ACTA NEUROBIOL. EXP. 1984, 44: 301-309

TWO-PROCESSOR SYSTEM, BASED ON THE ZX-SPECTRUM MICROCOMPUTER AND THE CAMAC MODULAR SYSTEM, FOR THE ANALYSIS OF PHYSIOLOGICAL DATA

Piotr J. KRUK and Janusz LIPSKI

Department of Human Physiology, Warsaw Medical Academy Krakowskie Przedmieście 26/28, 00-927 Warsaw, Poland

Key words: microcomputer, ON-line analysis, CAMAC, respiratory neuron

Abstract. The cost-efficient computer system composed of easy accessible elements was designed and set up for the purpose of both ON-line and OFF-line analysis of data obtained in physiological experiments. The system was supplied with the standard software, including special cross-assembler for CAMAC. The features of the system were verified during the experiments on respiratory neurons. It facilitates the analysis of experimental results.

INTRODUCTION

The amount of data obtainable in physiological laboratories can be so large that their proper analysis, without the use of a computer, is both impractical and time consuming. On the other hand, high costs of professional ready built computer systems often exceed financial possibilities.

Therefore we attempted to set up a system composed of relatively inexpensive elements. We wanted that this system should be suitable for ON-line work during physiological experiments, for controlling such processes as stimulation or regulation of an animal's physiological parameters, and for data collection and their primary analysis. This system should also be able to perform more sophisticated mathematical OFF-line processing (e.g., statistical analysis) of obtained data.

RESULTS

The structure of the system

As a result of our efforts a microcomputer system has been designed and set up. All elements of the system and connections between them are shown in Fig. 1.

The system is based on two main devices: personal computer ZX-Spectrum (1 in Fig. 1) (8) and modular system CAMAC (5 in Fig. 1) (2, 5).

The ZX-Spectrum (1 in Fig. 1) is one of the cheapest microcomputers with the Z80 microprocessor as the central processor unit (CPU). It has a full alphanumerical keyboard, internal 48 K of RAM and 16 K of

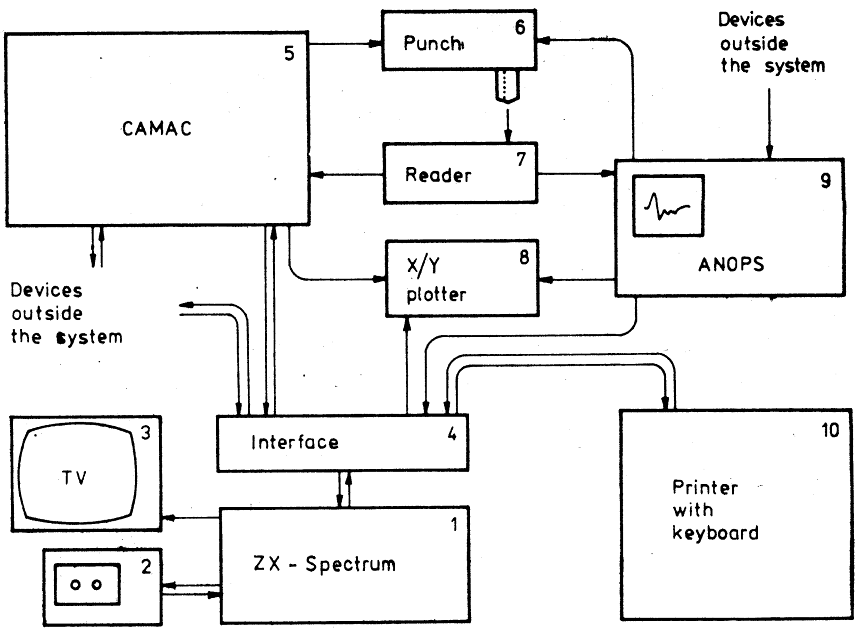

Fig. 1. Block diagram of the system. Arrows indicate directions of possible data transmission. For further description see text.

ROM, the latter containing the operating system, and BASIC interpreter. The ZX-Spectrum is directly connected to an ordinary black and white TV set (3 in Fig. 1, Neptun-150, Unitra) used as a monitor, and an ordinary cassette recorder (2 in Fig. 1, MK 232, Unitra) acting as an external tape memory.

The interface (4 on Fig. 1) for the communication between the ZX-Spectrum and other devices was designed and built especially for our system (ZETAtronik Teleradiomechanika[1]). It is based on Intel 8255

[1] The address of the firm: K. Zasadziński, Linneusza 1/18, Warsaw, Poland.

and 8251 I/O ports, and Analogue Device AD558 and AD570 converters. The interface enables the ZX-Spectrum to communicate bidirectionally with the CAMAC (5 in Fig. 1) and the printer (10 in Fig. 1). In addition, it enables data to be received from a digital machine ANOPS (9 in Fig. 1), see below, and other devices outside the system, and it enables data to be sent to them in both digital and analogue form.

The modular system CAMAC (5 in Fig. 1, Z.Z.U.J. "Polon"), with an autonomous 24-bit processor type 131, is based on the European standard of data handling "CAMAC" (2). Our CAMAC system contains, among others, the following modules: a memory with 2 K of 24 bit words (type 201), 10 bit digital to analogue and analogue to digital converters (type 712) with multiplexer (type 753), paper tape punch and reader interfaces (types 520 and 526B), 4 channel counter (type 401) and 2 channel preset counter (type 420A) for standard pulses.

The digital machine ANOPS-105 (9 in Fig. 1, Warsaw Institute of Technology) is specially designed for analysis of analogue and digital biological signals. It has 4 input channels, an oscilloscope screen and a memory containing 2000 16 bit words.

Our system also includes the paper tape punch (6 in Fig. 1, type DT 105, Z.U.K., Zabrze) and the reader (7 in Fig. 1, type CT 2100, MERA-KFAP), both controlled by CAMAC or ANOPS. The printer with a standard keyboard (10 in Fig. 1, type DZM 180 KSR, MERA-BLON) is connected to the ZX-Spectrum interface (4 in Fig. 1). The X/Y plotter (8 in Fig. 1) with an analogue input can be controlled by the CAMAC, by the ANOPS or, via the interface (4 in Fg. 1), by the ZX-Spectrum.

The function of the system

The system contains two controllers independent of each other: the ZX-Spectrum and CAMAC. Both of them have their own processors and memories and therefore are programmable.

By its digital and analogue outputs, the CAMAC can control the paper tape reader and punch, and can operate the X/Y plotter and other devices outside the system (e.g., stimulators, infusion pumps). However, its main function is collecting data from peripheral measuring devices during an experiment, and storing them in the memory. Application software is stored on paper tapes and can easily be loaded to the CAMAC's memory. The part of the system which is controlled by the CAMAC can also work as an independent subsystem due to the autonomus processor 131. It is very fast since it is designed for the purpose of service of nuclear devices. A single CAMAC operation lasts no longer than 1 μs. It can not, however, perform more sophisticated calculations because of the poor internal language of its processor 131 (7). It was designed to operate specialized CAMAC modules rather than for calculations. This language has very few arithmetical commands. Moreover, the processor is not provided with any standard software. Therefore programming of the CAMAC is extremely difficult when using the CAMAC itself.

The ZX-Spectrum microcomputer is used mainly for calculations and for the preparation of results for a subsequent presentation in a graphical form. It is useful to obtain the graphic form of calculated results during the course of an experiment. In our system this task is fulfilled by the TV set being used as a monitor of the ZX-Spectrum.

Applications programs for the ZX-Spectrum are stored on standard cassettes. Good standard software, containing a BASIC interpreter, makes programming of this computer easy. However, the ZX-Spectrum cannot work ON-line alone because of its low speed of operation. This is a consequence of the BASIC mode of work i.e., interpreting. Using the internal language of the Z80 processor (ZX-Spectrum's CPU) one can considerably increase that speed, but then programming becomes much harder.

The interface (4 in Fig. 1) enables data transmission between the ZX-Spectrum and CAMAC, thus integrating these two computers into one system. Data transmission (150 bites/s when using BASIC or 1200 bites/s when using machine code of Z80 processor) from the CAMAC to the ZX-Spectrum allows the latter to process the data during an experiment and thus joins it to the ON-line work (see: "Application example").

The experimental data are often collected by the ANOPS (9 in Fig. 1). It records analogue signals in a digital form, also providing the possibility of averaging. It can also count standard digital pulses in consecutive memory cells setting up a time histogram (e.g., PSTH (1)). ANOPS memory contents are continuously displayed on its screen as a graph.

The ANOPS-105 has four channels and can perform certain simple arithmetic operations on functions recorded in different channels (e.g., adding and subtracting). However, more complicated processing is not possible by the ANOPS itself, and for this purpose data from the ANOPS have to be sent to the ZX-Spectrum via the interface.

The plotter and the printer (8 and 10 in Fig. 1) make hard copies of results in a graphic and numerical form, respectively. The plotter controlled by the ANOPS can only copy the traces displayed on the screen, while if controlled by the ZX-Spectrum or CAMAC, the plotter can draw any programmed curve.

Application software for the system is written in with the ZX-Spectrum's keyboard. Programs for the ZX-Spectrum are usually written in BASIC, but other high level languages are applicable, provided one has appropriate software translators in the ZX-Spectrum version. FORTH (4) is especially useful, due to its speed.

Programs for the CAMAC are written in a special symbolic language ZX131 (designed by K. Zasadziński). Its description has not yet been published. The ZX-Spectrum, using a special ZX131 cross-assembler, translates those programs into processor 131 machine code and then sends them to CAMAC's memory.

Application programs for both computers of the system can easily be modified or expanded in the course of an experiment. Some parameters of those programs can be introduced or altered at the same time.

Application example

The program used in our recent experiments (6) is an example showing the possibilities of the system. In these experiments, we examined the influence of chemical stimulation of the carotid body chemoreceptors on the activity of single medullary respiratory neurons. Stimuli were applied automatically, in a present phase of the respiratory cycle.

The neuronal activity had the form of potentials appearing in each respiratory cycle in bursts,. with inactive periods in between.

The most important parameters describing a burst are (see Fig. 2):

(a) number of spikes,

(b) burst duration,

(c) maximal frequency,

(d) maximal increment of frequency.

Parameters (a) and (b) are self explanatory and need no comment.

The parameter (c) — maximal frequency is the highest value of the instantaneous frequency during the whole burst. The instantaneous frequency is here defined as the number of spikes recorded in a moving time window of constant duration divided by this duration (T). At every time the window ranges from the moment — T in the past to the present moment. Such a way of frequency measurement is called a "moving average" (3). One should not choose too high a value of T in order to avoid obtaining the average frequency instead of the instantaneous one. On the other hand, T should not be too low in order to eliminate random fluctuations of frequency value. Usually we choose T equal to 100 ms. Thus the instantaneous frequency was determined as the number of spikes which appeared during the last 100 ms.

The increment of the frequency is the first derivative of the instantaneous frequency (dF/dt). The parameter d, the maximal increment of frequency, is the highest value of this derivative during the burst.

We analyzed the changes of all those parameters following the application of the chemoreceptor stimuli. Therefore we were interested in the relative values of the parameters, i.e., the values in the burst appearing during the stimulus or immediately afterwards, divided by the mean values from the few preceding bursts.

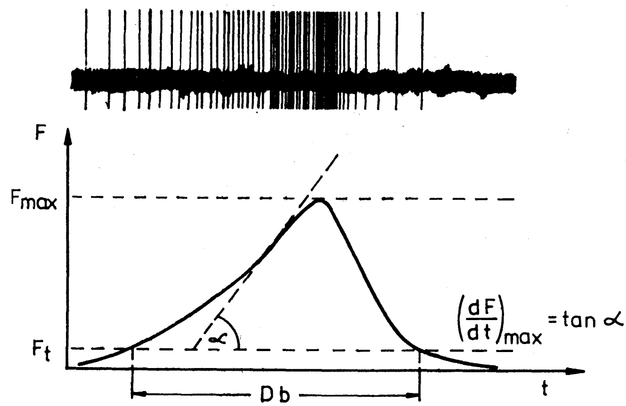

Fig. 2. Upper trace: a burst of spikes, recorded from a respiratory unit in the medulla oblongata of anesthetized cat during single respiratory cycle. Lower trace: a graph of the instantaneous frequency of these spikes with examples of the following parameters: F_{max}, the maximal frequency (c); α, the maximal slope of the curve, delimiting the maximal increment of frequency, (d); D_b, the burst duration, (b); F_t, the threshold frequency.

Two special programes, one for the CAMAC and one for the ZX-Spectrum were written for the purpose described above. Both computers acted simultaneously in the following way. Standard pulses coming from the measuring devices were recorded simultaneously and independently in five channels of the CAMAC's counter modules, informing the machine about times of occurrence of certain events. These were the following:

1. individual spikes,
2. onset of the stimulus,
3. end of expiration/beginning of inspiration (assumed as a time reference within the respiratory cycle),
4. end of inspiration/beginning of expiration,
5. clock pulse.

There was a certain short time interval, called a "bin" (measured using the clock pulses). It was a step of the window movement. In each bin spikes were counted and their number was stored in a subsequent CAMAC's memory cell. The bin duration was usually equal to 1 ms in order not to aggravate the resolution of the frequency measurement. The time window consisted of n bins, where n was a parameter chosen by the user (usually 100). The sum of the counts of spikes in n bins gave the total number of spikes in the window.

This number could easily be changed into the instantaneous frequency, when divided by T. Because they are proportional to each other, we can treat the number of spikes as a frequency, and we do it further on.

After computation of the instantaneous frequency its increment was calculated as the difference between the last value of the frequency and the preceding one.

The maximal values of these two quantities were then found. The beginning and end of the burst were recognized as the first and the last moment when the instantaneous frequency exceeded a given parameter F_t (threshold frequency, see Fig. 2). All time values were counted in bin units. The following numbers were stored in the memory after the end of each cycle:

1. total number of spikes counted in the cycle,
2. the burst beginning,
3. the burst end,
4. duration of inspiration,
5. duration of expiration,
6. maximal frequency,
7. maximal increment of frequency.

They were kept throughout the next four cycles and then erased. Thus, the information about the last four cycles was continuously accessible at each moment. If the stimulus had occurred in a given cycle, altogether 15 numbers were sent to the ZX-Spectrum. These were: the seven values of quantities, as listed above, relating to that cycle, the seven corresponding mean values relating to the four preceding cycles, and the stimulus onset.

The ZX-Spectrum was used to calculate other quantities from those received. These were: burst duration as a difference between the end and the beginning moments, and average frequency (see Fig. 2) as a ratio of the number of spikes to burst duration. The ZX-Spectrum also divided the values relating to the burst after the stimulus by the corresponding mean values relating to the four preceding bursts, thus calculating the relative values after the stimulus. The stimulus onset was also referred to the average duration of the respiratory cycle. It was also possible to refer this onset to the average duration of inspiration (or expiration) if the stimulus had occurred in it. The respiratory, inspiratory or expiratory p h a s e was thus calculated respectively.

On demand, the relative values of all bursts' parameters, i.e., a, b, c, d (listed above) and others, were continuously displayed on the monitor screen in the numerical form. Alternatively the graph of the dependence of one selected burst parametr *vs.* the stimulus onset phase was displayed. An example is shown in Fig. 3. The graph was drawn during the measurements and subsequent results were displayed immediately on the screen as new points of the graph.

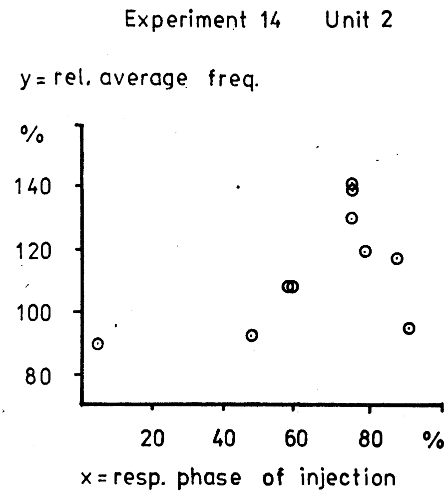

Fig. 3. Example of computer prepared graph of the relative average frequency against the respiratory phase of stimulus onset (injection) — see text.

This immediate presentation of results allowed us to see the features of the relations investigated in the course of the experiment. We could, therefore, decide earlier what should be measured next. Thus the research could be considerably shortened.

In the presented case the whole two-computer system acted ON-line because simple but fast operations which had to be contained in one bin were performed by the CAMAC, while more complex calculations were performed by the ZX-Spectrum, but this occurred only once every few seconds.

CONCLUSION

The described system fulfills all the requirements specified in the "Introduction". It facilitates physiological experiments and the analysis of results. Moreover, it enables many new functions to be performed, such as the automatic finding of neurons with microelectrodes, and the timing of stimuli dependent on certain parameter configurations (e.g., spike frequency in the neuron, blood pressure, respiratory phase, endtidal CO_2 etc.). The system's versatility allows it to used in many new ways which the user may device provided only that appropriate programs are written.

The system will be under further development in the future. For example it may be connected to a floppy-disc drive and to a digitizer.

Thanks are due to Prof. R. Tarnecki (Nencki Institute, Warsaw) and to Dr. F. R. Edwards (John Curtin School of Medical Research, Canberra) for their helpful remarks on the earlier version of the manuscript. This work was supported by the Polish Academy of Sciences, Grant 10.4.03.5.

REFERENCES

1. BURNS, B. D. 1978. The uncertain nervous system. Edward Arnold, London, 194 p.
2. Eur 4100e 1972. CAMAC — A modular instrumentation system for data handling, Revised description and specification. Joint Nuclear Research Centre, Ispra Establishment, Italy.
3. EVANICH, M., LOPATA, M. and LOURENÇO, R. W. 1976. Analytical methods for the study of electrical activity of respiratory nerves and muscles. Chest 70: 158–162.
4. HOGAN, T. 1982. Discover FORTH. Osborne–McGraw Hill, Berkeley, California, 145 p.
5. Single and multiprocessor measuring interfaces in CAMAC systems. (in Polish). Z.Z.U.J. Polon, Warszawa, 1980.
6. LIPSKI, J., TRZEBSKI, A., CHODOBSKA J. and KRUK, P. 1985. Effects of carotid excitation on medullary expiratory neurons in cats. Respir. Physiol. (in press).
7. Autonomic processor type 131. Manual measuring, (in Polish) Z.Z.U.J. Polon, Warszawa, 1978.
8. VICKERS, S. 1982. Sinclair ZX-Spectrum basic programming. (A manual), 232 p.

Accepted 11 June 1984

Janusz LIPSKI, Experimental Neurology Unit, John Curtin School of Medical Research. Australian National University, Canberra, ACT, 2601 Australia.
Piotr KRUK, Department of Neurophysiology, Nencki Institute of Experimental Biology, Pasteura 3, 02-093 Warsaw, Poland.