Processing the Ambulatory Electrocardiogram and Pulse Wave Signals With a Multiple Microprocessor Network

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List of Symbols

Q	Q Wave of Electrocardiogram
R(N)	Nth R Wave of Electrocardiogram
U	Pulse Wave Upstroke
I	Pulse Wave Incisura
S1	First Heart Sound
S2A	Aortic Component of Second Heart Sound
PTT=I-S2A	Pulse Transmission Time
RR=R(N)-R(N-1)	Time Interval Between Two R Waves
HR=1/RR	Heart Rate
LVET=I-U	Left Ventricular Ejection Time
PEP=U-Q-PTT	Pre-Ejection Period
EPR=PEP/LVET	Ejection Period Ratio

I. Introduction

A multiple microprocessor network that processes 24 hour recordings of the ambulatory electrocardiogram (ECG) and pulse wave signals is presented. This network is a specialized computer system for extracting information of clinical interest from the large quantity of data on the ambulatory tapes. The system identifies the location of the QRS complex of the ECG and the upstroke (time of rapid rise in pressure during cardiac contraction) and pulse incisura (time of aortic valve closure) of the pulse wave. Using these detected events, the microprocissor system determines the heart rate, left ventricular ejection time, pre-ejection period, and ejection period ratio. The network also detects ventricular arrhythmias by analyzing the shape of the QRS complex of the ECG.

II. The Ambulatory Signals and Parameters of Interest

A method for recording 24 hours of both the ECG and the photoelectric densitogram of the ear pinna, which provides the pulse wave signal, from ambulatory patients has been developed by Haffty et al. [1]. The information contained in these tapes is valuable for a better understanding of cardiac physiology and the effect of cardiac drugs on subjects performing routine activities. These tapes contain a large quantity of information that can be extracted with automated computer processing techniques.

The ECG and the derivative of the ear densitogram are the two signals actually recorded on the tape. The time relationship of these and other cardiovascular signals is shown in figure 1. The computer system will detect the following timing events from the recorded signals: the Q and R waves from the ECG and the upstroke and incisura from the derivative of the ear densitogram. Patient parameters that are determined from the detected events are calculated according to the formulas given in the List of Symbols. The first needed of these, the pulse transmission time, must be determined manually for only one cardiac cycle using the patient's phonocardiogram and ear densitogram [1] and entered into the system prior to the initiation of tape processing. The multiple microprocessor network will then calculate the remaining parameters.

In order to detect ventricular arrhythmias, a measure of the QRS complex morphology is made by calculating the value of the correlation coefficient of [4] for every heart beat. Before a tape is processed a number of normal QRS complexes that correlate well with each other are played into the system and used to construct a QRS template. When the tape is processed all QRS complexes are then compared with the standard template for the detection of abnormal beats by computation of the correlation coefficient.

III. Implementation of the Multiple Microprocessor Network

A general multiple microprocessor network (MMN) has been developed [2] to provide a structure that can be used to construct systems composed of many microprocessor and memory elements. As shown in figure 2, this structure consists of a number of memory phases connected with microprocessors that perform the required processing on the data in these memories. There is a read only memory attached to each microprocessor which contains the program to be implemented by that processor. The phases consist of random access memories that store system inputs and outputs and provide the means of communication between processing stages. The processor units obtain the data needed to perform the required computations from the memories of its input memory phase when the data is available and store the results in the memories of the following memory phase. An arbiter is used at each memory phase for allocating that phase of memories among the microprocessors that require them. Intermediate and final results of the operations performed progress through the phases of memories in the network as in a pipeline computer organization.

A block diagram of the MMN for processing the ambulatory signals is shown in figure 3. The memory phases are represented by the numbered horizontal dashed lines. The blocks between the memory phases represent individual microprocessors with the functions performed by these processors written inside the blocks. This particular implementation would require eleven microprocessors and seven memory phases. Additional capability would actually be added to the microprocessors for figure 3 that perform the filtering, fixed to floating point conversion, and correlation coefficient computation by connecting a signal-processing peripheral chip [7] to them. These additional circuits increase the arithmetic capability of the microprocessors and decrease the time required to perform the microprocessor's function.

The analog to digital converters simultaneously enter data into buffers contained in the memories of phase 0 for both ambulatory signals. When these two buffers are full they are then processed by the network while new buffers are filled with data. The ECG is first digitally filtered [8] to remove any noise and baseline shift and then the R and Q waves of the ECG are detected. The data points just before and after the R wave occurrence, those that include the QRS complex, are converted to floating point and used to calculate the correlation coefficient. This calculation involves a large number of arithmetic operations so separate microprocessors are used to calculate the numerator and denominator terms of the correlation coefficient expression. The microprocessor that detects abnormal beats performs the final division and uses both the value of the correlation coefficient and the time between the present and previous R wave to determine abnormality [3]. After analog to digital conversion the derivative of the ear densitogram is simultaneously passed through two digital low pass filters, one to eliminate noise from the waveform and the other to provide a signal used to detect the upstroke and pulse incisura [6]. The time occurrence of the R wave of the ECG is used to assist in the detection of the upstroke. The locations of the timing events are passed to a microprocessor that calculates all the required parameters mentioned above. A microprocessor in this network is activated when the data needed to perform its function is available in its input memory phase. Results are passed to the following memory phase without altering data that is needed by the next stage of microprocessors.

IV. Conclusions

A multiple microprocessor network that extracts clinically useful information from 24 hour (or any other time length) recordings of the ambulatory ECG and pulse wave signals has been presented. Implementing the required computing tasks with the network offers the following advantages: hardware modularity for easy system implementation and expansion by using the same microprocessor and memory units throughout the network, increased throughput with multiple processing units, and ease of modification of any of the processing steps by changing the read only memory associated with the microprocessor performing the changed step. The system could be expanded to include the processing of an additional ECG by duplicating the hardware used for the first ECG.

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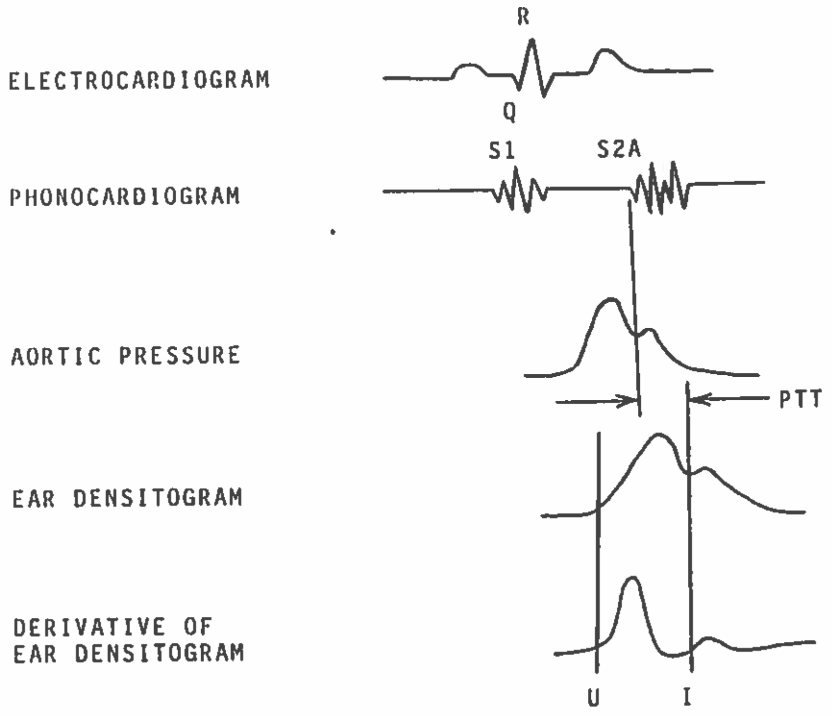

Figure 1. Time Relationship of Physiological Signals

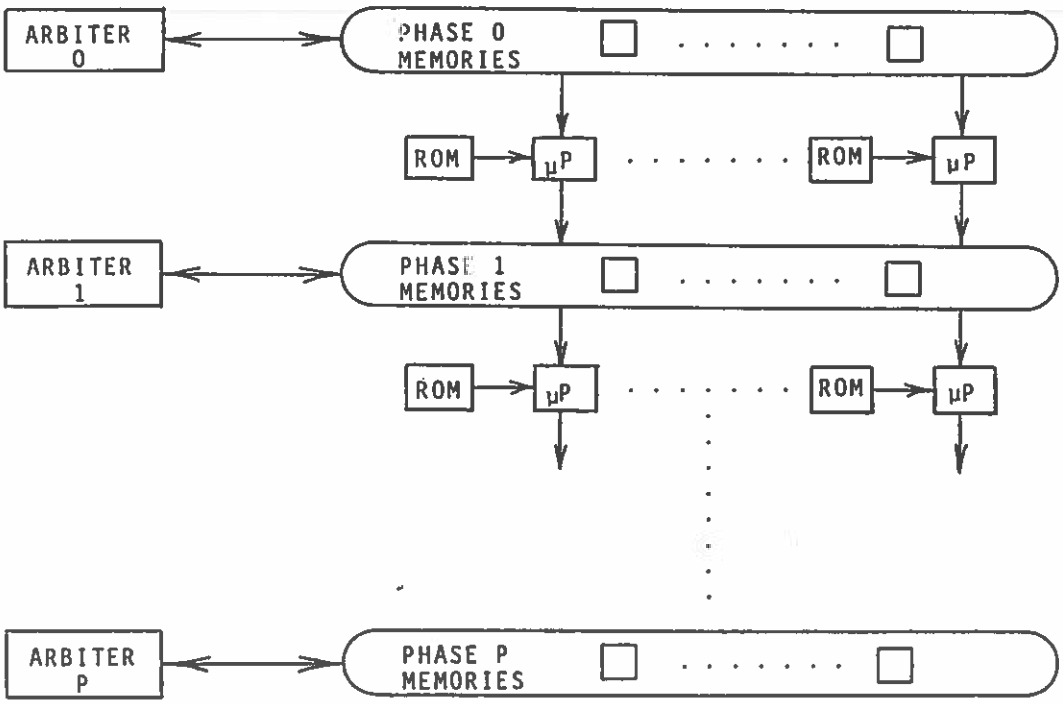

Figure 2. General Multiple Microprocessor Network

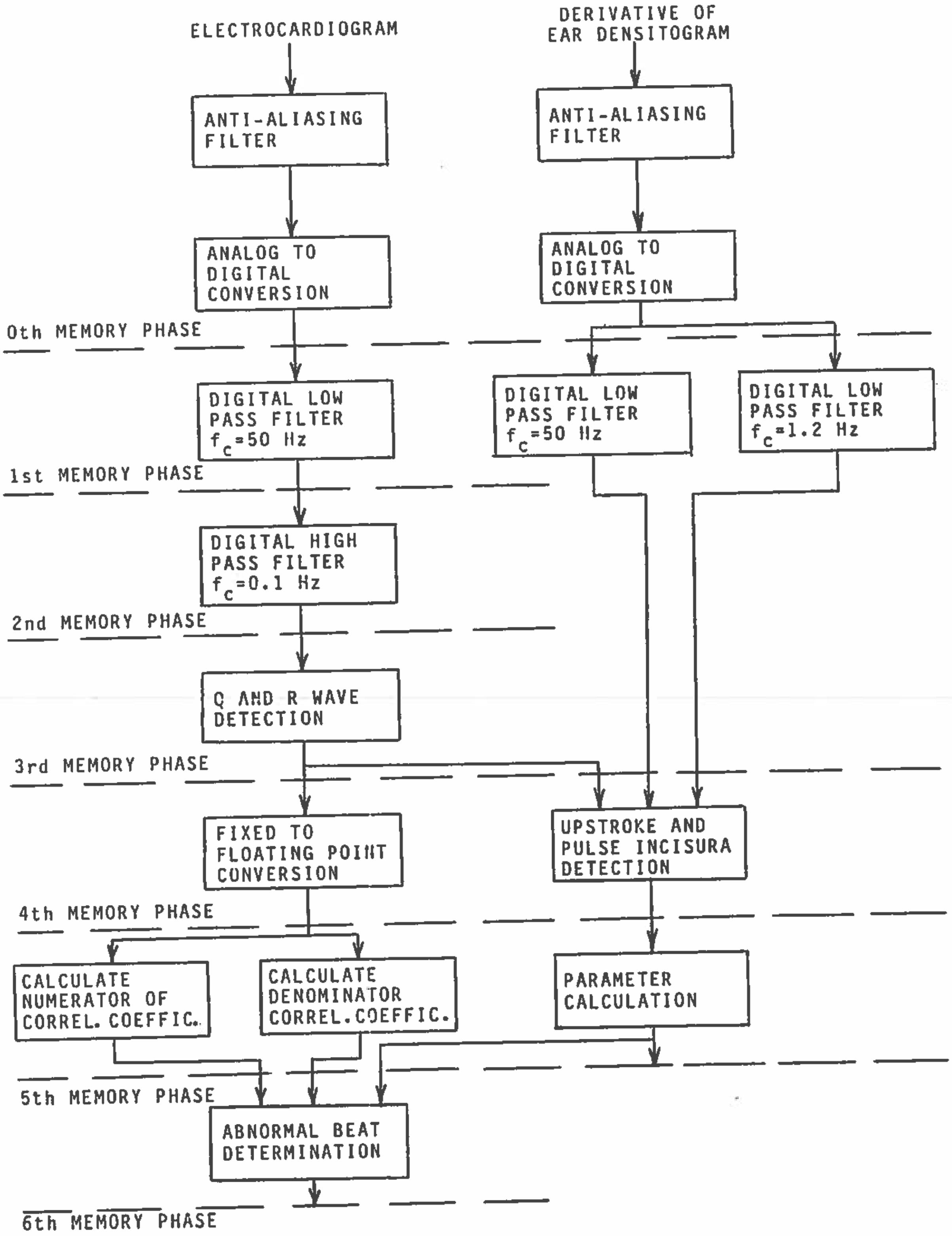

Figure 3. Multiple Microprocessor Implementation of Signal Processing Functions

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