of 40 Hz. In both figures it should be noted that the graph shows the needed memory size if only one channel of data is being acquired and an 8-bit A/D converter is used. Many microcomputer systems have 64K byte memory capacity but some of this is needed for software. Thus, the amount of memory available for data storage will actually be less than 64K bytes. The cost of additional RAM for a microcomputer depends on characteristics such as cycle time, access time, and technology used. Additional memory for S-100 bus microcomputers is available for approximately $300 for each 4K bytes of static RAM and approximately $500 for each 8K bytes of dynamic RAM. If the computer allows for future memory expansion, the computer capabilities can be increased by simply adding more memory in the future.

I/O control must also be considered when choosing a microcomputer. Included in I/O control are direct memory access (DMA) capability, interrupt capability, and peripheral interfaces. DMA allows a microcomputer to continue processing while data is being transferred. Additionally, if a microcomputer has interrupt capability, it does not have to periodically poll its devices to determine if some action is required by the microcomputer. These two features are very valuable in data acquisition as has been noted in previous chapters and should be features of the microcomputer selected. The interface circuitry obviously determines the type of peripherals which may be interfaced to the microcomputer. Interfaces should be included for an RS-232 port, storage unit, A/D converter, and CRT.

The selection of software is also important because it can make it much easier for a user to work with the microcomputer. Assemblers, higher

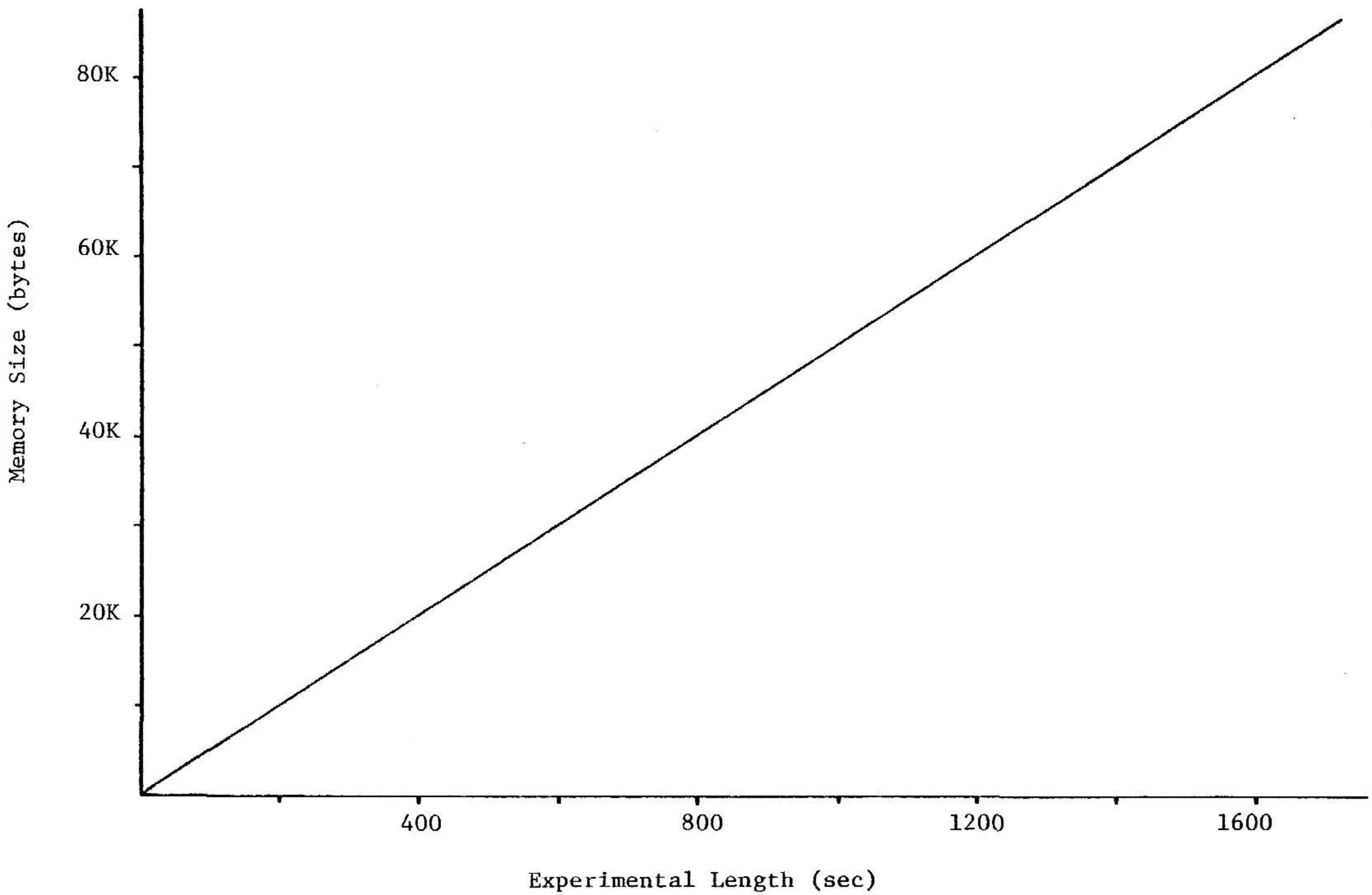

Fig. 13. Graph of Memory Size Vs. Experimental Length for Sampling Frequency of 40 Hz

level languages, monitors and executives are available on some microcomputers. An assembler should be included because assembly programs are needed for programs where execution time is critical. A higher-level language such as BASIC also aids in programming the microcomputer. BASIC is available in many microcomputers and can be easily learned.

Peripherals for the microcomputer must allow acquisition, storage, and display of data. An A/D converter system is a necessary peripheral for the collection of data. The A/D converter system described in Chapter 2 for use with the experimental system can handle 8 channels with sampling rates on each channel of up to 1 KHz or 1 channel with a sampling rate of up to 10 KHz. Accuracy is within 0.4%. The cost of parts for this particular system is less than $100. If greater resolution or faster conversion speed are necessary, A/D converters with better specifications are available.

A peripheral must also be available for data and program storage. Two peripherals which can be used are a floppy disk unit and a cassette unit. A floppy disk unit is a low-cost high-performance I/O device for microcomputer systems. Floppy disk capacity for microcomputers generally ranges from 100K to 300K bytes. Single drive units are available for less than $1000. Dual drive units are also available and allow the transfer of data from one disk to another. Cassette units are also used for data storage in many microcomputer systems. Cassette units are best used when there are a few data sets stored in known sequence. In general, cassette units may be less expensive although cassette units which cost thousands of dollars are available. An additional factor in the selection of a specific disk or cassette unit should be the availability of software support.

The final necessary peripheral for a microcomputer system for use in experiments in veterinary medicine is a printer. Even if a CRT is part of the system, a permanent record is desired in many cases. Factors to consider in the selection of a printer include required interface, speed, printing technique, and character set. The printer used as a peripheral to the experimental system requires an RS-232 interface, prints 45 characters/second, and costs approximately $1300.

An alphanumeric display terminal is a peripheral which could be valuable in an experimental environment. As a matter of fact, the computer used as the experimental system is frequently used as a display terminal. Displays permit fast access to information and allow the display of information without hard copy. Some displays also permit editing and formatting. Two special features which are extremely useful in the display of experimental data are color and graphics.

The following configurations are proposed as possible computer systems for experimental work in veterinary medicine. The systems give a wide variety of data acquisition, processing, and display capability. The system which will best fit in a particular experimental setting will be determined by factors such as the amount of data, processing speed required, and cost. Each system configuration is described below.

- System I
  - Microcomputer with 32K bytes of RAM
  - Software
    - Operating system
    - BASIC
  - Peripherals with interfaces
    - Printer
    - Cassette unit
    - A/D converter system

- System II
  - Experimental system described in Chapter II

System III
- Minicomputer with 64K bytes of read/write memory
- Software
  - Operating system
  - BASIC
- Peripherals with interfaces
  - CRT
  - Keyboard
  - Printer
  - Tape cartridge drive
  - A/D converter system
- Interrupt capability

System IV
- System III plus Intecolor 8001 as display unit

System V
- Minicomputer with 128K bytes of read/write memory
- Software
  - Operating system
  - BASIC
- Peripherals with interfaces
  - CRT with graphics capability
  - Keyboard
  - Printer
  - Plotter
  - A/D converter system
  - Dual floppy disk unit
- DMA and interrupt capability

System VI
- Similar to System V plus FORTRAN and increased processing and I/O speed

Approximate costs of these configurations are given in Fig. 14. The exact cost of each system will depend on the specific computer, peripherals, and options selected. Fig. 15 gives a comparison of the six systems. System I is used as a base and the other five systems are ranked accordingly. The categories used for comparison are defined below.

1. Memory size - Amount of read/write memory available for program and data storage.

2. Software - Includes operating system software, higher-level languages, and software for I/O control.

3. Processing capability - Variety and speed of processing which can be handled.

4. Display capability - capability of displaying data and results.

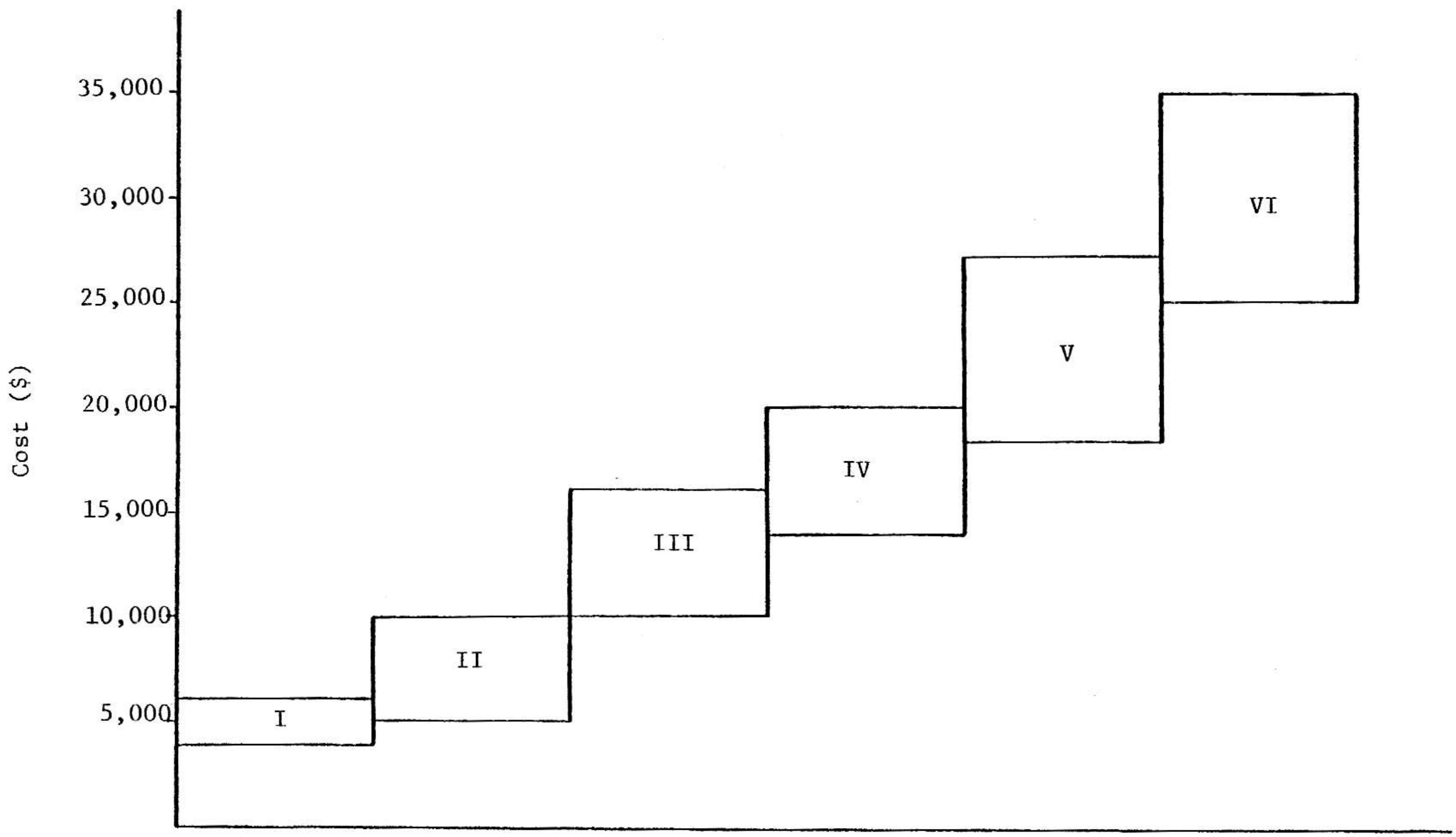

Fig. 14. Cost Vs. System Configuration

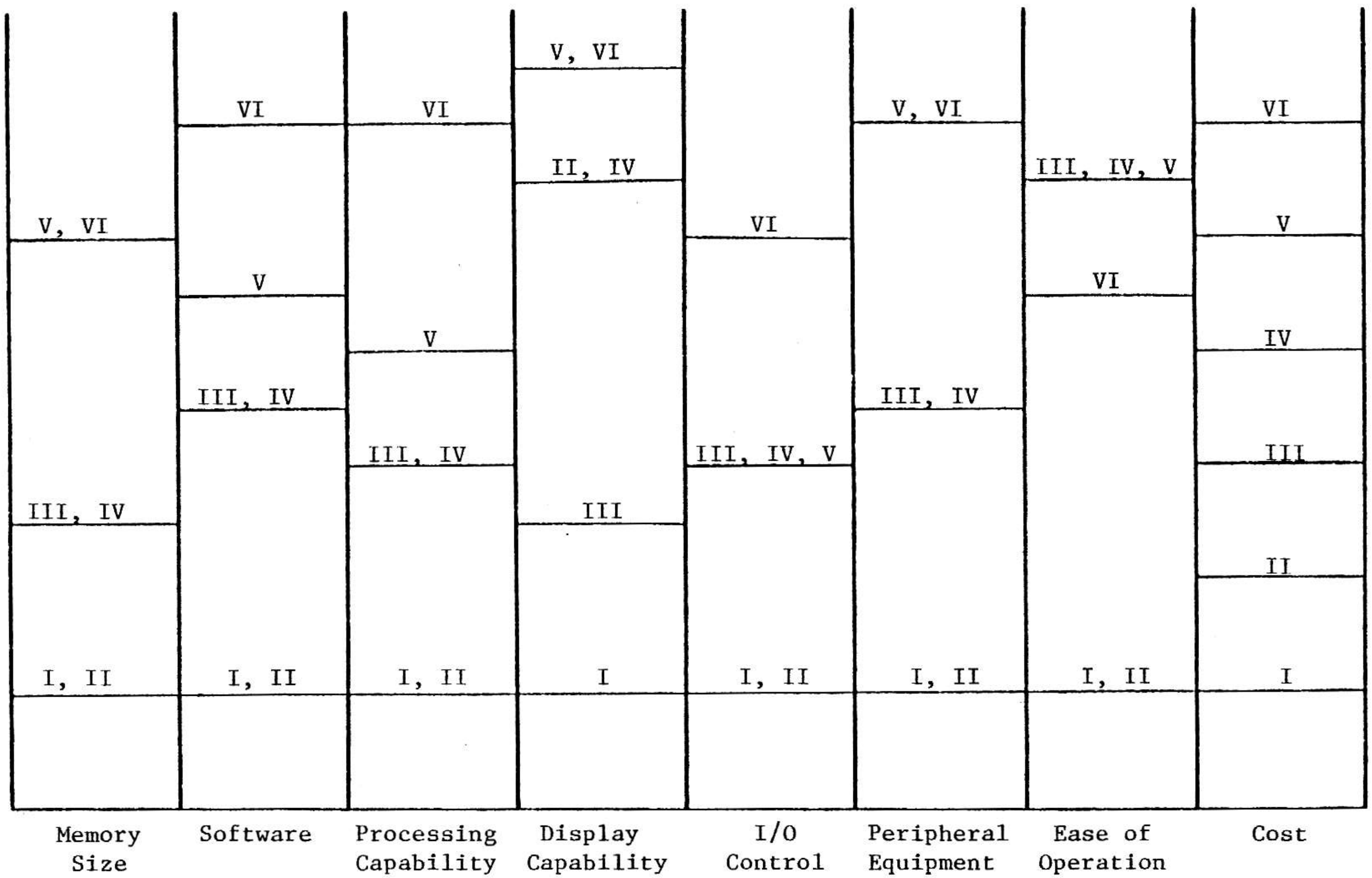

Fig. 15. System Comparison

5. I/O control - Ability to interface with a variety of I/O devices.

6. Peripheral equipment - Self-explanatory.

7. Ease of operation - Ease with which user can program the system for specific applications.

8. Cost - Self-explanatory.

The rankings are only approximations, of course, but they show some tradeoffs which must be considered when choosing a computer system for experimental work in veterinary medicine. System I is basically a minimum configuration. Data storage is limited by memory size and a printer is the only display device included in the system. Data processing may be done but size and execution time of the program may be a problem. System II is the experimental system which was used in the determination of system parameters. This system has excellent display capabilities but is limited by memory size and processing speed as is System I. System III offers more memory area for data and program storage and better processing capabilities. System III does not have graphics capability, however. In System IV, the Intecolor 8001 is used as a display terminal for System III. System V has increased memory size and more peripherals than the previous systems. Peripherals include a CRT with graphics capability, dual floppy disk unit, and plotter. The CRT has greater resolution than the experimental system but does not include color. The plotter can be very useful in acquiring accurate hard copies of graphs. This system will probably handle all applications. If sophisticated data processing is envisioned, though, a system such as System VI with a higher-level language and faster processing speed may be desired. Information on specific computer systems may be found in Datapro Reports on Minicomputers [10].

CHAPTER VII

CONCLUSIONS

The selection of a computer system for the acquisition, processing, and display of experimental data in a veterinary medicine environment must be based on many factors. Factors which must be given major considerations are memory size, software, processing capability, display capability, I/O control, peripherals, ease of operation, and cost. The amount of emphasis placed on each of the above is determined by the specific applications for which the computer system is to be used.

Microcomputer systems are available which can handle the acquisition, processing, and display of experimental data. Microcomputers have memory size, I/O interfaces, and DMA and interrupt controls which are comparable to some minicomputers. A minimum computer system for experimental work in veterinary medicine should consist of a microcomputer with a keyboard for user input, a cassette unit for storage of programs and data, a printer for display, and an A/D converter system for the collection of data. Software should include an operating system and BASIC so that programs can be easily written and executed. Also, a minimum of 32K bytes of RAM should be available. The computer system described above may be purchased for less than $5,000.

As system cost is allowed to increase, additional capabilities can be added. Increased read/write memory size and DMA and interrupt controls can increase the data acquisition capabilities of the system. The addition of a graphics display will aid in the display of experimental data. Increased processing speed and a higher-level language such as FORTRAN will increase processing capabilities. Also, peripherals such as floppy disk units and plotters can be added. The decision to include any or all of these features should be determined by the specific applications of the computer system. A minicomputer system with all of the above features may be purchased for approximately $35,000.

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A DATA ACQUISITION, PROCESSING, AND DISPLAY SYSTEM FOR EXPERIMENTAL WORK IN VETERINARY MEDICINE

by

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ABSTRACT

The principal concern of this thesis was the determination of system configurations for a data acquisition, processing, and display system for experimental work in veterinary medicine. An Intecolor 8001 microcomputer with peripherals was used as an experimental computer system to study the collection, processing, and display of actual experimental data. The results of the study were then used to determine parameters which must be given major consideration in the selection of a computer system in this environment. The parameters chosen include memory size, processing capability, display capability, ease of operation, and cost. Tradeoffs between the system parameters are necessary in the selection of a computer system for specific applications and price ranges. System configurations range from a minimum system which costs less than $5,000 to a system with excellent processing and display capabilities which costs over $30,000.