A Signals and Systems and Object Oriented Programming Approach to Development of ECG Analysis Software

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Abstract

A Visual Software Development Framework (VSDF) has been created to facilitate the software coding process of biological signal analysis. A special purpose graphical user interface (GUI) was developed using VSDF for automating the analysis and classification of waveforms in electrocardiographic (ECG) data. Graphing capabilities were included in the program to allow the user to plot the signal as well as trigger location. Object Oriented Programming (OOP) techniques were used in the Java programming language to calculate correlation coefficients between a template QRS complex and detected QRS complexes throughout an ECG recording. The OOP techniques employed in the development of the software package allow visualization of the entire analysis process. The ECG signal, read from a file, is stored into a simple array data structure and is passed to each of the modules. The signals and systems approach allows incorporation of trigger modules, data conversion modules, and numerical analysis modules directly into the software package, providing ease of software design.

1. Introduction

Classic signal processing and analysis of electrocardiographic (ECG) data employs pattern recognition of abnormal waveforms for classification of abnormal beats and arrhythmias. A variety of algorithms have been employed in the past three decades for morphological analysis of the QRS. These include feature extraction of signal parameters such as timing, amplitude, polarity of waveform, and area of difference. Novel methods have been proposed such as signature analysis of the QRS complex [1], polynomial coefficient techniques [2], normalized area of difference (NAD) [3] and amplitude distribution analysis (ADA) [4] as well as frequency domain methods [4]. A signal processing technique employed in our research laboratory (Medical Computing Laboratory, University of Michigan, Ann Arbor) is correlation waveform analysis (CWA), a statistical means for point-by-point comparison of digital data with a normal template [4]. We have used this technique on surface leads acquired from coronary care monitors [5] and intracardiac leads acquired in the clinical electrophysiology laboratory [6]. Software developed in research laboratories such as ours is typically platform dependent, not necessarily user friendly, not easily portable, and must typically be rewritten for a variety of systems.

The software design technique presented in this paper is a modular, hierarchical scheme that can be used to develop generic software packages for biological signal analysis.

Others have addressed this problem for a variety of applications. NEMESIS [7] is an object oriented system, with a highly modular structure, and network friendly interface for use in cardiology telemedicine. CAVIAR (Comparative Analysis of Vectorcardiograms and their Interpretation with Auto-reference to the patient) is an open and modular database management system that supports the acquisition and management of serial ECGs [8]. OODBMS (Object-Oriented Data Base Management System) applies similar techniques to management of temporal clinical data [9]. Twin Expert Systems for Complex Analysis of 12-lead ECGs reports an object oriented system that mimics the cardiologists’ decision-making methods[10].

We have designed an object oriented system development technique for automating the analysis and classification of waveforms in signals such as electrocardiograms, blood pressure data, and electroencephalograms. The modular techniques employed to develop the software package allow vivid visualization of the entire analysis process. The levels of abstraction allow the person developing triggering systems to work independently of the person developing systems which analyze and classify the triggered data. The ECG waveform is stored into a simple array data structure and is passed to the analysis module.

The signals and systems approach allows one to incorporate several different types of triggers and numerical analysis modules directly into the software package. The ECG module currently developed for our software model allows the user to graphically pick a
template QRS complex (by selecting forward and aft
ranges from point of trigger detection) and generate
correlation coefficients with all other trigger-detected
beats in the ECG signal. The user can set a threshold for
the correlation coefficient to classify individual beats as
normal or abnormal.

File conversion utilities were also built into the
program to allow reading (and conversion) of CODAS
(DATAQ Instruments Inc, Akron OH) and our custom
formatted SIG files (Medical Computing Laboratory, Ann
Arbor MI) directly, as well as signal files previously
converted into an ASCII (TXT) file.

2. Materials and methods

2.1. Materials

VSDF software was developed, tested, and deployed
on standard Pentium computers (Intel Corp, Santa Clara
CA). Since the purpose of this project was to demonstrate
software engineering methods as opposed to developing a
specific high-fidelity software package, specifications for
computing equipment were kept minimally sufficient to
run the operating system and compilers.

Java 1.3.1, an OOP programming language (Sun
Microsystems Inc, Santa Clara CA) was used to develop
the software. Using Java ensured portability of the
software system, since code written in Java can be
executed on any platform equipped with the Java
Runtime Environment.

Java’s Swing graphics library was used to develop the
graphical user interface. Additionally, a freely-available
plotting library for Java was used to provide charting
capabilities to the system.

Before developing the modules of the software, the
interfaces, protocols, and data structures were well
defined. Each module was then developed as an
independent identity.

2.2. Methods

The data preparation module consists of all operations
involved with acquiring data, formatting, and storage.
The end-result of this module is to obtain data from a
wide variety of sources (analog/digital recordings, digital
files, live acquisition directly from a physiological
measurement, etc.), transform them into a data structure
defining the notion of a signal in the computer memory.

The standardized format of all signal data subject to
processing and analysis, within a well-defined structure,
affords accessibility by all algorithms/processing
modules. (See Figure 1.)

After data have been prepared and stored in a standard
structure in computer memory, it is ready to be passed to
the algorithms-and-processing module (APM). The APM
module for our ECG software required triggering the
ECG signal for QRS detection and correlating waveforms
against a known normal template. After each QRS of the
signal has been correlated with the template, the
correlation values are sent to the data output module. (See
Figure 2.)

The data output module receives results from the
algorithms-and-processing module. Biological or physiological signals
are passed into the algorithm block. The processed data
are delivered as results.

The data output module receives results from the
algorithms-and-processing module and delivers them in a
format acceptable to the user. Custom outputs, such as
Excel worksheets (Microsoft Corp, Redmond WA), as
well as other file formats are programmed into this
module. Our model for analysis of electrocardiographic

and blood pressure data generated Excel data tables and also plotted them directly in the GUI using a plotting library. (See figure 3.)

The interfaces and data-flow diagrams for each module and sub-module were formally compiled into a specifications document. Documentation is a key component of VSDF and allows the developed modules to be part of the organization’s body of knowledge. As other software packages are developed in the lab, completed and documented modules are available for immediate use to developers and do not need to be recreated. This makes the software design process more efficient by reducing redundancy and produces quicker turn-around time, allowing the developers to focus their efforts on new tasks adding value to their final products.

2.3. Integration

Integration of the component modules was straightforward and the addition of future modules is uncomplicated due to the existence in VSDF of well-defined interfaces, protocols, and data structures. (See Figure 4.)

3. VSDF implementation

An exemplary account of the employment of VSDF was utilized in the simultaneous analysis of intracardiac electrogram (EGM) and arterial blood pressure (BP) signals to detect lethal tachycardias, done as a research project in the Medical Computing Laboratory. The ECG software processed the EGM and BP data concurrently to detect hemodynamic change, and analyzed the signals for rhythm irregularities such as stable versus unstable ventricular tachycardias (VTs). VSDF was applied to rhythm and blood pressure measurements to demonstrate ease of use and improved performance metrics.

3.1. Materials

Electrocardiographic and blood pressure signals from canines were acquired in an animal electrophysiology laboratory for subsequent signal processing. Data were recorded on a four-channel FM tape recorder (Hewlett Paqard).
Packard 3968 Instrumentation Recorder, San Diego, CA) (3 ¾ ips), digitized at 1000 Hz via a 12-bit A/D converter, on CODAS (DATAQ Instruments, Inc., Akron, OH) a real-time data acquisition system, and converted into a custom format (SIG). Once the signals were digitized they were displayed in a Windows utility program (Microsoft Corp, Redmond WA), AAELVIEW (Ann Arbor Electrogram Libraries, Ann Arbor MI) and converted into text format to be correlated by ECG software. The data were then plotted using Excel so that results could be viewed. Features implemented in the program for concurrent signal detection were: two-channel signal acquisition, ECG triggering, signal analysis algorithms and analytic output. Correlation waveform analysis (CWA) was employed for the detection of abnormal beats. Amplitude variation was used as a measure of normalcy for the blood pressure waveforms.

Results of the classification of benign versus malignant VT using ECG software produced results identical to earlier processing of the same data using our conventional means.

4. Conclusions

The purpose of this project was to demonstrate that a modular, hierarchical scheme could be used to develop software packages for signal analysis. Functions of classic ECG analysis software were reviewed and broken down into independent modules. Our specific model consisted of three modules: data preparation, algorithm and-processing, and data output.

In research laboratories, student-based research or project-based research is often driven by targets and deadlines which preclude an orderly and systematic development of robust software. Signal analysis software is typically ad hoc and platform dependent. The lack of portability and flexibility results in replication of effort many times over. We propose a methodical, structured approach for the creation of programs designed for the academic laboratory. VSDF is intended to provide a framework for the construction of easy to use, portable software suitable for multi-site utilization.

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References


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