SMT BOARD FOR ACQUISITION OF ELECTROCARDIOGRAPH SIGNALS AND GSM TRANSMISSION

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ABSTRACT

Portable equipments for telemedical applications is one of the most innovative sectors in biomedical engineering. Health departments of governments are interested in tele diagnostic systems to avoid collapses in hospital and urgency services. In this paper, we describe a potable electrocardiograph/holter equipment with telephony and GSM transmission, using a surface mount technology with low voltage battery supply. This project has been developed in collaboration with Teleasistencia Cardiotest, S.L. This prototype is patent pending.

1. INTRODUCTION

In this article we will describe a micro controller-based system board for prototyping of embedded electromedicine applications. It consists of a standard Motorola MC68L11 microcontroller system for acquisition of electrocardiograph (ECG) signals and transmission by public switching telephony network and GSM network.

According to figure 1, the low voltage electrocardiograph signals are captured with three standard electrodes and then amplified by a scale factor of 1000. Three output interfaces are required:

- The audio interface. The amplified electrocardiograph signal is frequency modulated for transmission by telephony or GSM network. At destination, a demodulator equipment recover the ECG signal.
- The infrared interface.
- The asynchronous standard RS-232 interface.

The application has two modes of operation.

- Normal mode. The electrocardiograph signal is captured, stored in a non-volatile flash memory and then reproduced using the three interfaces described.
- Holter mode. The electrocardiograph signal is monitored and stored in a ring memory. If the cardiac rhythm is above or below two determined threshold values, then a four minutes ECG block data is stored: two minutes before the event and two minutes after the event. This window of four minutes has a transcendental information about the heart failure.

The main limitations of the design are space and consumption. A portable equipment with a low voltage battery supply is required. The photograph of figure 2 illustrates the final ECG equipment (white box) and the ECG signal transmitted to a laptop. The screen of the laptop shows the ECG signal and the pulse detection with an algorithm similar to the one implemented in the microcontroller.

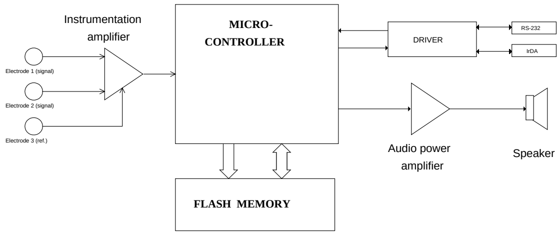

Figure 1: Block diagram of SMT board

In next two sections, we explain the hardware and software of the ECG application. Section III shows the final prototype and some results, and finally conclusions will be pointed out in section IV.

2. SYSTEM DESCRIPTION

The hardware is customized to the application requirements: low voltage detection watchdog failure system, parallel and serial ports for interfacing, timers and multichannel A/D converters. The Motorola MC68L11 is the low voltage version of the well known MC68HC11 microcontroller [1]. The system clock frequency is 8 MHz. All the integrated circuits used have the possibility of a shutdown mode, to save battery.

2.1. Analog stage

It consists of the electrodes located on the patient, the cables attached to the electrodes, and the differential amplifier. The electric current picked up by the electrodes from the body surface passes to the amplifier and, after an appropriate low-pass filter, the analog signal is digitally converted using the ADC of the microcontroller. The sampling rate is 100 Hz to reject induced noise from 50 Hz power lines.

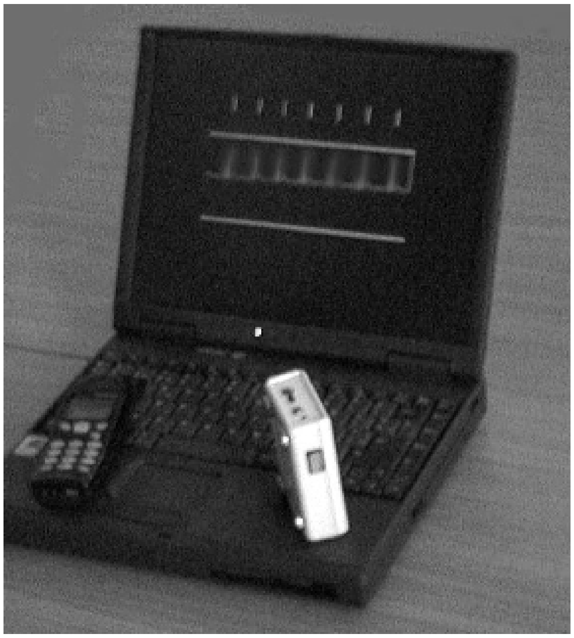

Figure 2: Portable electrocardiograph equipment (white box) and ECG signal transmitted to a laptop

2.2. Serial Communication link

A serial communication link is needed to provide communication with a personal computer. This serial link is both RS-232 and IrDA 1.2 interface. It enables a bidirectional communication: the ECG captured can be transmitted to the PC, and programs may be downloaded from the PC.

As the serial communication interface of the microcontroller is not IrDA compatible, it is necessary a transceiver that stretches the incoming infrared pulse into a full baud period. The use of a non electrical link (like the infrared link) allow the electrocardiogram to be generated on line.

2.3. Audio Power Amplifier

A bridge-connected audio power amplifier capable of delivering 1W of continuous average power to an 8Ω load with less tan 1% (THD+N) over the audio spectrum has been used.

2.4. Memory

Existing 68L11 on-the-chip memory resources are not sufficient for most of intended applications. This was the reason for using the microcontroller in the expanded bus mode, and extend memory resources. The external memory must be a non-volatile, read-write memory, to store the ECG data. The best solution, due to the restrictions of space and consumption, is a single, low voltage FLASH memory to store both program and data. The minimum size required is $512K \times 8$, because of the big deal of information generated in the Holter mode. As the memory map of MC68L11 has a size of $64K \times 8$, the FLASH memory must be paged.

Flash Memory has flexible sector architecture that can be acceded as fast as 70 ns. Sectors can be locked in-system or via programming in order to protect information stored previously.

3. SOFTWARE DESCRIPTION

For programming purposes, the design has a third mode of operation, that is, the Test mode.

Test mode is entered whenever new routines has to be downloaded from the host development PC. The board is then connected to the host PC by using SCI port of the MC68L11 to change the application software.

The system operation mode (normal or holter) run the program downloaded previously.

3.1. Test mode

In test mode, the host PC can read or write any position of the FLASH memory. Particularly, a new program or routine may be transmitted using the serial link (RS-232 or IrDA) and allocated in the same or in a different sector.

A design programmable on board allows for improvements or changes in parameters or functionality, after the design has been manufactured. This is a key point in this project, as some accessories will be added in the future.

3.2. System mode

As the MC68L11 has not a digital to analog converter, the best solution is to use a pulse count modulation method to provide that converter. Among the different possibilities [2], the best choice is to implement a PWM output signal with an external output RC low-pass filter.

The output signal is frequency modulated at 1900 Hz with a deviation of 255 Hz, that is transmitted through the telephone or GSM network. A medical center receives this signal with the demodulator equipment.

A heart rate detector must be implemented for holter operation mode. The goal is to detect if the cardiac activity is above or below two threshold values, determined as 140 and 40 pulses per minute [3]. A simple mathematical condition can not be implemented for heart rate detection because the peak value of the cardiac pulse depends on people's age, position of the electrodes, the electrical contact .... As a consequence, a complex mathematical condition has been implemented. The key idea is to detect the typical 'v' or inverted 'v' of a heart pulse using four consecutive samples (figure 3). The mathematical expression takes into account three circumstances:

- Absolute values: the module of the difference between two consecutive samples must be higher than a threshold value, called JUMPPULSE, and of different sign than the difference between the next three consecutive samples, that must also be higher than the threshold value JUMPPULSE.
- Slope: the absolute value of the slope of the lines joining the four points must be higher than a threshold value, called SLOPEPULSE.

- Timing: whenever a pulse is detected with the last two conditions, we wait for 0.3 milliseconds for a new detection. This condition is used to avoid non desired peak values in the sternum position of the electrodes.

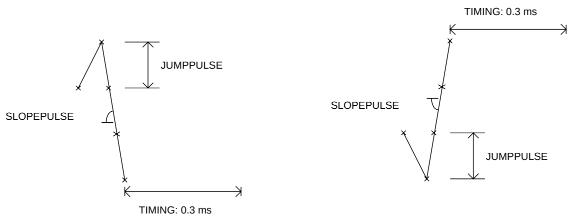

Figure 3: Heart rate detection

4. PROTOTYPE AND RESULTS

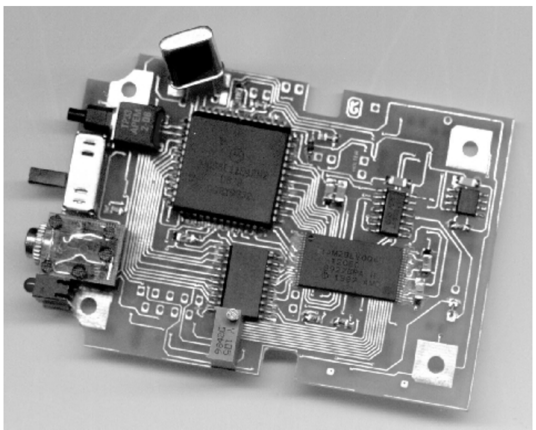

Figure 4: Prototype board: top view

Figures 4 and 5 show the top and bottom view of the final board. Board dimensions are (in mm) 81×55. The battery supply is 3 V and consumption is 40 mA when the audio amplifier is operating, and 10 mA when monitoring the ECG signal in the holter mode. That means that live battery allows for 700 ECG transmission with the audio interface and 72 hours in the holter mode.

Figures 6-9 show some results captured with our prototype in several positions. Pulse detection algorithm has been tested for these waveforms with patients between 5 and 65 years old. A 100 % pulse detection succeed has been achieved.

5. CONCLUSIONS

A portable electrocardiograph/holter equipment has been developed with restrictions of space and consumption. This prototype can be used autonomously, with the serial or infrared interface with a PC, or as a modulator equipment in conjunction with the demodulator one. The main target of the prototype consist of providing customers a tele assistance service with a 24 hours medical center.

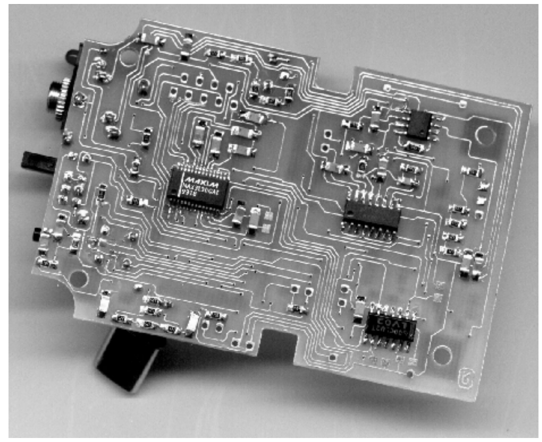

Figure 5: Prototype board: bottom view

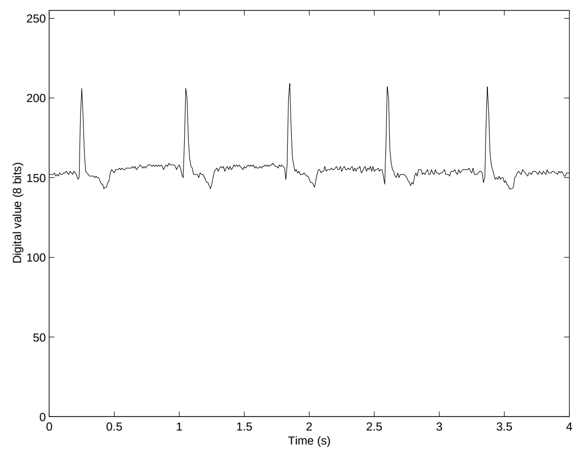

Figure 6: ECG record: chest position

The holter mode of operation, with a four minutes windowed memory, fills the gap that nowadays exists between the conventional ECG equipment and the Holter with 24/48 hours continuously storing information.

The three electrodes acquisition system allows for the detection of arrhythmias and several heart failures. Nevertheless, we are working now in developing a new accessory to provide the traditional 10 electrodes expansion and to capture the 12 lead ECG signals.

6. REFERENCES

[1] Motorola Inc., *MC68HC11 Reference Manual*, Motorola, Rev. 3, 1991.

[2] C. Halper, M. Heiss and G. Brasseur, *Digital to Analog Conversion by Pulse Count Modulation Methods*, IEEE Trans. Instrum. and Meas., vol. 45, no. 4, pp. 805- 814, Aug. 1996.

[3] J.W. Hurst and R.C. Schlant, *The Heart*, McGraw-Hill, Health Proffesions Division, 7^{th} edition, 1990.

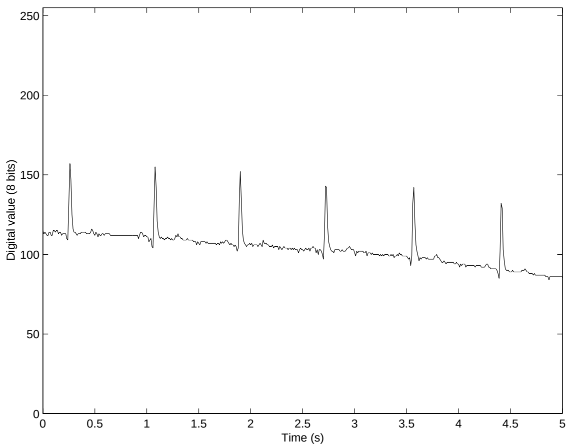

Figure 7: ECG record: sternum position

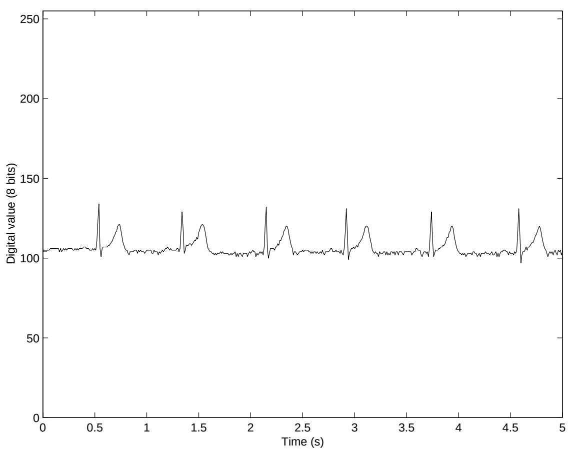

Figure 8: ECG record: collar position

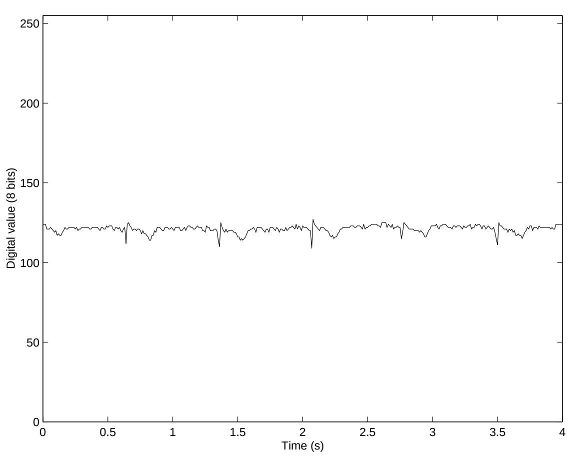

Figure 9: ECG record: lateral chest position