Real Time Holter Monitoring of Biomedical Signals

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Abstract

Monitoring of the electrocardiogram during normal activity using Holter devices has become standard procedure for detection of cardiac arrhythmias, transient ischemic episodes and silent myocardial ischemia. Existing devices mostly record "twenty-four" hour activity and then perform off-line record analysis.

We present realization of an intelligent DSP-based Holter device for continuous electrocardiogram monitoring. Battery operated Holter device is realized using Texas Instruments TMS320C542 DSP board with Del Mar PWA Amplifier Digicorder. The proposed device could be used either for acquisition of anomalous ECG sequences (arrhythmic events, ST segment deviation, etc.) and storing to flash memory, or as a warning device during normal activity or exercise stress test.

Implemented environment could be used as high-performance input/output processor. It could provide 3D virtual reality stereo output and new inputs such as user's emotional state, which could be used as significant feedback for computer applications.

1. Introduction

Holters are portable, battery operated, devices for monitoring of physiological signals [Deanfield87, DelMar, Levin86, Mulcahy89, Subramanian86]. Lack of processing power limited function of holter devices mostly to data acquisition. Traditionally, holters were used to monitor ECG (heart electrical activity) or EEG (brain electrical activity) and record 24-hour activity on cassette tape. Recorded signals are then analyzed off-line using dedicated diagnostic systems. Recently, a new generation of holter devices use solid state memory instead of magnetic tape.

With the current state of processor technology, standard processing of biomedical signals, such as filtering, statistical and morphological analysis, do not require significant processing power. This is particularly the case for the new generation of DSP processors with the processing power in excess of 100 MIPS, even in a portable environment. The main reasons for this are low sampling frequency (typically less than 1KHz) and a relatively small number of channels (up to a dozen).

On the other side, new sophisticated signal processing algorithms require significantly larger processing power (for example, non-linear dynamics [Hoyer98], neural networks [Tsoi94, Maglaveras98], wavelets [Bahoura97], etc.).

This paper presents development of a portable system for real-time analysis of ECG signals. It could be used either as an intelligent holter device or as an advanced warning device. It is very important for a range of clinical and diagnostic devices.

2. Personal Medical Applications

Embedded real-time systems have an increasingly important role in our technology oriented society. These systems will be used for human-computer interactions, in virtual societies (e.g., virtual reality, telemedicine), as well as to control complex systems [Jovanov99b]. The applications often require processing of large volumes of data and generating multimedia presentations of the data. Progress and availability of multimedia and virtual reality (VR) technology has made possible a new trend of perceptual data presentation [Jovanov99]. New immersive environments are particularly appropriate to improve insight into complex multidimensional phenomena [Jovanov99b].

The next generation of computer systems will probably be characterized by significantly improved human-computer interface and a higher level of interaction. New input technologies such as eye gaze, foot-based input, speech, and outputs such as tactile, influence not only the VR environment but gradually change the desktop environment as well. The ever decreasing cost of this technology has resulted in its commercial availability for desktop and mobile computers. Therefore, multi modal presentation already use visual sense, hearing [Begault94], touch [Burdea96], and for some experiments sense of smell [Pavic98].

New inputs such as emotional state of the user may provide significant feedback for computer applications. It is easy to conceive expert system based user interface trying to match our emotional state with appropriate screen settings, background music, even scents. We foresee an important role of personal medical applications within that wider framework of real time applications.

3. Real Time Monitoring of ECG

Monitoring of the electrocardiogram during normal activity using Holter devices has become standard procedure for detection of cardiac arrhythmias, transient ischemic episodes and silent myocardial ischemia [Subramanian86, Deanfield87, Mulcahy89]. Most existing ECG devices record twenty four hour activity from two or three leads and then perform off-line record analysis. The new generation of holter devices is capable of analyzing and interpreting electrocardiographic signals in real time [Levin86].

The most important problems in real time ECG analysis are [Pan85, VanAlste85, Levin86]:

- Physiological variability of QRS complexes. Large variability in waveshape of the QRS complex, for instance large T waves with a high frequency characteristic similar to QRS complex, requires a reliable recognition algorithm.

- Base-line wander (a very low frequency change of isoelectric level of ECG).
- Power line interference (50 or 60Hz noise induced by power lines).
- Muscle noise.
- Artifacts due to electrode motion.

Signals are usually bandpass filtered to eliminate noise [Pan85, VanAlste85]. However, care must be taken to preserve morphology of ECG for further analysis [Maglaveras98]. Filter design in the previous generations of real-time processing systems was limited by available processing power. The present generation of DSP systems allows more flexibility in filter design and algorithm implementation.

Standard annotated databases, such as the European ST-T database [Taddei92] and the MIT/BIH arrhythmia database, provide means for algorithm evaluation [MIT-BIH].

4. Implementation

Real time ECG processing system is implemented using a Texas Instruments TMS320C54X DSKplus board (with 40 MIPS TMS320C542 processor) and a Del Mar PWA ECG Amplifier. The amplifier is a dedicated three channel ECG holter amplifier with low power consumption. A set of electrodes and their leads are optimized for holter applications [DelMar]. Typical setting is presented in Figure 1.

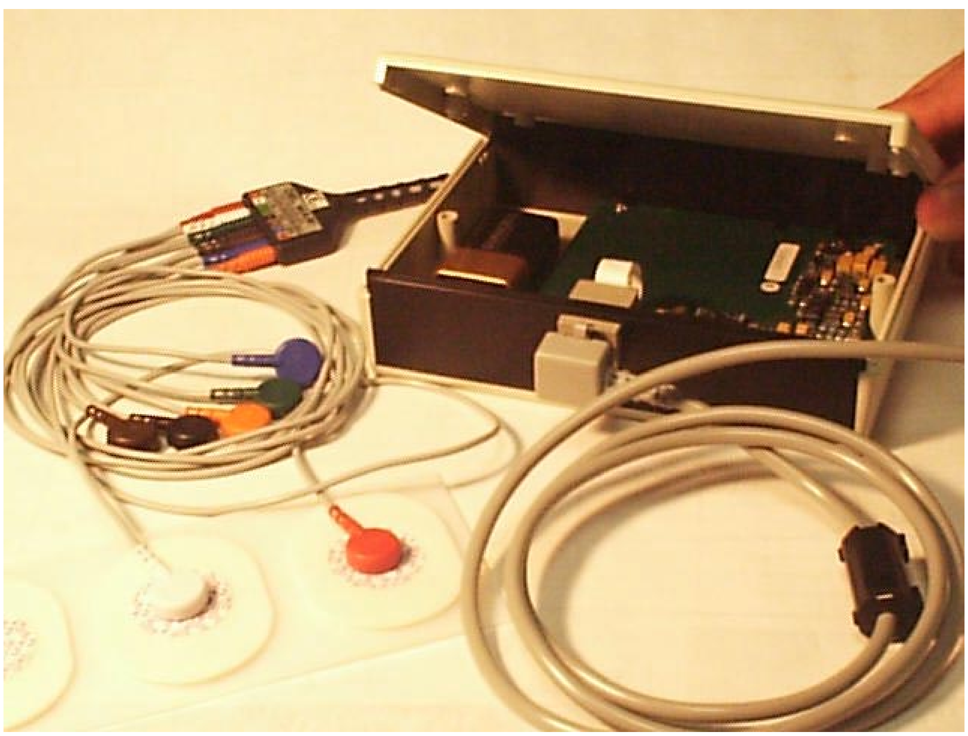

Figure 1. Real time DSP holter monitor

Further changes to the development environment include use of a TMS320VC5402 low power processing board with daughter board for LCD and flash memory interface (Figure 2). Flash memory will be used for large data storage. Row ECG consumes approximately 40 MB/channel/day. With reliable algorithm, only critical sequences would be recognized and stored for archiving and additional off-line processing. In the case of wireless connection of the device with a central monitoring system, critical sequences would be immediately transmitted. Typical examples are arrhythmias, ischemic changes ST segment, etc.

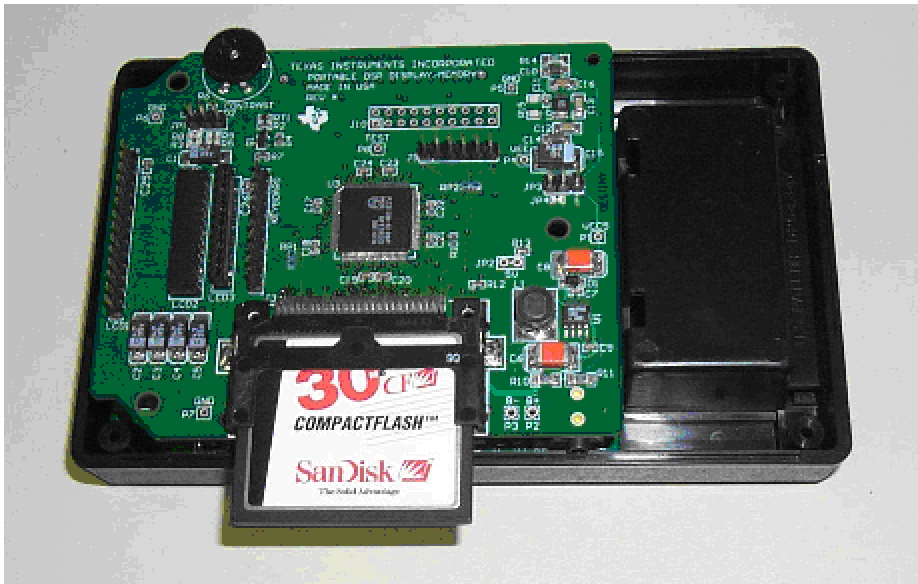

Figure 2. DSP board with flash memory interface

High performance VR interfaces require processing of new inputs (such as tactile), and new outputs (complex audio scenes, for example). In order to reduce the amount of communication between the central station and the device, sonification would require encoded sounds. Good candidates could be MP3 encoded sound files. In that case, communication would be reduced only to the selection of different sound sources and the alteration of parameters. Real time decoding and processing (such as modulation, 3D sound, etc) would require a processing power of more than 50 MIPS. That would mostly depend on the complexity of the sound scene. For a speech response, algorithms such as LPC or CELP voice coder would require 5-15 MIPS for voice synthesis.

5. Conclusion

Personal medical applications require devices with high peak performance and low power consumption suitable for battery operation. Our experience with the environment for real-time ECG analysis indicates that the C54X family of processors is well suited for personal medical application. High performance allows sophisticated signal processing algorithms when necessary, while power efficient processing modes preserve battery power for prolonged system use.

In addition to monitoring of physiological signals, we plan to use the proposed environment for development of a high performance user interface. New inputs will include correlates of the user's physiological and emotional states [Jovanov97].

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