Miniature Microcontroller-based Heart Rate Telemeter Processes Single Precordial Lead

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ABSTRACT

A miniature single-channel heart rate monitoring device has been developed specifically for use in critical care situations, such as intensive care units. The externally-worn device is placed directly on the chest above the heart, allowing acquisition of the electrocardiogram without the use of leads. The 8-bit microcontroller-based transmitter digitizes the preconditioned ECG and identifies the signal in real-time using a robust QRS detection algorithm. Data is output from the microcontroller only when an abnormal heart rate or low battery voltage is detected. When it is necessary to output data from the device, the digital data is transmitted by frequency modulation to a nearby nurses' station. At the monitoring station, the transmitted data is demodulated by the receiver and processed by another microcontroller which then activates the appropriate alarms.

INTRODUCTION

Cardiac monitors are ubiquitous in the clinical environment. A common use of these monitors is in hospitals' cardiac intensive care units, where they primarily monitor heart rate [1]. Battery-powered monitors which utilize telemetry are portable (e.g.: the Holter monitor). They typically involve a belt-worn transmitter with wires connecting the device to electrodes placed over the designated areas of the body. However, a definite potential for undesirable noise or interference can occur from induced currents resulting from the use of these wires [2]. Besides corrupting the signal, the wires and dispersed arrangement of this system can become a hindrance not only to the patient, but also to the physician and medical staff. This paper describes a non-interacting heart rate monitor that permits the acquisition of a precise ECG, using no lead wires, which simply notifies the monitoring station when an ECG abnormality is detected. This small reusable unit represents a substantial benefit in situations where the patient is unattended and where ECG monitoring is essential, such as in ICU or post surgery recovery room. In addition, this system's design features minimal power consumption and size, accurate transmission and recovery of data, low cost, repeated use, and reliable heart rate detection.

METHODS

The packaged transmitter unit is approximately 6 cm by 5 cm, very lightweight, operates from a replaceable battery, and has a completely enclosed transmitting antenna. The electronic components used in the transmitter are low power surface mount components. Three disposable dry electrodes, which acquire the Lead I ECG, are placed on the bottom of the device. The electrodes contain adhesive on both sides, enabling attachment of the device to the patient. They are also replaceable allowing for simple repeated use of the device.

A block diagram of the system is shown in Figure 1. The circuitry located inside the transmitter consists of a signal conditioning stage, a signal processing stage and a frequency modulated radio frequency stage. The micropower amplifiers which comprise the signal conditioning stage acquire the Lead I ECG with high CMRR and ample gain so that the full scale range of the A/D is used. The signal conditioning stage also bandlimits the signal at 50 Hz to prevent aliasing at the sampling stage. After the signal is conditioned, the ECG is ready to be processed. The Motorola MC68HC05P6 microcontroller is the core of the signal processing stage. This device contains an 8-bit A/D converter, ROM, RAM, timer, and communication interfaces. The analog ECG is sampled at 200 Hz by the 8-bit ADC. The MC68HC05P6 has 4k of ROM which is sufficient memory for the chosen signal processing program. The real-time QRS detection scheme used is similar to one developed by Pan and Tompkins [4]. This method uses linear digital filtering, nonlinear transformation, and decision rule algorithms to analyze the QRS complex on the bases of slope, amplitude and width. Initially, the digitized ECG signal is passed through a software bandpass filter which is implemented by cascading a low-pass filter and a high-pass filter. The bandpass filter attenuates noise by passing only frequencies in the 5-15 Hz range. Subsequently, the processes of differentiation, then squaring, and finally moving-window integration are performed. QRS decision rules distinguish a valid QRS complex from peaks detected after the bandpass filter stage and the integration stage. By continually updating two sets of thresholds, the

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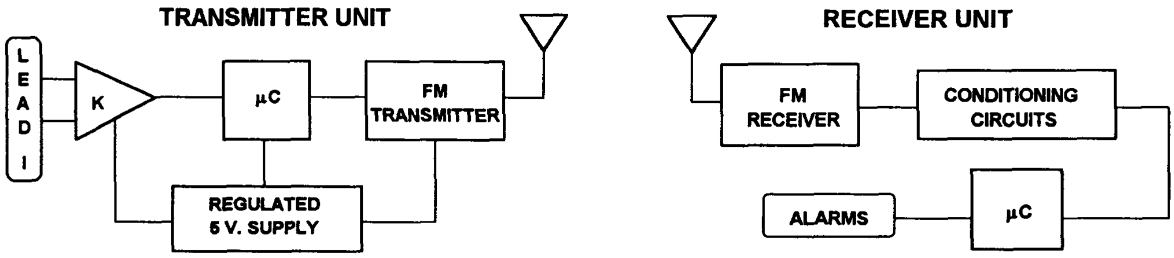

Figure 1: Block diagram of biotelemetry system

algorithm is adaptive to ECG changes, such as QRS morphology and heart rate.

If an abnormal heart rate is detected, the microcontroller will generate an alarm signal which is sent out of the serial port. This signal is transmitted to a nearby monitoring station by the crystal-controlled, 175 MHz frequency modulated RF circuit. The receiving end of the system receives the signal, demodulates it and triggers the alarms for either an abnormal heart rate or low battery voltage. All of the IC components in the transmitter are powered by a 5 volt micropower voltage regulator containing additional circuitry for on-chip low-battery detection, with power supplied by a replaceable 9 volt DC alkaline battery. Packaging of the telemetry device utilizes miniature, low power, inexpensive, readily available, discrete surface mounted circuit components on a multilayer printed circuit board.

RESULTS

A clear, precise ECG with an amplitude of approximately 1 mV is acquired from electrodes separated by approximately 2 cm on the base of the transmitter. The instrumentation amplifier in the signal conditioning stage produces a CMRR greater than 85 dB. The conditioning stage supplies a gain of 3500 with low power consumption. The signal processing stage contains a robust QRS detection algorithm with criteria adaptable to a specific patient. The HC05 contains all of the necessary features to PCM encode the data, and it operates from a 5V source. Of the numerous possible encoding formats and modulating techniques, the PCM/FM format was chosen because of its superior performance, especially in noisy environments [3]. The operating radio frequency of the telemetry-based system is selected to be at 175 MHz, providing adequate range and good performance in a hospital environment and compliance with FCC Rules and Regulations, Part 15.

DISCUSSION

The common technique for non-invasive ECG telemetry systems requires the use of lead wires for heart rate monitoring. These invite not only a physical hindrance to the patient and the physician, but also induced noise currents from nearby power wires, therefore contributing noise to the acquired ECG [2]. In cardiac intensive care units, heart rate monitors typically use a single precordial ECG lead to sufficiently monitor the heart rate [1]. The described single-channel precordial wireless RF telemetry system eliminates induced interference and electrode contact disconnection or noise caused by pulling of the lead wires. Because size, weight, and power consumption are of primary interest in a telemetry device, the small, lightweight, low-powered instrument described represents an improvement in critical care ECG monitoring.

ACKNOWLEDGMENTS

The author would like to sincerely thank her advisor, Dr. Jeutter, for all of his expertise, guidance, and support. His time and patience is greatly appreciated.

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