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DESCRIPTION AND ANALYSIS OF THE HEWLETT-PACKARD 78220 ARRHYTHMI--ETC(U)
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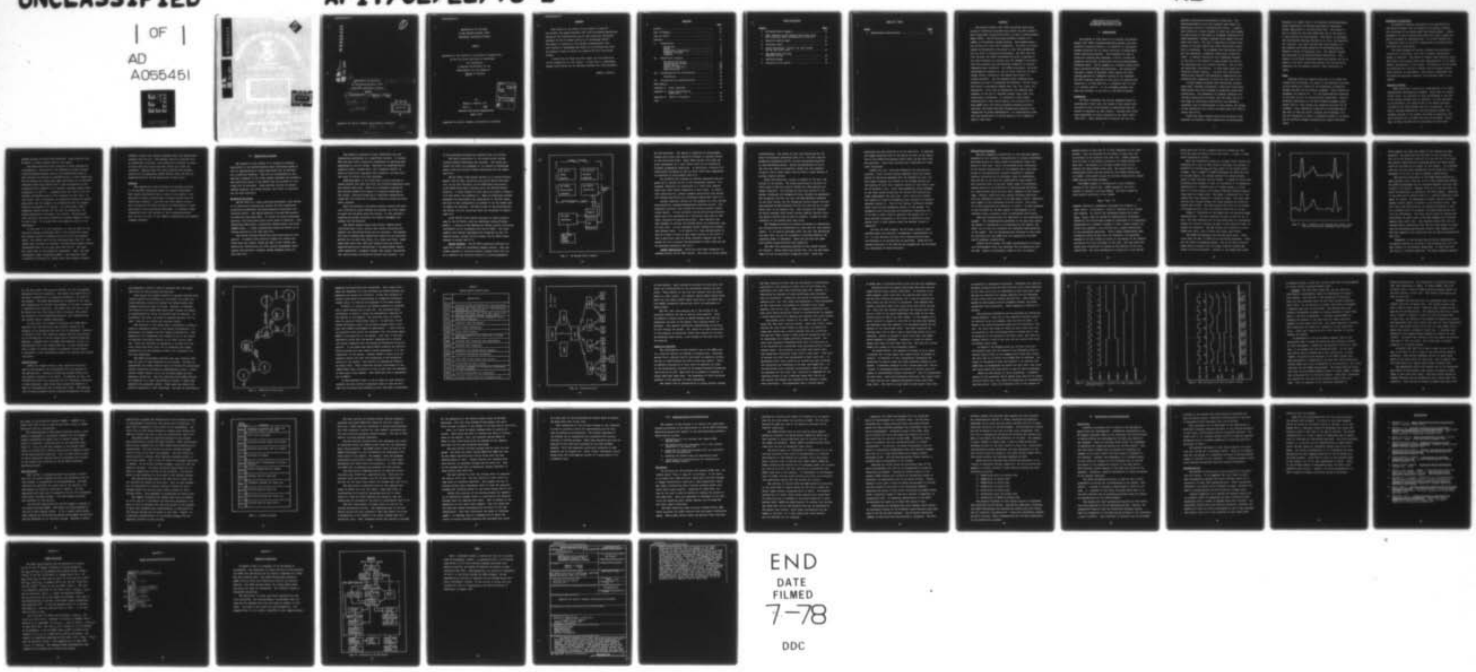

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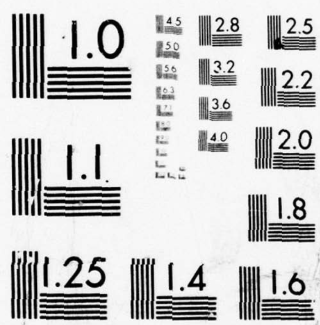

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DESCRIPTION AND ANALYSIS
OF THE HEWLETT-PACKARD 78220
ARRHYTHMIA MONITORING SYSTEM.

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(10) Samuel L./Harris
2nd Lt USAF

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DESCRIPTION AND ANALYSIS OF THE HEWLETT-PACKARD 78220 ARRHYTHMIA MONITORING SYSTEM

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

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by
Samuel L. Harris, B.S.
2nd Lt USAF
Graduate Electrical Engineering

March 1978

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Preface

This report is the result of my attempt to describe and analyze the Hewlett-Packard (HP) 78220 Arrhythmia Monitoring System so that modifications can be made using the techniques employed by the Air Force Institute of Technology (AFIT). The report is confined to the general considerations that will confront a programmer who takes up the modification task. No attempt is made to modify the present HP heart monitoring system.

I would like to thank my wife, Joyce, for her assistance in the preparation of this report. I also wish to acknowledge Captain Pete Miller and Dr. Matthew Kabrisky for their guidance.

Samuel L. Harris

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Abstract

The Hewlett-Packard (HP) 78220 Arrhythmia Monitoring System is ventricular-oriented and detects the most significant ventricular contractions (PVCs) of Lead II electrocardiograms (ECGs). The HP monitoring software consists of a number of relocatable program modules. The program modules are divided into three main categories. The first is called system initialization, the second is real time processing, and the third is background processing. The real time portion includes the AZTEC transformation which is applied to the input waveform and records only the changes in the waveform that succeed some predetermined threshold to achieve a tremendous data reduction. The AZTEC counterpart, the Walsh transformation employed by the Air Force Institute of Technology (AFIT), evaluates a 128 sample data vector of a located waveform. The low sequency Walsh transform coefficients are used in processing the waveform. The HP system has levels of processing called zero, one, two, three, and background. Level zero is responsible for swapping data segments in and out of "working storage" where real time processing is performed. To incorporate AFIT program characteristics into the HP system, the routines that expect AZTEC data, the level processing transfer and exit routines, the buffer and data storage area along with the timing must be given consideration. An investigation found that the modification of the HP system is not a feasible task at this time.

DESCRIPTION AND ANALYSIS
OF THE HEWLETT-PACKARD 78220
ARRHYTHMIA MONITORING SYSTEM

I. Introduction

The purpose of this report is to analyze the Hewlett-Packard (HP) 78220 Arrhythmia Montoring System, and theoretically determine whether it is feasible to incorporate changes involving the Air Force Institute of Technology's (AFIT) monitoring software. Both programs are used to locate and identify QRS complexes, P waves, T waves and premature ventricular contractions from electrocardiogram waveforms (ECG). The HP program is a complete system which uses a modified HP-21MX microprocessor. The system also includes a number of displays, alarm signals and hard-copying devices for immediate viewing of the waveforms. The AFIT computer algorithm is the result of research performed by J. H. Reid (Ref 10), J. Vasselli (Ref 11) and J. P. Ditucci (Ref 2). It is a software package only. When last revised, it was run on a CDC 6600 processor.

Background

To fully understand why the two programs should be scrutinized at this time, the reader of this report must be aware of some of the history of monitoring heart patients in hospitals in this country. Coronary care units were established in major hospitals in the early 1960's (Ref 10:2). Their purpose was to monitor and care for patients recovering from myocardial infarction. The electrocardiogram is the most commonly used signal for monitoring a patient's cardiovascular status. A myocardial infarct is a heart ailment in which the blood supply to some portion of the heart is decreased sufficiently to cause myocardial ischemia (reduced blood supply) and possible cell death. The loss or reduction of a good blood supply in the heart muscle may cause ventricular ectopic foci to discharge. The discharge from ventricular ectopic foci generates a premature ventricular contraction (PVC). If several ventricular foci discharge randomly at the rate of two hundred to three hundred per minute, the ventricles will not contract smoothly. This is called ventricular fibrillation. In this state there is no effective cardiac pumping. A patient with ventricular fibrillation requires cardiopulmonary resuscitation and defibrillation immediately to save his life (Ref 10:3).

As data became available from established coronary care units, evidence accumulated to show that ventricular fibrillation was often preceded by premature ventricular contractions. The appearance of numerous premature ventricular contractions indicates that the heart may be on the verge of ventricular fibrillation, and therefore, medication must be administered to help control the firing of the ventricular foci before the heart goes into fibrillation (Ref 10:3).

Until now, most coronary care units monitored their patients by intensive visual observation of oscilloscope tracings of a single lead of the standard electrocardiogram. Visual observation is normally performed by registered nurses experienced in the monitoring task. The nurses rotate in shifts so that they spend only one or two hours at a time watching the oscilloscope. This system of watching the oscilloscope tracings existed in all but a few hospitals not long ago. One which has switched over recently to a new computer monitoring system is the Kettering Memorial Hospital located in Kettering, Ohio. The computer system was developed by the Hewlett-Packard Corporation. This system, the HP-78220 Arrhythmia Monitoring System, may be an answer to the heart monitoring problem, but some pertinent questions must be answered before a final conclusion is drawn.

Scope

Although there are numerous questions to be asked concerning this new system, the scope of the questions discussed in this thesis are limited to the fundamental differences between the AFIT and HP software programs. These differences encompass the aspects of : (1) the transformation performed on the data and (2) the identification algorithms. Since an excellent description of the AFIT software program already exists (Ref 2), this thesis will primarily describe the HP software. This information along with an understanding of the flow of data and control through the HP program, will lay the foundation on which to determine whether it is feasible to institute changes concerning the aspects mentioned above.

Fundamental Assumptions

An objective decision pertaining to the feasibility of instituting changes into the program could greatly increase the efficiency of any future heart monitoring system. A basic assumption is that a modified HP system will have a higher degree of accuracy in detecting PVCs. It is also assumed that a foundation will be laid for a system able to process atrial waveforms more effectively.

The newly designed HP system, although very elaborate in controls and indicators, still has a somewhat unacceptable degree of accuracy. The rhythm of certain heart patients cause many false alarm signals which were characteristic of the unmarketable predecessors of the system. The alarms of the HP system are sometimes shut off for a patient with an unusual rhythm. This situation is undesirable. This report investigates the HP system by applying a sequence of analytical steps to the system.

Research Strategy

These steps first involve the investigation of the AZTEC preprocessing transformation program. Since this is a feasibility study, the influence of this microprogram on the rest of the system software must be examined. If this influence is too extensive, the substitution of the Walsh transform utilized by the AFIT software may not be practical. To insure a thorough examination, the relationship between the software modules of the system, the modes of operation, the data structure and the AZTEC data must be analyzed. Secondary to these concerns are the procedures by which each program locates and identifies waveforms. Some attention will be given to these concerns later in the report.

The areas mentioned above formulate a basic strategy for investigation. Since most of the information needed is about a Hewlett-Packard system, most of the documentation used in this analysis is authored by representatives of that corporation. The one hundred and forty-eight page description of the HP-78220 Arrhythmia Monitoring System (Ref 4) has an abundance of discrepencies when compared to the assembly language program which accompanies it (Ref 5). A probable cause for this is that the software development work is still underway at this time. In this study, when a discrepency is discovered between the system description and the program, the information from the program printout is assumed to be correct. In other cases, where a comparison cannot be made for the lack of information, the system description is assumed to be correct. Working under such conditions may have introduced an unknown degree of error in this study. It is hoped that this degree of error is not significant.

If the error is of any substance, it will be found in the structural design methodology used in this feasibility study. The complete system is analyzed with the aid of two analysis tools: the bubble chart and the structure chart (Ref 7). The bubble chart consists of "bubbles" (circles) which denote actions (transformations) on the input data (Ref 7:2-3). The input and output data of the bubble are conceptual. Here, the word "conceptual" means "simplified names". The structure chart is derived by dividing the bubble chart into afferent (input), efferent (output) and central transform (what the system does) elements (Ref 7:2-10). This process results in modules with an hierarchial structure. The modules are connected by lines in which data and control may flow either up or down the structure. Because these two charts describe the software modules and the parameters passed between them, the task of understanding what the HP system does is made clear.

Comments

This feasibility study involving the possible revision of the HP-78220 monitoring system is entirely theoretical. Even though experimental data is used in this report, it is mentioned to merely substantiate a concept derived from the theoretical analysis. Also note that this thesis is written to bring the Air Force Institute of Technology up to date with current heart monitoring technology. It provides indept information about this subject so that interested parties will not have to refer to the immense documentation and assembly language programs.

II. Theoretical Analysis

The purpose of this chapter is to furnish an adequate description of the Hewlett-Packard heart monitoring system so that an understanding of system operations will be provided for a potential modifier. This will be accomplished by presenting a synopsis of the entire system (hardware and software); then particular parts of the system that are relevant to this study will be discussed. These portions include the preprocessing programs, the system modules, the levels of operation and the data structure.

HP Monitoring System

The HP 78220 is a highly developed arrhythmia alarm system. It is ventricular-oriented and detects the most significant ventricular arrhythmias including premature ventricular contractions (PVCs). The system operates at around 84% accuracy in detecting individual PVCs. It covers the entire arrhythmia spectrum, utilizing three alarm levels based on severity: life-threatening (RED alarm), premonitory (YELLOW alarm), and minor (GREEN alarm). A single computerized system can handle up to sixteen patients at one time (Ref 6:3).

The system includes around-the-clock monitoring for each patient. It samples each patient's signal two hundred and fifty times per second; checks for QRS, P and T waves, and ventricular fibrillation and other serious arrhythmias every second; and performs a complete rhythm diagnosis every minute (Ref 6:4).

The automatic detection of most premonitory and life threatening arrhythmias is a significant feature. It detects PVCs and most other ventricular arrhythmias by examining beat morphology as well as rhythm. Detection of supraventricular premature beats, "missed beat", and "irregular rhythm" is based on ventricular phenomena (R-R interval), but may alert the staff to atrial or AV node problems.

Referring again to the multi-level priority systems of alarms reveals that they come with the attention-demanding visual and audible alarm cues. There is an automatic override by more serious alarms and a manual or automatic resetting of the alarms. Previous alarms may be inhibited automatically along with the initiation of Patient Selector alarms and strip chart recorder.

Next, an artificial pace-pulse detector detects and monitors artificially paced rhythms and displays the total number of paced and non-paced beats per minute. It also provides a flashing pace-pulse indicator, and signals pacemaker non-capture and non-function.

The status display shows alarm status, rhythm status (including heart rate), ectopic beat status (including frequency), and monitoring status for all patients. The display will also on demand give significant events for any monitored patient for the past nine hours, in a trend plot form. Trend plots show heart rate, PVC rate (plotted rate per minute), asystole/ventricular fibrillation, R-on-T/multiform, ventricular tachycardia, irregular rhythm, poor signal, monitoring off, paced rhythm, and manually entered event markers. All of the preceding functions are updated every two minutes.

The staff communicates to the system solely through clearly labeled pushbuttons and switches. The system may notify the staff with messages on the display if mechanisms detect noise and baseline wander associated with the signal (Ref 6:4).

The HP 78220A 8-bed system consists of a Control/Display Module (one HP 78221 controller and one HP 5671B Video Monitor), an HP 2108 Processor, an HP 2748B Paper Tape Reader, an HP 7826B Strip Chart Recorder and an HP 7811A/B Patient Selector. A block diagram of these parts are shown in Figure 1 (for more detail see Appendix C). There is additional bedside equipment for measurement and transmission of the ECG signal. The Lead II ECG configuration is assumed to be the method used to obtain the waveform. The ECG is sent to the oscilloscopes (HP 5671B), and the controller which are indicated in Figure 1 (Ref 6:5).

An HP 78220B 16-bed system includes the same equipment used by the HP 78220A, plus one additional Control/Display Module. A variety of HP bedside and central station monitoring instruments can be interfaced with the HP 78220. The alarm signals from bedside instruments are connected so that the bedside alarms, central station alarms, and HP 78220 alarms operate in series (Ref 6:5).

<u>System Software</u>. The HP 78220 monitoring software consists of a number of relocatable program modules. They are linked together to form one absolute program which will run as a complete self contained system on a microprogrammable

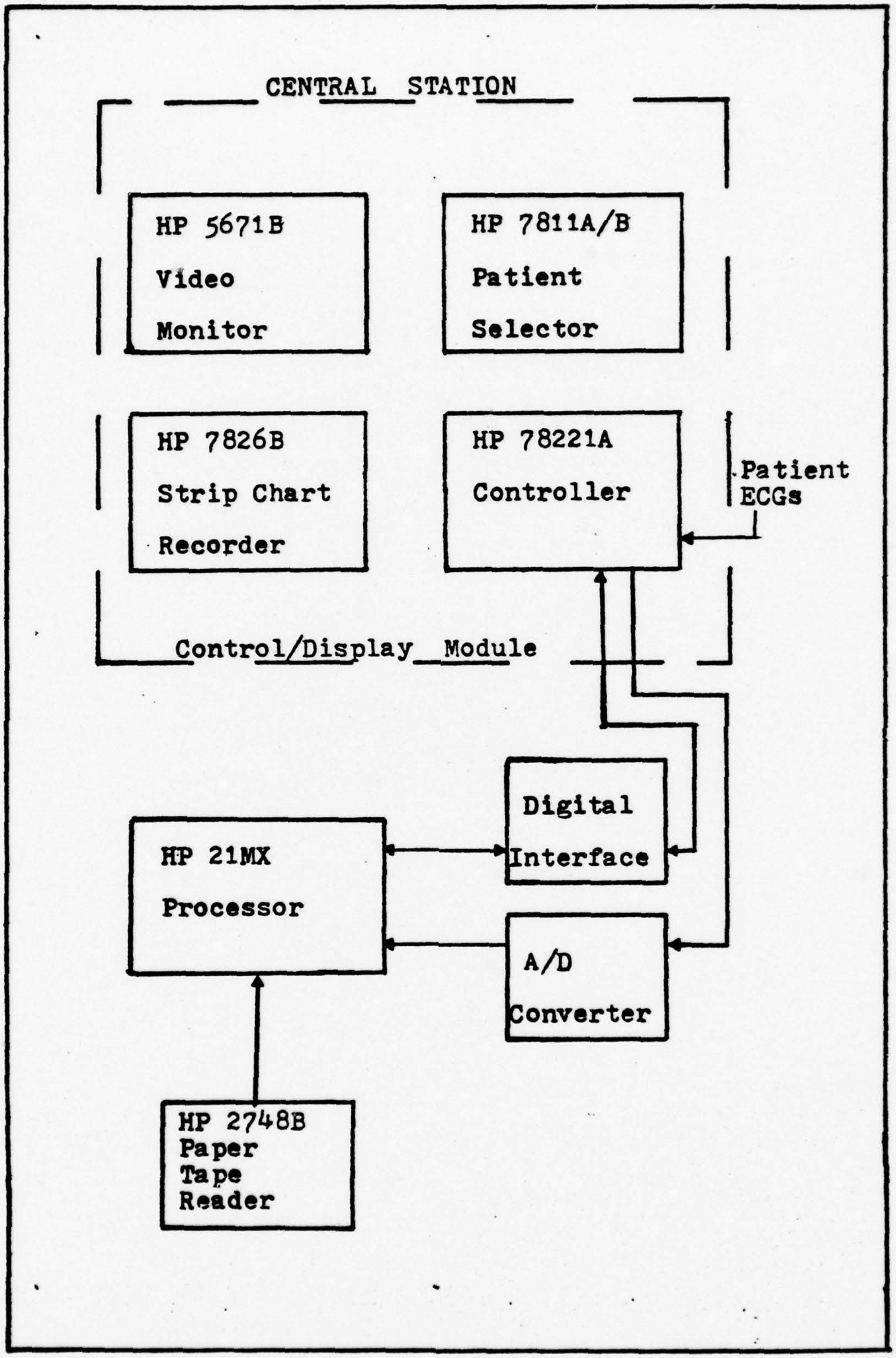

Fig. 1. HP System Block Diagram

HP 2108 processor. The system is supported by microprogram modules which have been specially designed to perform certain of the monitoring tasks. These tasks require very high computer performance at a level which could not be achieved by ordinary programming techniques. In particular, virtually all input/output processes as well as first level data compression is performed by microprogram (Ref 4:1).

All variable data storage is entirely separated from programs and is defined by one of the relocatable modules. The programs themselves are structured in a "read only" fashion since they never modify themselves or each other. To obtain this characteristic, special program instructions were defined for linking subroutines and processing input/output (Ref 4:1).

Another important feature of the programs is a well defined multi-priority, foreground/background executive system. This executive allocates time between the various patients (often called users). It also initiates various monitoring functions which need to be performed for a particular user such as data input, analysis and generating alarms. This executive has been designed to provide the maximum amount of calculation time for each user. It also minimizes system overhead and interaction between users. It is similar to a time sharing system in that an attempt is made to give equal service to all users so that a particular user who makes excessive demands upon the system will not interrupt the monitoring of other users and yet be processed adequately (Ref 4:3).

<u>System Organization</u>. There are three main categories of programs within the HP 78220 system. The first is called system

initialization. The second is real time processing and the third is background processing (Ref 4:4). The real time and background processing provide the main processing functions of this monitoring system. System initialization is run at the time the system is originally loaded into the computer. It may be run at other times; such as after a power failure or during a manual restart.

After initialization, control is passed to the real time portion of the system. The actual monitoring of patients involve input of ECG and control information, ECG analysis and rhythm diagnosis. Also during the real time portion of the system, foreground and background status displays are generated. The foreground involves the real time ECG waveform displayed on the video screen, and the background status display involves the accumulative ECG waveform for both one hour and up to eight hours prior to the present time. Both displays are enhanced by status messages which reveal certain physical aspects about the patient whether they be past or present. Alarms are also displayed on the screens when they occur.

The background portion of system processing is responsible for initializing the accumulation of trend data for each patient (user). It is usually performed after the real time processing for each user, but may be initiated or continued whenever the executive deems it necessary. There are one hour and eight hour buffers associated with this operation.

The real time processing portions of the system consist of "levels". These levels are called zero, one, two and three. There is also an additional background level. Level zero previously has been referred to as the executive. It performs the highest priority task of the system and that is the execution of the AZTEC microprogram (which reads the ECG data from the patients). Level zero initiates and terminates all other level processing.

Levels one, two, three and background are functionally oriented. Level one does rhythm diagnosis using the accumulation of statistics gathered from the waveform by level two. This seems illogical but details of the program provide for the running of level two a specific amount of time before level one is allowed to run. Level three generates status messages on the video screen along with the current ECG waveform and other enhancements for each user. Level three also handles the display of trend and background data whenever the system's operator desires it. This is the distinct difference between level three and the background portion of the system: the background only initializes and accumulates information and it is left to level three to generate the display for it. A more detailed discussion on the levels of operation is presented later in this chapter under the heading "Levels of Operation".

As with the AFIT program, the HP system takes an input waveform (ECG) and performs a mathematical transformation on it. It then extracts the most vital characteristics from the waveform so an analysis may be performed. These are the primary functions of the AFIT and HP programs and the following is a discussion of these functions.

Preprocessing Programs

The real diagnostic capabilities of the existing computer programs for the automatic interpretation of cardiac arrhythmias are being tested in a small number of hospitals across the nation at this time. One of the problems which contributed to the belated applications of the programs was a poor definition of the quantitative criteria necessary to generate reliable identification of different types of arrhythmias. This was due to the lack of a sufficiently large number of well selected cases of the most common types of arrhythmias. Another reason is the difficulty of detecting ECG waveforms on a beat-to-beat basis and over short segments of ECG recordings. Finally, there are still serious problems associated with the information content on the ECG signal itself, especially with regard to the occurrence of atrial events. The P wave is of small amplitude and difficult to detect. In some instances it may be masked by the QRS complex or superimposed on the trailing T wave in several types of arrhythmias (Ref 9:370).

This last problem shows the importance of the preprocessing program. The transformations performed on the data must reduce the amount of information to be processed by the digital computer, but it must not eliminate the essential characteristics of the signal. The two transformations involved in this study are the Walsh and the AZTEC which are employed by the AFIT and HP programs, respectively.

Within the HP system, the AZTEC transformation is located in a microprogram which also performs the I/O associated with the ECG. Being a microprogram, AZTEC is able to process a greater amount of data than if it were programmed in the usual fashion. This is indicated by the number of users that can be serviced by the system at one time (16). AZTEC interacts with the rest of the system by means of two large buffers for each user. One buffer is a circular buffer which is one hundred and twenty-eight words long. The second buffer is twenty-eight words long and serves as the dynamic memory area for AZTEC. This buffer allows for two-way communication between AZTEC and the HP 78220 software.

The AZTEC program is activated by a clock interrupt located in the control box. AZTEC requires a few micro-seconds to process a previous sample. The first sample V_o, sets initial conditions on two limits:

$$V_{max} = V_{min} = V_o \qquad (1)$$

Samples obtained at subsequent interrupts are compared to these limits. If exceeded, a limit is replaced by the voltage just sampled. As long as the difference between the limits ($V_{max} - V_{min}$), does not exceed an experimentally determined threshold, the fluctuating voltage is considered to be adequately represented by a constant voltage or "line", midway between the limits (see Appendix A for notation and a compact description of the processing algorithm). When a sample necessitates separating the limits by more than the threshold, the preceding average of the two limits is stored in the memory of the computer and called the value (voltage) of the line. The time since the limits were initialized is stored as the duration of the line (Ref 8:128). The line information is stored as a "line entity" which uses bits 0-8 of a program word for voltage and bits 10-14 for duration while 9 and 15 are clear. A "pair" of data words describes an entity.

When the difference between the voltage limits exceeds the threshold and a pair of data words is recorded, the process is restarted by setting V_{max} and V_{min} equal to the latest sample voltage. When a signal of higher frequency and amplitude such as the QRS begins, the voltage samples will change rapidly. Lines of short duration will be formed. A series of lines, each containing four samples or less, is considered to be adequately represented by a constant rate of voltage change, or slope. This is true as long as the voltage difference between adjacent lines does not change sign. The slope is terminated by a line longer than four samples or a change in signs. The slope duration and the voltage between the lines bounding the slope are stored (Ref 8:128). The slope entity uses bits 0-9 for change of voltage and bits 10-14 for duration while bit 15 is set.

Figure 2 illustrates an ECG signal and its resulting AZTEC representation. The data reduction is about a rate of ten to one. The high frequency but low amplitude noise is interpreted simply as a line as long as the peak to peak amplitude does not exceed the threshold. The QRS complex wave consists of seven AZTEC word pairs, four of which are slopes (Ref 8:129).

The AZTEC microprogram also detects paced beats. These occur when the user is aided by an artificial pacemaker. There are two kinds of pacemaker spikes. One is the every interval spike which coincides with the normal interval between QRS waves (or R-to-R interval). Another is the demand pace spike

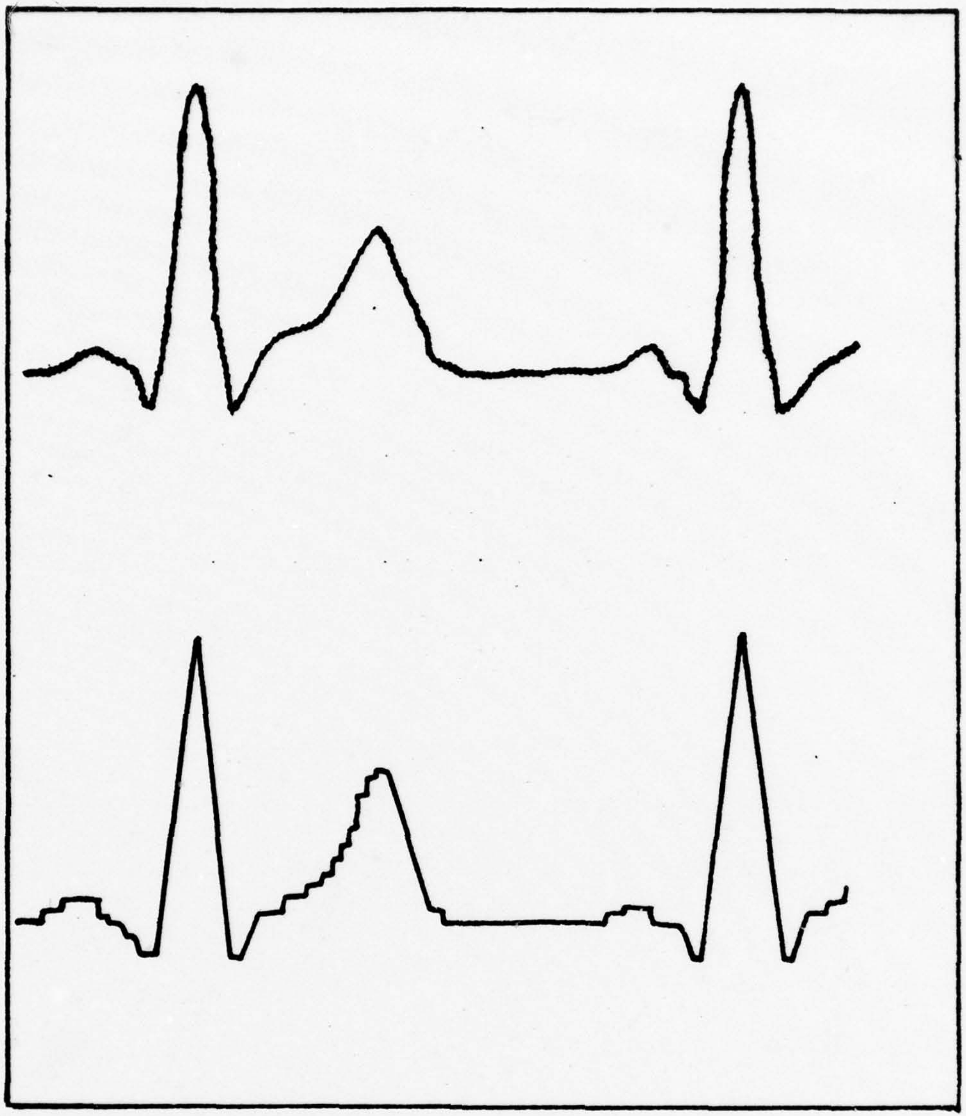

Fig. 2. ECG: Sampled at 500 samples per second (top) and resulting AZTEC representation (bottom)

which engages only when the normal R-to-R interval has been exceeded. The paced entities use bits 0-8 for voltage and bits 10-14 for duration while bit 9 is set and bit 15 is clear. The details explaining the morphology behind the paced entity could not be found by the author of this thesis. It is assumed that the line and slope information and the known fact that a pacemaker is in use, is used to produce a paced entity.

The previous description of the AZTEC preprocessing program indicates that there has to be a close association between the AZTEC microprogram and the analog-to-digital converter that is part of the system. However, this is not the case when the Walsh transformation is applied by the AFIT program. Referring to the work done by Ditucci (Ref 2), a location algorithm (finds peaks of R waves, the beginning of Q waves, and the interval between located peaks) is applied to the waveform first. Then the R wave peak identified by the location algorithm is used as a reference point in forming a 128 sample data vector that is to be transformed. This data vector covers 37 ordered samples before the peak R wave of the QRS complex and 90 ordered samples after (Ref 2:14). This analysis showed that the low sequency Walsh coefficients were the only ones needed to recognize the discriminating features between a QRS complex and a PVC (see Appendix B for subroutine used for Walsh transformation, Ref 2:73).

Therefore, it can be seen that the Walsh transformation is applied directly to the area of the waveform that is of the most concern to the analysis being done. It does this with the help of a location algorithm. The Walsh transform samples all the data within this area and filters out the low sequency components which are essential. This means that relatively all the data is sampled and is therefore available to the rest of the program. The AZTEC transformation is applied to the input data immediately and records only changes in the data to achieve a tremendous data reduction. This means that the rest of the HP system has only this reduced data to analyze, thus making the selection of distinguishable features more formidable and for certain events, perhaps impossible.

At this time, the thought of replacing the AZTEC transformation with the Walsh may seem feasible because of the increase in the preferred data that will be processed. However, it should be noted that seventeen program modules are believed to be incorporated in the HP system used at Kettering Memorial Hospital. Remember that the AZTEC transformation is part of a microprogram which also handles ECG I/O. It must communicate with a number of system modules to accomplish certain tasks. A discussion on the relationship between the modules will clarify the matter.

System Modules

Within the program modules, many techniques which are used by cardiologists are incorporated into the analysis of the ECG waveform. Numerous routines are present which cover the physical condition of the heart. In addition to this, the differences between the conditions are not completely separated in some instances. Many exits from routines are based on a chain of circumstances, all of which must exist. The description of these processes involve running accumulation of counts and hysteresis, which is used to determine what the normal heart rate is from previous calculations.

Even though the program consists of separate modules which should simplify the breakdown of the system, the inter- and intraconnections inside and between the modules makes this program anything but easy to follow. However, to discover the effects of the AZTEC data which flows through the system, an understanding of module interaction must be obtained. To accomplish this task, two aides in software analysis will be used. They are the bubble and structure charts.

The first-cut of the bubble chart illustrated in Figure 3 shows an elementary version of the system configuration. In particular, the bubbles entitled "Signal Verification", "Beat Separation" and "Diagnosed" are related to two of the levels of operation previously referred to as level one and level two. Level one performs the diagnosis on the beat and sets alarm conditions while level two is concerned with signal verification and the grouping of beats into "families" with the same morphology.

The AZTEC microprogram performs some user oriented tasks when the user is first connected to the system. The data is transformed into AZTEC entities which are tested for reliability. Certain conditions including an unprocessable entity, a buffer overrun (AZTEC buffer), or an out of range signal are subsequently tested for. Then the resulting valid AZTEC entities are separated into beats consisting of P waves, T waves, QRS complexes and pacemaker spikes. These beats are placed into families depending on beat morphology. The beat is individually

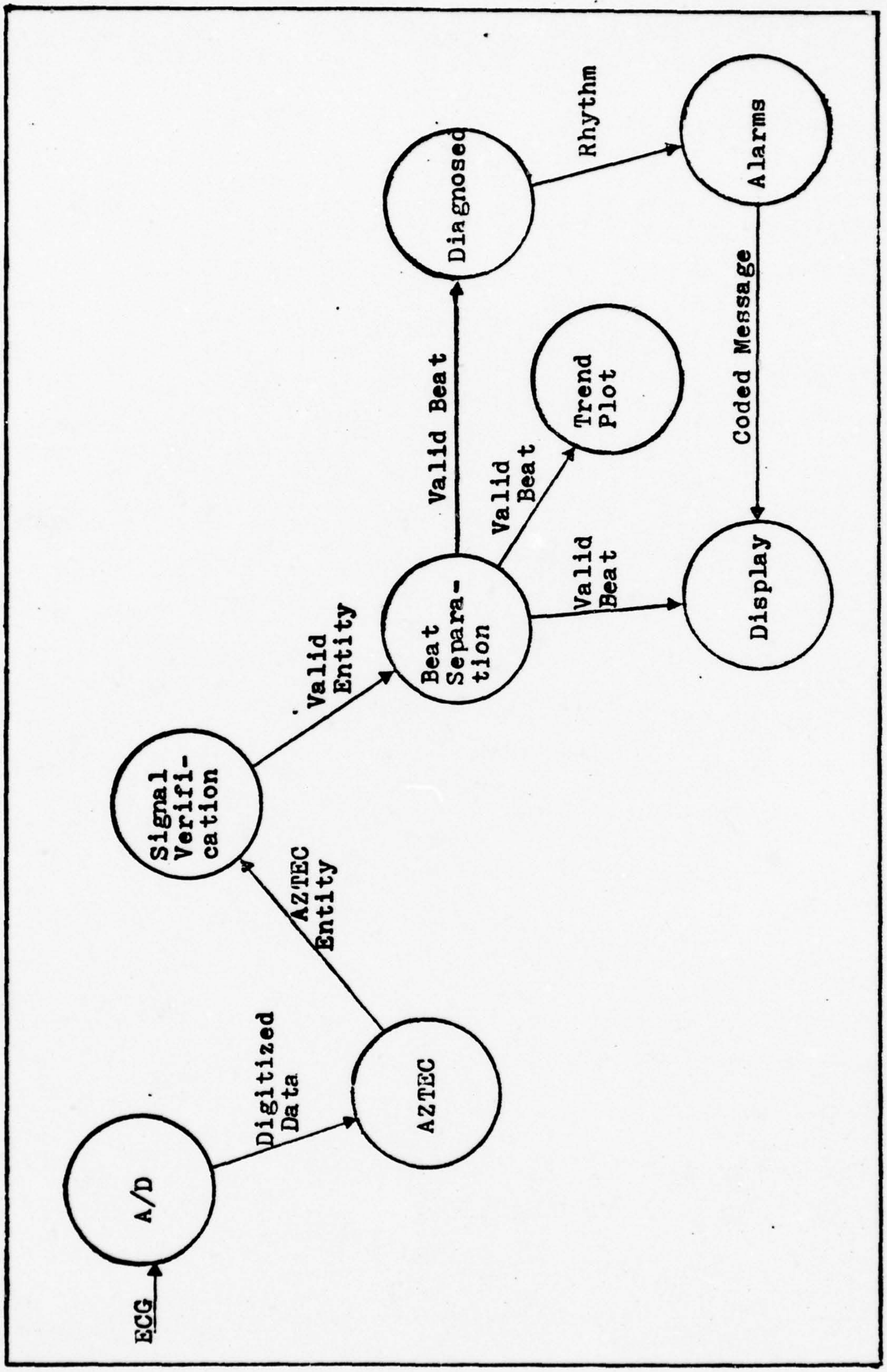

Fig. 3. First-Cut Bubble Chart

diagnosed and statistics are accumulated. Next, these valid beats are diagnosed as an ECG waveform and rhythm messages are generated and alarms are initiated. During this sequence of events, valid beats are accumulated in background processing (trend plots), or they may be displayed on the video screen.

In Table I a listing of the system's modules is presented with a brief description of each one. The structure chart, illustrated in Figure 4, shows the hierarchical formation of the modules in the program. The structure chart is derived from the system's bubble chart (Fig 3). In addition, the HP system description (Ref 4) and software program (Ref 5) were also used (AZTEC microprogram is implicated). A first look at the structure chart gives the impression that the module named MONIT is the executive of the system. Note that it has been previously stated that the system's organization is divided into three categories with the system initialization being one portion. In the sense that module MONIT contains the initialization routines and sets overall system parameters, it is the "executive" of the system. However, MONIT's control does not directly concern the real time processing or the background portion of the system. This control is implemented directly by module LVLO. LVLO's functions include, maintenance of the time-of-day clock, allocation of time to each user and swapping of each user's data segment. LVLO functions rely on parameters set in MONIT.

In the structure chart, it can be seen how LVLO directly controls the four levels of operation (keep in mind the fact that the collection and buffering of real time data is performed

Table I

System Module Descriptions

Module	Description
MONIT	performs system configuration; initialization
LVLO	performs real time data input; user swapping; maintenance of time of day
LVL1	contains executive for level one; initializes most of the memory unique to each user
DIAG	performs diagnosis of ECG; generates rhythm and status messages
ALARM	performs alarm processing
TPSAV	saves trend information
GOPLT	draws trend display
LVL2	contains executive for level two; verifies ECG signal
QRSP	performs beat detection and measurement
BEATD	performs beat diagnosis
LVL3	generates the system status display
BINIT	initiates background processing
CLOCK	sets time of day under user control
FGRND	determines who gets display
FLASH	contains programs for background enhancement of status display
BSUBR	utility subroutines for background
DSPLY	contains subroutines for background text

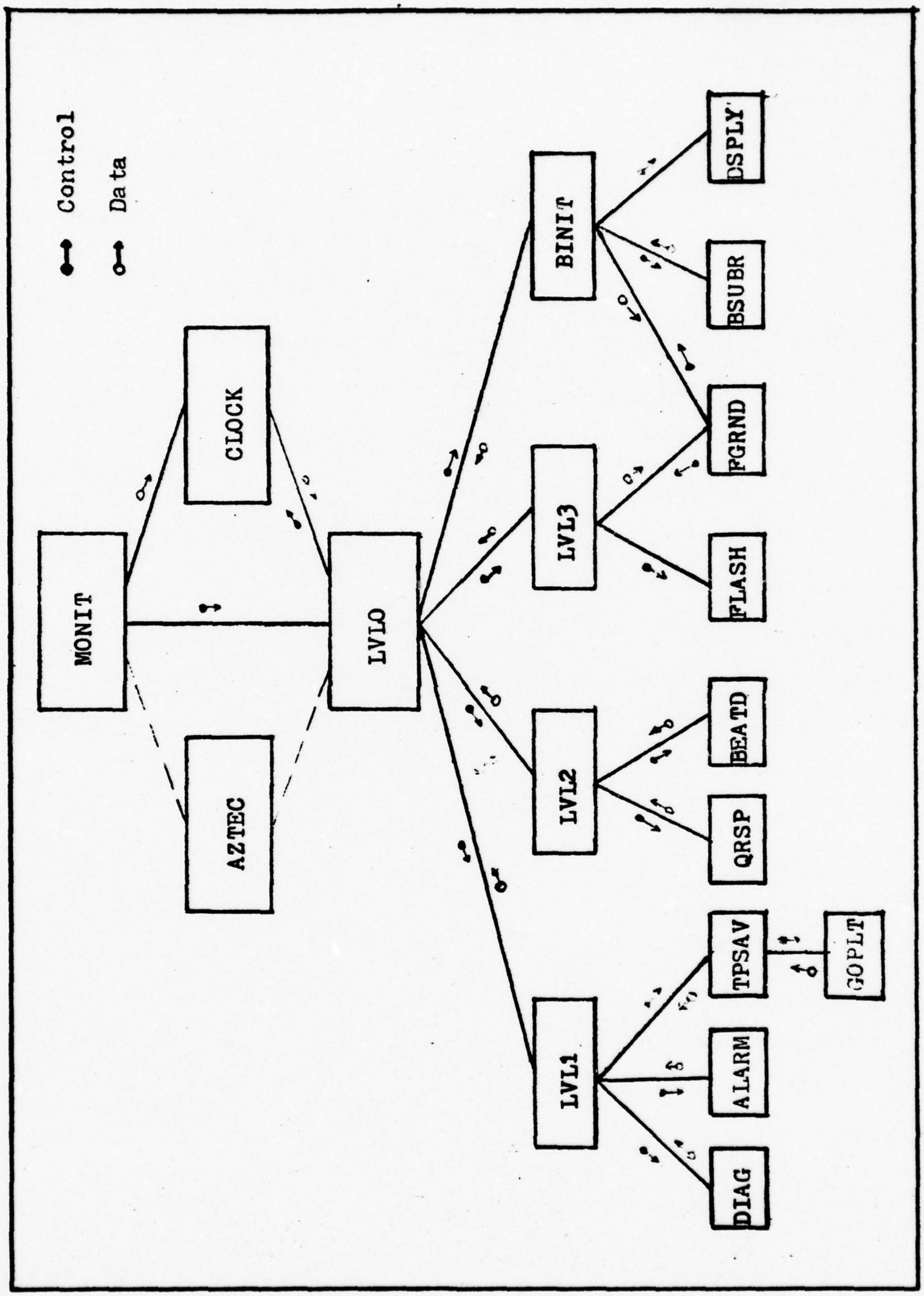

Fig. 4. Structure Chart

in this module). Small executive routines for each level controls the initialization of the subordinate modules for each level. These modules in turn may call modules that are subordinate to other levels. For example, module TPSAV (saves trend plot) may call module GOPLT (draws trend plot), yet GOPLT may call BSUBR (background subroutines) which is subordinate to module BINIT.

The fact that these modules are at the bottom of the structure explains the use of them by other modules. Since the physical display screen is shared between real time and background portions of the system, this coupling effect is produced. This greatly inhibits an understanding of the flow of data through the system. Yet, there is a clear distinction of the presence of particular levels that operate on the data. By examining these levels, a new insight to the data flow will be achieved.

Levels of Operation

The investigation of each module's use of the AZTEC data is a long and tedious job because of program size. Knowledge gained from a detailed look at the levels of operation provide the key to understanding the flow of data and control. Since an adequate description of each level of operation is found in the documentation provided by the Hewlett-Packard Corporation (Ref 4:48,52,77,118), there will be no attempt to describe in detail what each level does. The importance of this discussion pertains to the sequence of level processing.

The normal flow of processing for a single patient (system has been running for some time and the patient is functioning correctly) is the running of levels one, two and three consecutively with level zero initiating each one. However, in describing the sequence of level processing, many variables must be considered. Inasmuch as the levels of processing are numbered zero, one, two, three and background, a first assumption is that this order of succession is followed in all cases. However, this is not true. There are certain conditions that must exist before particular levels of processing may be engaged. A brief description of an example will explain this point further.

The system clock, located in the 78221 controller, generates 250, 4mS clock ticks per second. Level zero (LVL0), which divides the time slices issued to each user, is entered 250 times each second via a clock interrupt from the controller. One may ask, "What causes a lower priority processing level to be interrupted by a higher priority processing level?" The level zero executive determines which level of processing is to be initiated for a particular user providing certain circumstances exist. For instance, in an eight user system level zero despatches thirty-one clock ticks to each user. Level zero is entered the first few microseconds of each clock tick. It determines which level should be in control and also initiates the collection and buffering of the real time AZTEC data. In the particular case of system initialization, where the user is processed for the first time, level one is bypassed and the learning routine is run ("learning" means that for one or two minutes the system will assimilate the patient's normal beat morphology). This guarantees that a certain amount of AZTEC data is processed before level one does any diagnosis.

Deviations from the normal processing flow occur for any single patient given certain conditions. In relation to the above example, level three will run usually after level one and two have finished processing, but it may be initiated before levels one and two can be completed. This happens when certain conditions exist that cause exits from levels one and two. There are two primary conditions for leaving level one. One is a test of the Least Significant Bit (LSB) of the time-of-day clock and LSB of the user number. If the numbers don't match, control is passed to level two of the next user because odd numbered users are supposed to be processed during the odd seconds of the time-of-day clock. The other condition for exiting level one is when a user's monitoring status is set to learning. Control is passed to level three where the appropriate message is displayed. Similarly, a noisy or chaotic signal will cause an exit from level two. The code for a noisy signal will appear on the foreground display.

As stated before, this sequence of events is by no means a standard but it does depict the complex order of changes in control. In addition to this, optimization techniques are introduced to service users that make excessive demands on the system. A potential modifier of this system might ask, "How do 'levels' of processing enable the system to provide quick response to extraordinary patient conditions?" This is accomplished by level zero. Level zero allocates additional time (clock ticks) to users who had not completed processing during their last time slice. The last two clock ticks of each user's time slice is dedicated to background processing. Therefore, any user who finishes processing and has more than two clock ticks remaining in its time slice, will be terminated by level zero and a user who had not finished will resume execution for the remainder of that time slice (for details see Ref 4:6). This feature is needed for ECG signals such as irregular rhythms, and sinus tachycardia (fast heartbeat). These signals are difficult to process.

The preceding information can be unclouded by introducing timing diagrams. Since all of the possible situations cannot be depicted on any one diagram, only two will be shown. In Figure 5 the four-millisecond system clock is pictured at the top. The level zero pulse is shown for each clock tick, and the sequence of level processing which is common when a user is being put on the system for the first time. Note that the diagram depicts a view of one user who has a given time slice of fifteen clock ticks.

In Figure 6 the diagram shows how the data lines are multiplexed along with the scheme of bed addressing (Ref 4). Inverse logic is used in the diagram which shows what states the bits must be in before valid AZTEC data is obtained. The figure is discussed at this time because it is believed that AZTEC data is accumulated and stored for each user, then level zero calls forth this data which is used in level processing.

There are many phases of level processing. A generalization of this procedure (which places level zero as the executive and levels one, two, three and background as subordinates) has been given. Since the foreground part of the program is

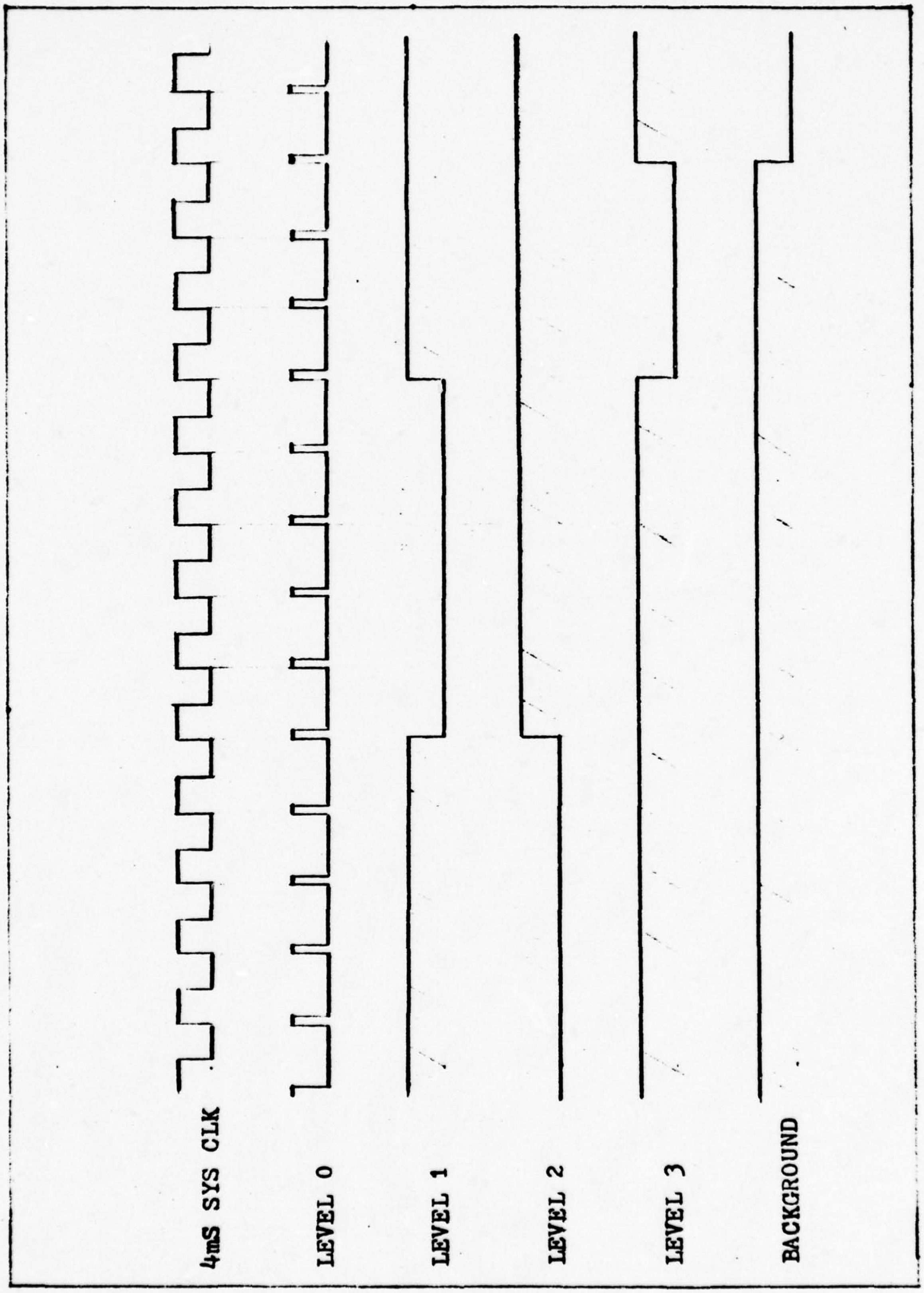

Fig. 5. Level Processing: Typical for user hooked up for the first time

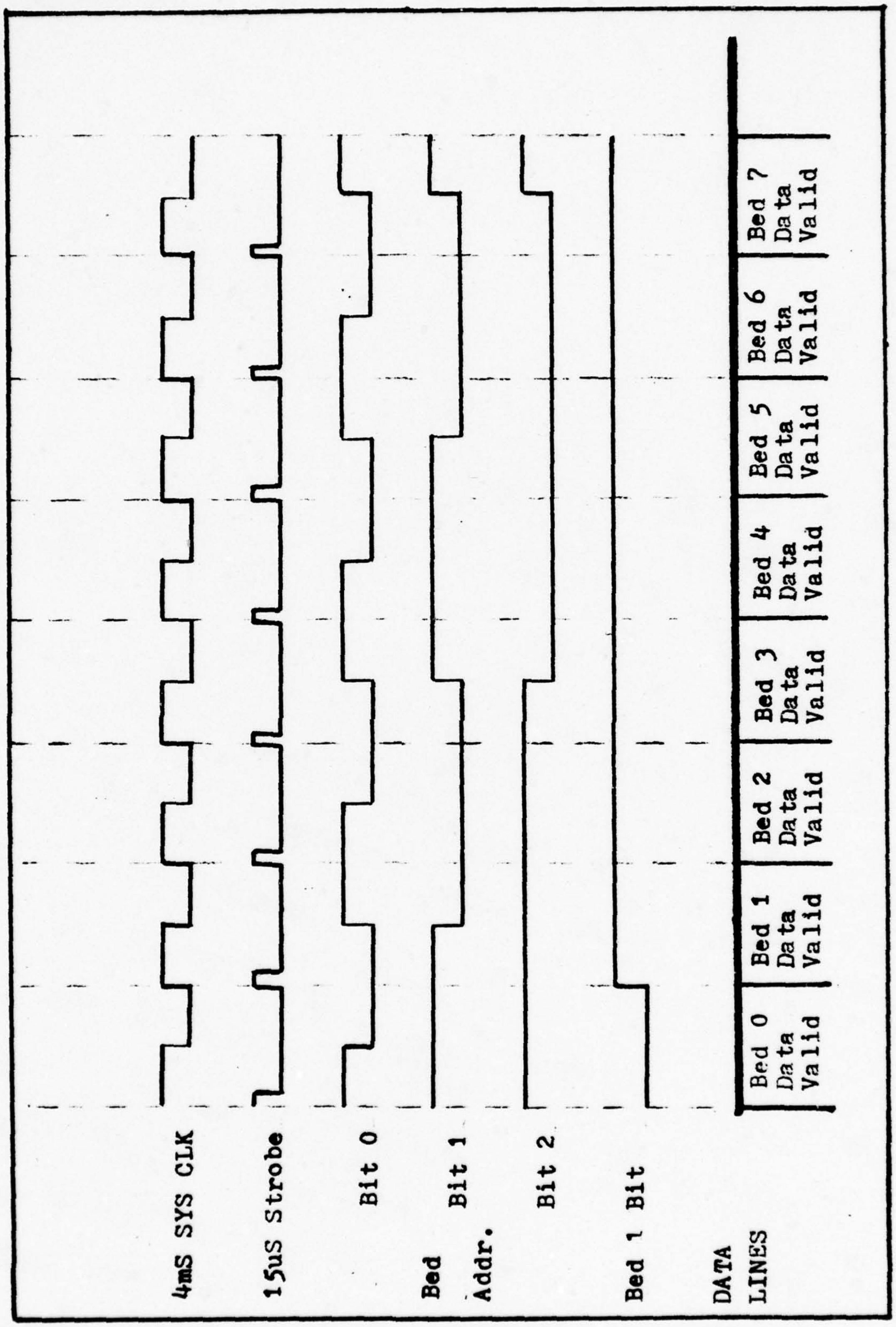

Fig. 6. Bed Addressing And Data Transfer Timing

of primary concern, levels one, two and three must be investigated as to how control is passed between them.

Control. The fact that levels one, two and three are individually interruptable, makes the description of control flow complex. The priority of the interrupts is such that level one may interrupt level two and level two may interrupt level three. In the passing of control, each level is assigned a register save area of four words. The register save area contains information necessary to resume execution of each level where it was last interrupted. A location labeled RSVAD is assigned the address of the save area by a small executive program for each level (Ref 4:8). The "level executive" executes with interrupts off before the initiation of that particular level. These small executives aid in the transfer of control between the levels.

An examination of the HP software programs (Ref 5) and description (Ref 4) shows the entry and exit routines utilized by level processing. Concerning the passing of control to level zero, it is assumed that two procedures exist. In the first way, module LVLO is entered via a jump instruction, to label "LVLOO", initiated by the trapcell in the 78221 control box. This association is explained by the fact that LVLO collects and buffers AZTEC data which is generated by the controller, the A-to-D converter and the AZTEC microprogram. The second case for entry into LVLO involves MONIT passing control to label "TREND" in BINIT with interrupts off to initialize memory. After this, interrupts are enabled and the next clock interrupt causes entry into LVLO. This is explained by the functions performed at system initialization. The background is initialized before real time processing is begun. At label "NOSWP" (Ref 5:5) of module LVLO, a jump to LVL2E instruction passes control to the exit routine in level two. This routine then passes control to level one.

Programs exiting from level one processing jump to label "LVL1X" (Ref 5:5) of module LVL1. The "LVL1X" routine ends with a jump to level three. Conflicts exist between the program and the HP description. The description (Ref 4:53) states that, "control is passed to level two with interrupts off". In this case, the wording of the program is accepted as correct. The description (Ref 4:52) states that when the least significant bits of time-of-day second counter and the user number do not match then control is passed to level two. A thorough investigation of the program module presents no evidence of this routine. The search was limited to the area where the description said it could be found. The routine may be located elsewhere or in another module.

In module LVL2 (Ref 5:3) a test is made to see if the user is on line; if not, a jump to the exit routine LVL2E is performed. This routine transfers control to label LVL1E which is the entry point for level one. Also in module LVL2 (Ref 5:8) there is a jump to label LVL1E in module LVL1.

The description (Ref 4:118) states that if the background has control of the display, then control is passed to label LVL3Z to exit from level three. This exit occurs because no display functions can be performed by level three under this condition. This routine is located in module LVL3 (Ref 5:15) and jumps to the subroutine labeled "RREGS". "RREGS" is in module LVL1 (Ref 5) and is used by all three levels tc resume execution after an interruption.

The understanding of these small executive routines will enable a programmer to incorporate changes into the program without disrupting the normal flow of control between the levels of operation. Referring back to the structure chart (Fig. 4), it can be seen that changes in the modules subordinate to modules LVL1, LVL2 and LVL3 would be needed to alter the HP identification algorithm. Also the data which is used by these subordinate modules should be discussed with respect to the overall data structure of the HP 78220 Arrhythmia Monitoring System.

Data Structure

The "levels" of processing enable the system to handle more than one person because the real time processing done by this program is accomplished by multiprogramming. The same functions are performed for every user of the system in the same manner and using the same area of memory. The data associated with each user is swapped in and out of a designated area called "working storage". All data related functions are performed in this section.

All the data associated with the HP program is located in one module entitled COMNS. This module is found attached to the end of each program module. It is a common source module which defines the HP monitoring system microprogram instructions and the addresses of all variable storage. Whenever a system modification requires the redefinition of any variable storage or microprogram instruction, this module must be modified. It must then be appended to each module and be reassembled. The first line of this module contains a comment which starts with *$$ and contains the date of the last modification (Ref 4:15).

The module COMNS is presently arranged so that system macro-instructions occupy the first section. These instructions were created uniquely for the 78221 system from existing micro-instructions. The next section is called "working storage" which is used by the real time programs. The next section is called executive storage, which contains variables global to the entire system. This is how the module is arranged physically in memory. In the actual software program, there are just two distinct sections: one being the macro-instructions and the other an alphabetical listing of the variables. The section which is most important to this study is the working storage.

The working storage area is the same for all users, but its contents are unique for each user. When the user changes, all the information in working storage is moved out into a holding buffer and the next user's data is moved in from a holding buffer. This swapping is accomplished by module LVLO.

The segment containing the swapped data must be ordered in such a way as to facilitate the functions performed on the data, as well as preserve the read only nature of the program. To make this statement more understandable, a description of the working storage will be given at this time. Figure 7 is a pictorial representation of the working storage with the beginning variable of each section.

First Variable	Section
MNTM1	Temporary variables for MONIT and contants unique to each user
EPSAD	Level zero addresses
TB1AD	Locations within trend plot buffer
L1SAD	Register save areas for all levels
POPAD	Pointers to arrays
UDSLC	User X and Y coordinates of status display
SWTCH	Global storage for all levels
ZERPT	Storage used by level one
HRSW	Permanent storage for level one
SIGCT	Storage used by level two
DSRTN	Permanent storage for level two
OLDAL	Storage used by level three

Fig. 7. Working Storage

The first section of working storage includes temporary variables for module MONIT and constants that are unique to each user. MONIT uses four variables at system initialization. The "user constants" involve the "user number" associated with the user currently occupying working storage. The rest of this section is mostly address constants.

The next section involves level zero addresses that point to locations within the AZTEC control block for the particular user being processed. The AZTEC control block is used by the AZTEC microprogram to store information and communicate with other parts of the system. For example, level two programs (accumulates statistics) extract information for data input processing from these level zero addresses. In other words, the AZTEC data is gathered and analyzed via this section.

The next block of addresses points to locations within the trend plot buffer for a particular user. There are two circular trend plot buffers; one for the most recent hour and one for the eight hours before the current hour (Ref 4:17).

The next block of addresses point to the register save areas of levels one, two, and three. Since each level is interruptible with priority decreasing from one to three, there is a need for their register save areas so that processing may be continued at the point of interruption (Ref 4:17).

The next block points to arrays which are used by the various processing routines. The remaining words in the constants section are user oriented in that they denote the X and Y coordinates of the origin of the status display area for a particular user. Also, contained within this section is storage for the generation of the status display using the HP-21MX microcode. Note that this storage should appear with level three storage to adhere to the scheme of the data module (Ref 4:17).

Next, is a block of global storage which is used by all levels. These words are used to indicate the state of various parts of the system. Also, the location labeled RSVAD is found in this block which holds the address of the register save area for the user currently executing.

The next section includes storage used by level one programs. The first two words labeled ZERPT and ZERRT are used by the memory initialization routine which sets the user working memory to zero. Closely related, but separate from this section, is permanent storage used by level one. This is the storage that must be maintained between transfers to other levels from level one.

The next section is level two storage which is organized the same as level one. The last portion is level three storage which is similarly organized. This signals the end of working storage where afterwards there is found the executive storage with variables global to the entire system (Ref 4: 19).

Within the structure of the working storage the capability of interaction between levels is indicated by the separate storage areas and register save areas. This is similar to the separation of each user's data segment. Both the levels and the users may resume processing from the point of the last interruption. This fact illustrates two types of "exchange jumps". An exchange jump is a program exit in which the states of various working registers and variables are stored in a save area so that processing can resume later in exactly the same state that is was left.

This information on the working storage is very important in that it provides a basis for understanding how the real time processing is accomplished. The various functions of the program can be categorized and correlated with certain sections of working storage. These same functions may also be associated with functions performed by the AFIT software program. With this awareness, particular variables of both programs can be singled out. These "links" (variables) should narrow down the investigative process to a point where it is a feasible task.

III. Considerations for Modifications

The purpose of this chapter is to discuss the significant aspects pertaining to the modification of the HP 78220 Arrhythmia Monitoring System with respect to the AFIT monitoring software. These aspects include:

1. Identifying all the routines that expect AZTEC encoded data;
2. The modification or replacement of all the routines identified in statement one;
3. Replacing the AZTEC microprogram with the equivalent Walsh I/O microprogram;
4. Checking the buffer sizes and processing times;
5. Identifying the considerations for transfers and exits between levels.

Provisions

To identify all the routines that process AZTEC data, the "Bubble Chart" (Fig. 4, page 21) is utilized. In the chart, it is shown that AZTEC entities (coded data) are sent through a "Signal Verification" phase and a "Beat Separation" phase. The signal verification phase involves software module LVL2 which tests signal quality. Beginning at label SCAN, the rest of the code in LVL2 is devoted to testing the quality of the coded data. Tests are performed to determine if the user is in the operating mode; buffer overrun; out of range ECG and other signal conditions.

The beat separation phase involves software module QRSP which processes the AZTEC entities from the signal verification phase. Module QRSP detects beats and measures their features.

Routines for deriving the normal R-R interval and the search area for the other waves are included in QRSP. The features measured by QRSP are used in the analysis performed by the "Family" subroutine.

The AZTEC encoded data is also used by module BINIT. Background programs, including modules BSUBR and GOPLT, have been designed to process ECG data from the control box via the AZTEC microprogram. BINIT, BSUBR and GOPLT process AZTEC coded data for use in background trend plots.

The second aspect of "modifying" or "replacing" all of the routines mentioned above could be accomplished by a detailed investigation of the modules and routines listed previously. From a limited study of modules LVL2, QRSP, BINIT, BSUBR and GOPLT, replacing the modules is not necessary unless the routines are written in such a way that processing is prohibited when AZTEC coded data is not present. If replacement is unnecessary, only the AZTEC line and slope entities will have to be modified into appropriate values that the routine can utilize.

The routines of modules LVL2 and QRSP perform calculations on the coded data to obtain values for the width, height and offset (space between preceding beat) of beats. The numerous calculations to obtain these values indicate that replacement of these routines is probable if the Walsh transform is used. Modules BINIT, BSUBR and GOPLT consist of routines that process the coded data into an ECG waveform that can be displayed on the system video screen. Since fewer calculations are performed on the data, it is more likely that these modules will be modified and not replaced.

Replacing the AZTEC microprogram with the equivalent Walsh I/O microprogram is a realistic task. The HP microprocessor has a usable microcode (with additional address space) and debug software packages that encourage a user to write microprograms. Writeable control store (WCS) cards can be loaded with up to 256 words (one module) and up to four cards may be used with the HP 21MX. Therefore, ample space is available for the microinstructions of a Walsh microprogram. In addition, the Walsh microprogram could be placed in nonvolatile programmable read only memories (PROMs) with the aid of a high speed PROM writer support system developed by HP. With HP microinstruction format manuals, a suitable Walsh microprogram can be created.

Checking the buffer sizes and processing times of the Walsh microprogram will have to be accomplished by actually executing the program. Testing for buffer overrun of the present AZTEC buffers will provide the information needed to determine the appropriate size of the Walsh buffers. Timing depends on how long it takes the Walsh microprogram to provide the data needed by the rest of the processing programs. Examining the amount of data within the Walsh and AZTEC buffers after a specified length of time will provide a comparison of processing times. If necessary, manipulation of the Walsh microprogram can speed up or delay the access of data.

Identifying the transfers and exits between levels should be considered because of the different identification algorithms used by the HP and AFIT software. The HP system transforms (AZTEC) the ECG first and then performs a diagnosis. The AFIT software locates the waveform (QRS complex) and then performs the transformation (Walsh) to obtain discriminating features. Knowledge of the level exit and entry routines will aid in modifying the structure of the HP software. The routines are labeled and can be called at any time to alter level processing. This will aid in changing the HP system by allowing the location program to run before the transformation of the data. For example, at label "NOSWP" of module LVLO, a jump to LVL2E instruction transfers control to the exit routine in level two. Since level two processing locates waveforms, the jump instruction to the exit routine could be changed to the entry routine (label LVL1). This would simulate the technique employed by AFIT.

Entry and exit routines were located and described in the "Levels of Operation" section (page 25). To aid a would-be programmer, a concise listing of these labeled routines and their functions are given:

1. LVLOO-entry point for module LVLO
2. TREND-exits to module LVLO
3. NOSWP-exits to module LVL2
4. LVL2E-exits to module LVLO
5. LVL1X-exits to module LVL3
6. LVL1E-entry point for module LVL1
7. LVL3Z-exits to RREGS in module LVL1

The aspects discussed in this chapter should be considered when modifying the HP system. Tracing the AZTEC data, replacing the AZTEC microprogram and checking the buffer sizes and timing are all essential considerations. Along with identifying transfer and exit routines, these considerations are the most significant to the modification process.

IV. Conclusions and Recommendations

Conclusions

Specific conclusions must be based on the information gained from the investigation. Information pertaining to the HP program structure leads to the conclusion that modifications to system modules are encouraged by the read only nature of the programs. There are routines which assist the programmer in modifying the operating modules and the data module. Only the data module (COMNS) must be modified if variables are changed in any other module (the data module is appended to all modules). However, the replacement of a software module is more difficult because all new variables must be defined and placed in the appropriate section of the data module. This condition exists because of the read only nature of the programs. Therefore, complete modification is given assistance by the program structure.

The level processing structure is used so that a multiprogramming situation can be assimilated by the system. This enables the system to process a large number of users at one time. The analysis of this level structure shows that it is the most efficient way of processing multiple users and should be incorporated into the AFIT software.

The program and level processing structure are both effective when employed by the HP processing system. However, the information obtained from the theoretical analysis implies that the integration of the AFIT and HP software is too formidable a task to achieve. This conclusion is derived from the procedure followed by the location and identification algorithms for each monitoring system. Extensive modifications are required to incorporate AFIT techniques into the HP system.

This conclusion can be challenged by the possibility of sufficient manpower becoming available to the would-be modifier. In this case, the HP system could be completely modified. The total worth of the finished product would be a greatly improved HP system with an increased capability of detecting difficult waveforms (P waves).

The analysis performed in this thesis supports the assertion that the HP has a creditable system. There is no apparent need for the design of a completely new heart monitoring system unless it consists of only hardware. A complete hardware system would decrease processing times and increase efficiency.

Recommendations

The present HP system pays little attention to the detection of P waves. It is suggested that the P wave be given more consideration because the P-to-R interval serves as an indication of heart beat synchronization. After a myocardial infarction, the normal P-to-R interval is wider, therefore the heart is desynchronized and less effective firing occurs.

Another suggestion is to provide the present system with an automatic state of relearning the user's rhythm and beat morphology after a number of skipped beats have occurred. The previously learned beat will still be available, therefore the system will have two sets of prototypes to use in beat analysis. This aspect could aid in the detection of some paced beats which are hard to classify.

There are five recommendations that are directed toward the present AFIT software. The first is that more emphasis should be placed on the atrial events of the ECG. It is suggested that a "learning" routine be developed that learns the patients normal P wave just as the QRS is learned. The second recommendation is to add a number of techniques used by physicians to locating and identifying waveforms. The third desirable concept is to provide for the identification of pacer spikes within the ECG using the information gained from the HP programs. The fourth recommendation is to incorporate the level processing and data swapping functions of the HP system into the AFIT software. Since AFIT is still in the software phase of its system, it will be less complicated to modify. Being in the software phase of development makes the fifth recommendation seem distant. However, the fifth recommendation is that a complete hardware monitoring system be developed.

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Appendix A

AZTEC Algorithm

The AZTEC transformation may be described as follows. Let V_i be the i^{th} sample following an initial sample V_o. Let V_{max} and V_{min} be the maximum and minimum values, respectively, of the set $(V_i)_o^m$ where (i) ranges from 0 to m. If V_{max} minus V_{min} is less than or equal to K for the set $(V_i)_o^{n-1}$ and V_{max} minus V_{min} is greater than K for the set $(V_i)_o^n$ then the set $(V_i)_o^{n-1}$ is said to form an AZTEC "line" L. The line L is completely specified by its value, nu(L) = $\frac{1}{2}(V_{max} + V_{min})$, and its duration, tau(L) = n times the sampling interval. Let V_n now be the new V_o and repeat the process. This much of the transformation is called a zero-order linear interpolator with aperture K/2[4]. It has the property that, if L contains the sample V_i, then the absolute value of nu(L) - V_i is less than or equal to K/2.

Let L_i be the i^{th} AZTEC line following a line L_o. The line L_i is said to be a "plateau" if tau(L_i) is greater than T. We call L_i an "extremum" if (nu(L_{i+1}) - nu(L_i)) (nu(L_i) - nu(L_{i-1})) is less than zero. The line L_i is a "bound" if L_i is a plateau or an extremum. A set of AZTEC lines $(L_i)_1^{m-1}$ is said to be a "slope" S if no L_i is a bound and L_o and L_m are bounds. The slope S is completely specified by its value, V(S) = V(L_m) - V(L_o), and its duration, tau(S) = (the summation as (i) goes from 1 to m - 1) tau(L_i). The complete AZTEC transformation then consists of an ordered set of bounds and slopes.

Appendix B

Walsh Transformation Subroutine

```
      SUBROUTINE WALSH(DATA)
      DIMENSION DATA(128),DUMMY(128)
      N = 128
      NN = 128
   99 K = 0
      DO 100 J = 1,N,2
      K = K+1
      L = J+1
      DUMMY(J) = DATA(J)+DATA(L)
      DUMMY(L) = DATA(J)-DATA(L)
  100 DATA(K) = DUMMY(J)
      DO 101 J = 2,N,2
      K = K+1
  101 DATA(K) = DUMMY(J)
      NN = NN/2
      IF(NN.GT.1)GO TO 99
      S = 1./FLOAT(N)
      DO 102 J = 1,N
  102 DATA(J) = (DATA(J))*S
      RETURN
      END
```

Appendix C

Theory of Operation

In Figure 8 (Ref 4) a synopsis of the HP system is illustrated. The controller is shown with the A-to-D interface for AZTEC data processing and the digital interface for alarms and user oriented data. The AZTEC microprogram generates AZTEC entities which are buffered and used by the software modules. The AZTEC working memory is a large buffer where the trend plot data is accumulated. The "History" buffer is background processing.

The "Executive" is level zero which regulates the real time processing. The working memory, microprogram swap routine and the register save area are shown in respect to each other. The rest of the blocks are self-explanatory. The diagram (Fig. 8), as a whole, simplifies a very complex system.

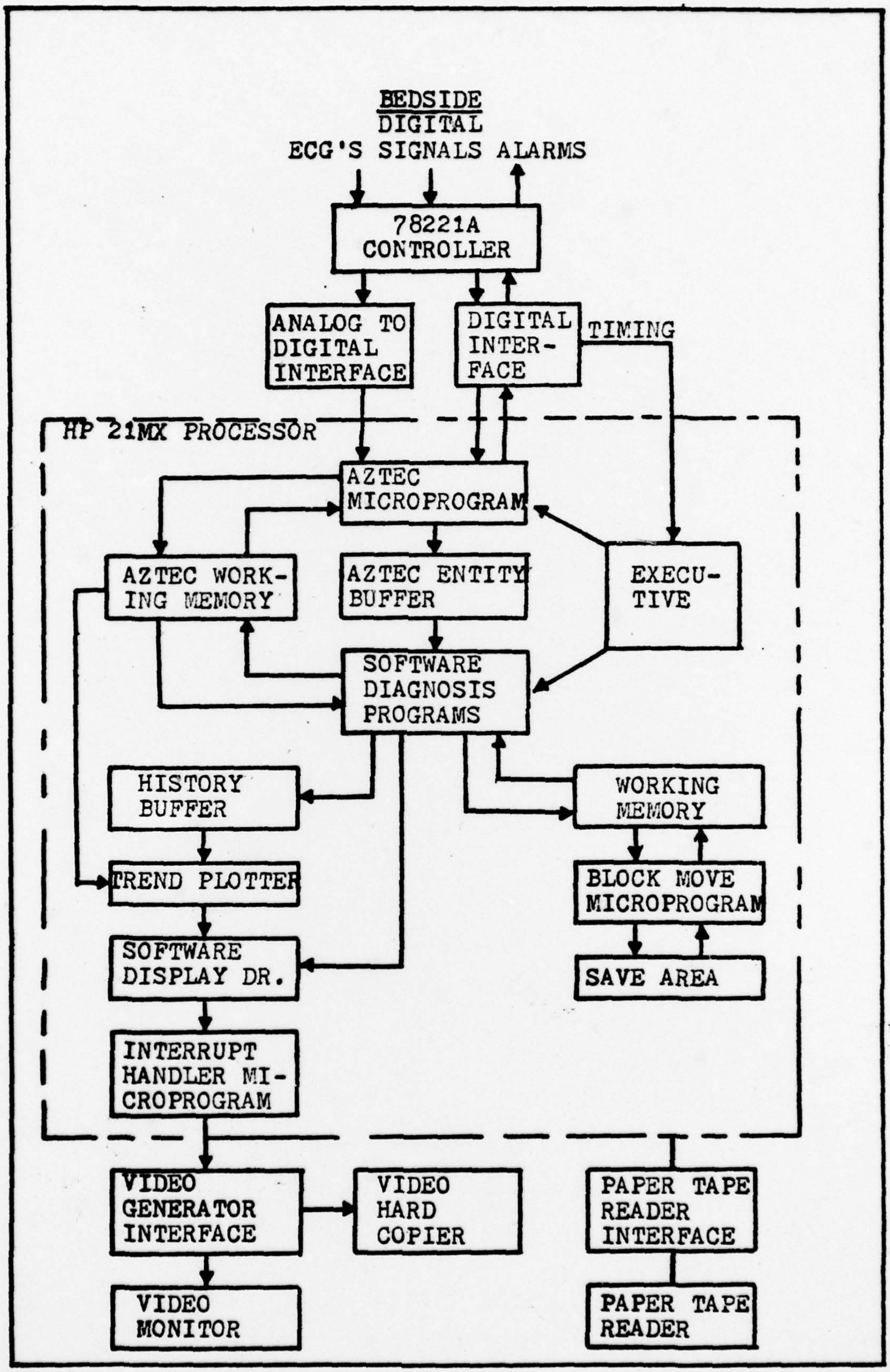

Fig. 8. Overview of the HP System

Vita

Second Lieutenant Samuel L. Harris was born on 13 October 1952 in Birmingham, Alabama. He graduated from J. H. Phillips High School in 1971 and attended Tuskegee Institute from which he received the degree of Bachelor of Science in Engineering in May 1976. Upon graduation, he received a commission in the U. S. Air Force through the ROTC program. He was employed as an electrical engineer for the Alabama Power Company, Birmingham, Alabama. He was called to active duty and entered the School of Engineering, Air Force Institute of Technology in August 1976.

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The Hewlett-Packard (HP) 78220 Arrhythmia Monitoring System is ventricular-oriented and detects the most significant ventricular contractions (PVCs) of Lead II electrocardiograms (ECGs). The HP monitoring software consists of a number of relocatable program modules. The program modules are divided into three main categories. The first is called system initialization, the second is real time processing, and the third is background processing. The real time portion includes the

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AZTEC transformation which is applied to the input waveform and records only the changes in the waveform that succeed some predetermined threshold to achieve a tremendous data reduction. The AZTEC counterpart, the Walsh transformation employed by the Aif Force Institute of Technology (AFIT), evaluates a 128 sample data vector of a located waveform. The low sequency Walsh transform coefficients are used in processing the waveform. The HP system has levels of processing called zero, one, two, three, and background. Level zero is responsible for swapping data segments in and out of "working storage" where real time processing is performed. To incorporate AFIT program characteristics into the HP system, the routines that expect AZTEC data, the level processing transfer and exit routines, the buffer and data storage area along with the timing must be given consideration. An investigation found that the modification of the HP system is not a feasible task at this time.

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