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A MICROPROCESSOR BASED SYSTEM FOR CARDIOVASCULAR SIGNAL ANALYSIS

L. Bedini, E. Bozzi
B. Carbone, L. Dall'Antonia

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L. Bedini, E. Bozzi, B. Carbone and L. Dall'Antonia

Consiglio Nazionale delle Ricerche, Istituto di Elaborazione dell'Informazione, 56100 Pisa, Italy

Abstract

A microprocessor based systems is proposed for on-line analysis of cardiovascular signals. The system is easily software adjustable to fit necessities in several biological experiments or clinicals measurements. An application is presented for studying the effects induced in cardiovascular system by drug administration.

Keywords

Cardiovascular system analysis, on-line measurements, microprocessor biomedical application, signal acquisition and processing, hemodynamic laboratory automation.

I. Introduction

The investigation of a cardiovascular system needs the acquisition and the analysis of several biological signals simultaneously detected from different parts of the system (MURGO, 1975; MASON et al., 1972).

The concurrent acquisition of different signals is a difficult task due to the large number of data collected. The analysis is a critical part since a large number of computation must be executed for each

signal to achieve significant results from a clinical or physical point of view.

Cardiovascular signals often are the responses to different stimuli, physical or pharmacological, and it may be useful or even necessary to make an on-line analysis for dynamically updating stimuli to responses or for carrying out measurements only when particular responses are present (MURGO et al. 1977).

In several cardiovascular laboratories measurements are still manually accomplished, analyzing the strip-chart recording produced by a polygraphic system (SALCEDO and SIEGEL, 1976; MASON et al., 1972).

In other laboratories, to relieve the operator from a tedious work of manual measurements and calculations, systems were proposed in which the analysis is carried out in semi-automatic mode: signals are stored on a CRT monitor, with electronic refresh. The user can define by means of pointers the intervals on which the intrument must execute a measure, for example an area computation, which is performed automatically. Results are more accurate and obviously require a less tedious work than those obtained by manual methods, but they cannot be produced on line. Generally signals must be first recorded on magnetic tape and then processed.

In some laboratories mini-computer based systems are used. This choice is very reliable and provides good performances: on-line data acquisition and analysis is allowed. However such a choice is very expensive and therefore it is accessible to advanced laboratories only (BEDINI et al., 1977; HUNTLEY et al., 1981).

The development of microprocessor based systems has progressed to the point where it becomes practical to utilize then in clinical or laboratory applications (FORGUES and GOLDBERG, 1979).

In this paper a microprocessor based system is proposed for on--line analysis of cardiovascular signals. The system is easily software adjustable to perform several types of experiments or clinical measurements. As an example, an application is presented for studying the cardiovascular effects induced by pharmacological stimuli (drug administration).

II. Some characteristics of cardiovascular signals

In the present section a brief review of the principal measurements that are usually executed on cardiovascular signals is reported. Some peculiar charactheristics, particularly useful in the design of the microprocessor based system, are pointed out.

Analysis of cardiovascular system is often related to pressure or flow measurements. An example of some typical cardiovascular signals is reported in fig. 1. Most measurements may be included in the following classes (WELKOWITZ and DEUTSCH, 1976):

a) pressure signals: measurements are usually related to the evaluation of the maximum and minimum value; sometimes evaluation of peak rate of pressure rise (maximum of dp/dt) may be required.

b) flow signals: evaluation of direct, inverse and mean or pulsatile flow is usually required.

c) coronary flow: it needs special processing for evaluating both the diastolic and systolic flow. Further measurements on the mean and pulsatile flow are often required.

In executing some measurements, special points of signals must be detected: e.g., to evaluate diastolic and systolic coronary flow, the times shown on fig. 2 must be detected.

Usually data collected from pressure and/or flow measurements are used as a basis for successive processing to obtain secondary results

(MURGO et al., 1977).

Some characteristics of cardiovascular signals facilitate the design of a microprocessor based system, useful in the above measurements; they may be summarized as follows:

a) bandwidth: the cutoff frequency is less than 50Hz; sample frequency of A/D converter be therefore chosen in the 200-250Hz interval, using antialiasing filter with 40db/decade response slope.

b) periodicity: cardiovascular signals are not periodic; however, if analysis is performed in a sufficiently short time intervals, they may be considered ripetitive with a time varying period; R-R interval of the ECG signal, which is not time constant, may be assumed as signal period; if R-R intervals are normalized so that they assume a constant value, cardiovascular signals may be modeled, in sufficiently short interval, by the sum of a periodic signal and white noise; this property will be successively referred to as quasi-periodicity; it may be used for improving the signal to noise ratio by averaging signals over several successive cardiac cycles.

c) redundancy: time intervals in which cardiovascular signals may be considered quasi-periodic are usually greater than the ones strictly necessary for accomplishing measurements; this allows to acquire data in a noncontinuous way and, eventually, to use some cycles for estimating useful parameters for following measurements.

d) interdipendence: the cardiovascular signals are not indipendent of each other. Since they are generated by a common cardiac activity, they are strictly interrelated. This makes easier the detection of signal points which are used in several measurements. Relation to R peak of ECG signal is particularly useful.

III. The microprocessor based system

The proposed system is based on microcomputer products of Z80 family. It uses a dual 8 inch floppy disk, a graphic display, an alpha-numeric video keyboard and a printer. The microcomputer controls an A/D converter and a multiplexer to sequentially acquiring digital data from each cardiovascular signal.

In fig. 3 the block diagram of the system is reported. A picture of the system is shown in fig. 4.

The software has a modular structure. Several assembler modules may be easily interconnected by using a high-level language program to fit different experimental applications.

Each assembler module performs a given function, as listed in the following:

-) experiment control: this module allows the operator to specify the experiment control data, i.e. sampling frequency of A/D converter, number and nature of signals, types of measurements, number of cardiac cycles used to average the single cycle results, time interval between two successive measurements.

-) signal calibration: this module performs an automatic calibration of cardiovascular signals.

-) signal display: this module displays acquired signals on a CRT monitor. Special marks are provided to evidence special points useful in measurements. Time scale expansion is also provided.

-) pressure signal processing: evaluation of maximum, minimum and means value inside a cardiac cycle is carried out.

-) left ventricular pressure processing: the first derivative of signals is computed and its maximum is evaluated.

-) coronary flow processing: diastolic, systolic and mean flow is evaluated.

-) flow signal processing: direct, inverse and mean flow is calculated.

-) ECG signal processing: this module evaluates R- R intervals and mean cardiac rate. A synchronizing signal, generated in coincidence with the R peak, is sent to other modules.

Each module provides facility to average single cycle results over a prefixed number of cardiac cycles.

The availability of a dual floppy disk provides facilities to generate a data base for experimental or clinical data.

IV. Experimental results

The proposed microprocessor based system has been tested in a experimental application to evaluate its performance. The selected application concerns analysis of cardiovascular signals detected from experimental animals when drugs are administrated (BEDINI et al., 1982).

In the following some design criteria, used to software adjust the system to the particular application, are illustrated, along with the results.

The experiment concerns measurements about ECG signal, flow and pressure signals, coronary flow.

To make easier the use of the system, the choice has been made to specialize each input channel for a given measurement. The operator must pay attention to connect each cardiovascular signal to the appropriate input channel. In table I measurements executed on each channel are reported; three channels (2, 3 and 4) are provided for pressure measurements, two channel (6 and 7) for flow measurements.

Tab. I - List of measurements executed on each input channel

Channel Number	Measurements	Units	Printed Abbreviation
1	Mean heart rate	Beats/min.	HR
2 & 4	Sistolic ⎫	mmHg.	SBP
	Diastolic ⎬ Pressure		DBP
	Mean ⎭		MBP
3	Contractylity Index (peak dP/dt)	mmmHg/sec.	C.I.
5	Sistolic ⎫	ml/min.	SCBF
	Diastolic ⎬ Coronaric Flow		DCBL
	Mean ⎭		CBF
	Pulsatile Cor. Flow	ml/beat	PCBF
	Coronaric Resistance	mmHg/(ml/min.)	CR
6 & 7	Direct ⎫	ml/min.	DBF
	Inverse ⎬ Flow		IBF
	Mean ⎭		MBF
	Pulsatile Flow	ml/beat	PBF
	Resistance	mmHG/(ml/min.)	Res.

The software specialization to the application has been made using BASIC languages supported by CP/M Operating System control.

Several function modes are provided by the system; the operator may select each mode by pressing a specific control key on the key-

-board. All the possible modes are dispayed when the program begins to run or when the operator presses the key "R".

The system provides the following function modes:

-) Initial mode (control key "I"): the operator is requested to give information about input channels effectively used in experiment, date and time (hour, minutes and seconds) in which experiment begins, number of cardiac cycles over which single cycle results must be overaged, time interval between two successive measurements. These data are sent by keyboard.

-) calibration mode (control key "T"): the system displays the number of each input channel in use. The operator must give data to calibrate each input signal.

-) Sampling mode (control key "S"): input signals are sampled and displayed on CRT monitor.
The obtained samples are stored in a RAM memory. For each channel 1024 bytes of memory (input buffer), first input-first output organised, are provided.

-) Single measurement mode (control key "M"): this mode may be entered only when sampling mode or displaying mode is running. When key "M" is pressed, the system stops sampling input signals and executes measurements on the sampled data stored in memory. Results are then printed.

-) Automatic measurement mode (control key "A"): pressing key "A", a system clock is enabled to interrupt at time intervals defined on the initial mode. On interrupt, the system controls that sampling mode is running and that input buffers contain valid data. Then it executed measurements and prints results.

-) Displaying mode (control key "V"): this mode may be entered only when sampling mode is running. This mode allows the operator to visually check on CRT monitor if the system correctly recognizes special signals points useful for the measurement. When key "V" is pressed, the system stops sampling signals and a processing activity starts to recognize such special points on the sample stored in memory. Analyzed signals are then displayed on CRT monitor; recognized signal points are evidenced by special marks.

The operator may complete the measurements and print results by entering key "M".

Results of a measurement are shown in fig. 5. They are obtained by an experiment in which adrenaline had been administred to a dog.

An example of displayed signals on CRT monitor, when sampling mode has been entered, is shown in fig. 6.

V. Conclusions

The experimental results prove good performance of the designed microprocessor-based system. The hardware configuration and the availability of software modules, each oriented to a given measurements, allow to easily particularize the system to a given application using high level languages and, therefore, to have a very low cost.

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Figure Captions

Fig. 1 - Example of typical cardiovascular signals.

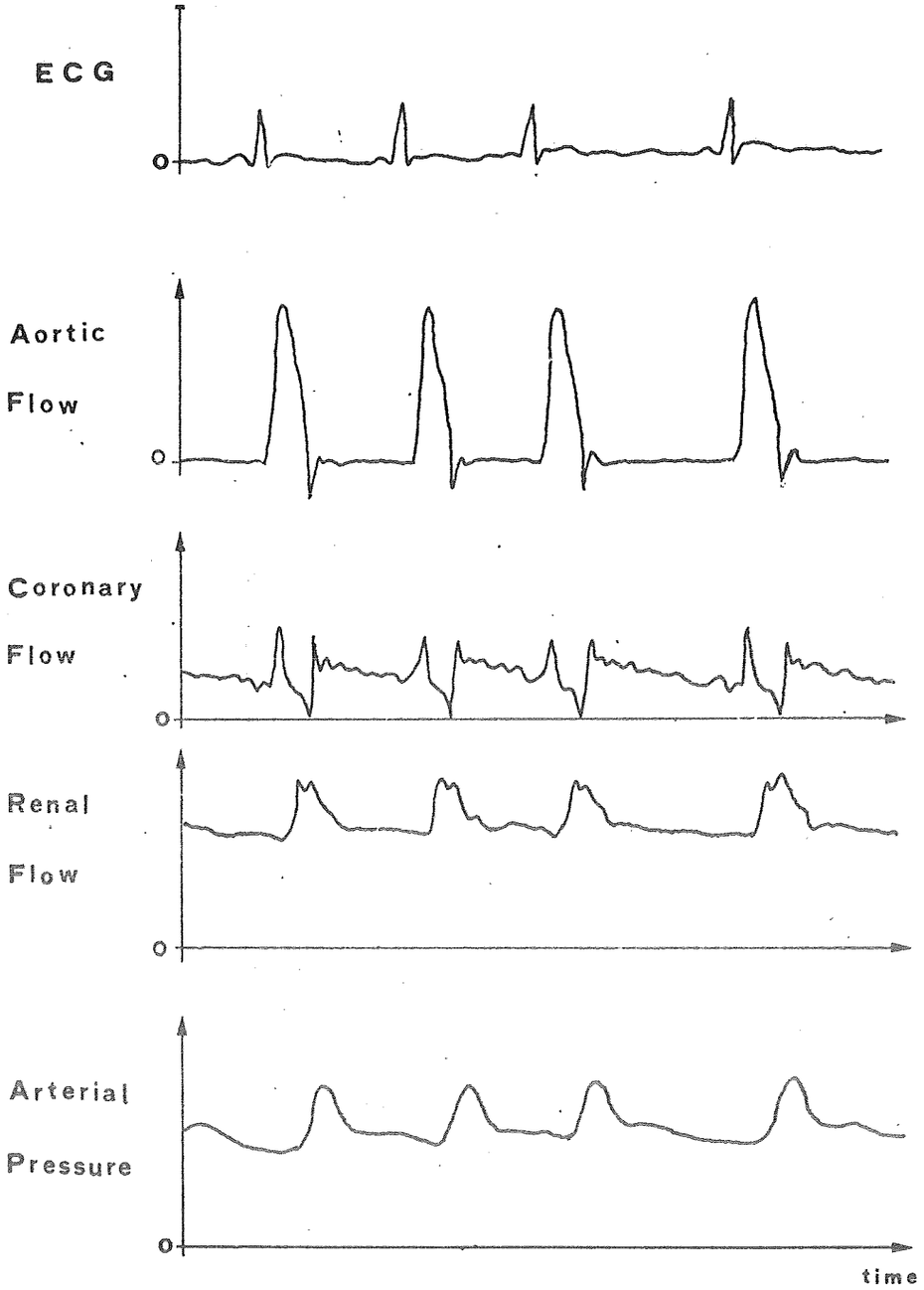
Fig. 2. - Systolic and diastolic coronary flow.

Fig. 3 - Block diagram of the microprocessor based system.

Fig. 4 - Picture of the microprocessor based system.

Fig. 5 - Example of printed results. They are obtained by an experiment in which adrenaline is admistered to a dog.

Fig. 6 - Example of signals displayed on CRT monitor. Typical signal points used in measurements are evidenced.


ECG
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Aortic
Flow
0
Coronary
Flow
0
Renal
Flow
0
Arterial
Pressure
0
time

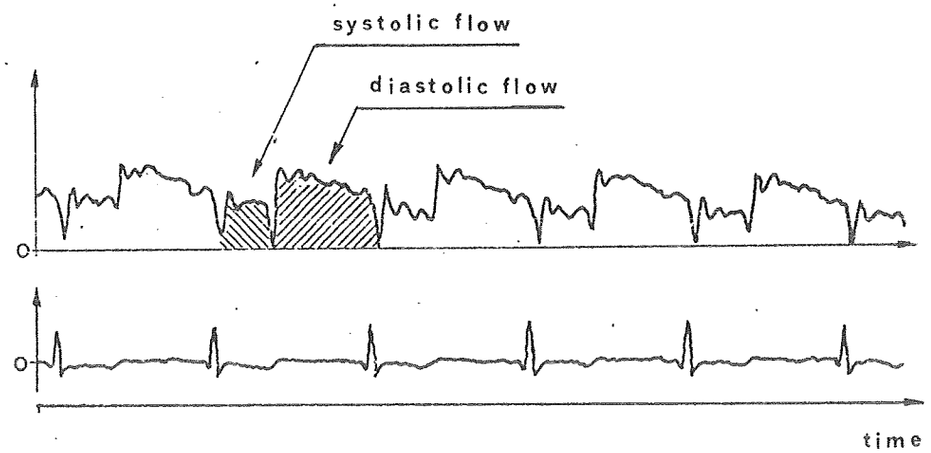
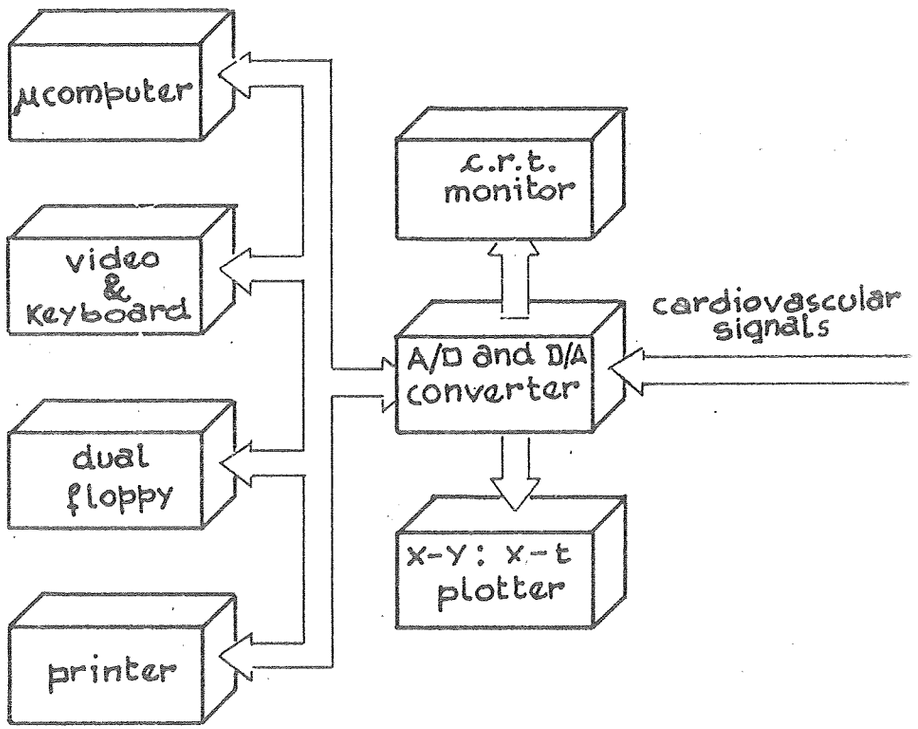


FIG. 2.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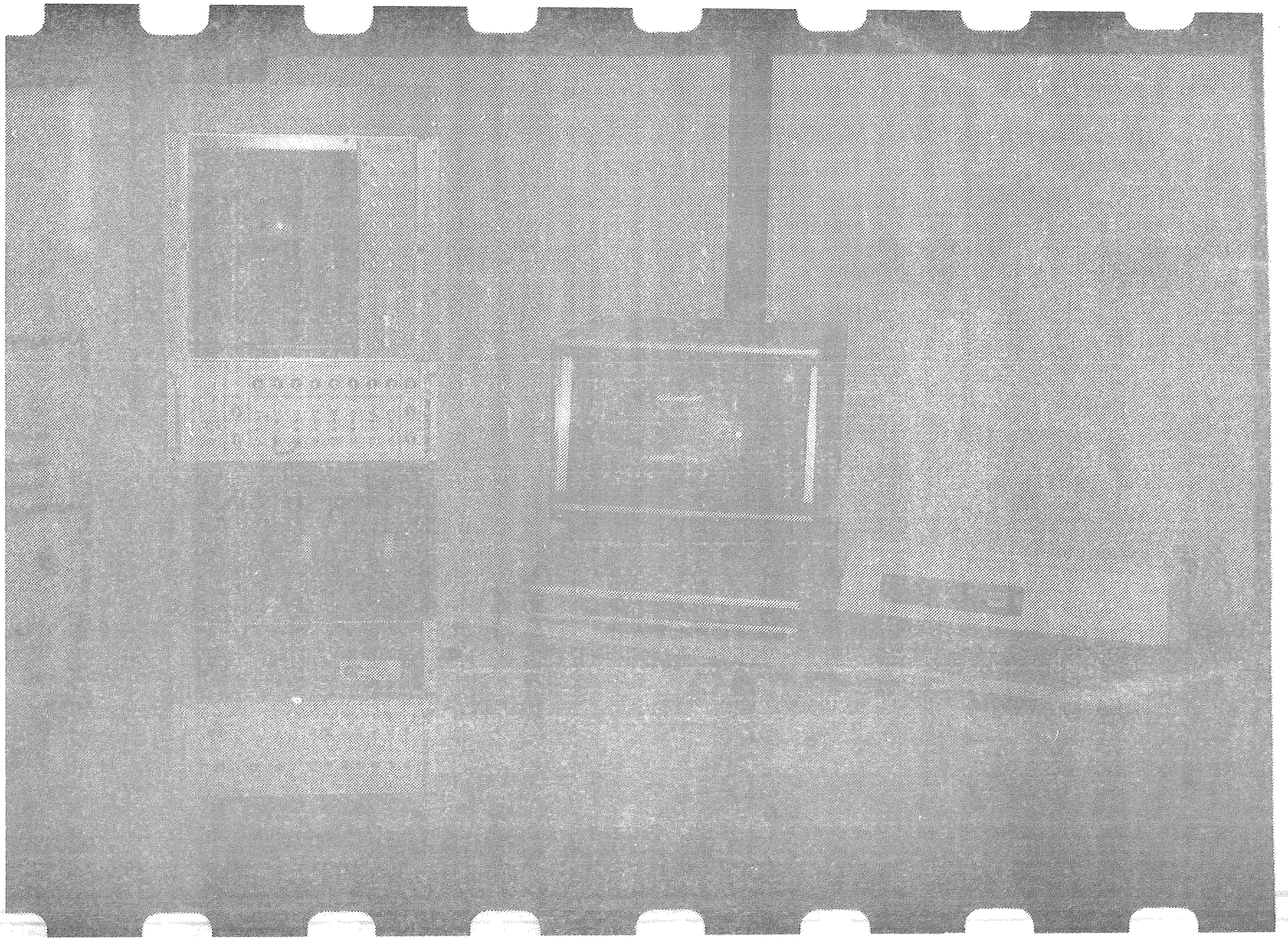
video & keyboard
dual floppy
printer
c.r.t. monitor
A/D and D/A converter
x-y : x-t plotter
cardiovascular signals



HR	SBP	DBP	MBP	DBF	IBF	MBF	PBF	Res.	Time
127	40	12	21	16	0	16	0.122	1.354	11 40 13
127	39	12	21	16	0	16	0.124	1.313	11 40 23
128	33	11	18	15	0	15	0.115	1.198	11 40 33
128	35	9	17	14	0	14	0.105	1.235	11 40 43
======>>>	adrenaline administration								
150	56	11	21	33	0	33	0.220	0.636	11 40 57
151	51	9	19	36	0	36	0.240	0.514	11 41 07
146	47	10	19	38	0	38	0.261	0.493	11 41 17
140	41	8	18	37	0	37	0.263	0.483	11 41 27