DESIGN OF A PROTOTYPE FOR DYNAMIC ELECTROCARDIOGRAPHY MONITORING USING GSM TECHNOLOGY: GSM-HOLTER

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Abstract- **Monitoring patients with serious cardiovascular problems is invaluable in preventing further crises and achieving a faster, more effective attention. To this end, noninvasive cardiologic tests such as dynamic electrocardiography (e.g., Holter) have proven useful in clinical practice. The present document puts forward a novel Holter system that benefits from the GSM mobile telephony standard widespread technology. The suggested design adds to the traditional Holter capabilities the attractive features of real-time processing and possibility of monitoring the patients' heart anywhere, anytime.**
***Keywords* - Dynamic electrocardiography, ECG monitoring, GSM, Holter.**

I. INTRODUCTION

Monitoring the electrocardiogram (ECG) signal from heart-disease patients is crucial in many pathologies. In some cases, recordings of a few minutes taken twice per day may suffice; in other occasions, monitoring should be more frequent; in the rest of cases, a continuous recording is necessary. In these latter scenarios, the solution typically adopted consists of keeping the patient in hospital or carrying out the acquisition remotely from the patient's home.

As a result of technologic innovation, several modalities of ambulatory electrocardiography are currently available in the market [1]:

- Intermittent ambulatory electrocardiography.
- Vigilance ambulatory electrocardiography.
- Monitoring with real-time analysis and telephonic transmission.

The first procedure registers the recordings at certain hours or after pressing an alarm button ('event recorder'). Sometimes the acquired recordings are transmitted to the control center through the public telephone network (PTN). The second type of methods is mainly used in hospital environments or ambulances. In order to minimize the patient attention time, information is transmitted from the ambulance via the cellular telephony network. Finally, the third technique continuously monitors the patient at their own home, analyzes the recordings in real time, and sends any anomaly to the control center via the PTN. Some of these techniques have not been widely employed, due to their high cost or their lack of acceptance by the medical community.

A. Dynamic Electrocardiography: Holter

Dynamic electrocardiography is a noninvasive cardiologic test of proven usefulness in clinical practice. It consists of a portable system which is uninterruptedly carried by the patient and registers all cardiac episodes over 24-48 hour periods. These systems allow ECG analysis in every-day situations in which the patient has suffered sickness, faints or aches.

Classical systems comprise a recording unit, a reproduction and analysis system, and a printing system. The recorder used to be a tape analog system, but has been substituted by a solid-state memory based digital storing system, the device currently employed. The recorder is connected to the patient with cables and electrodes positioned in pre-established locations. The recording is usually composed of 2 to 3 leads, and so 5 to 7 electrodes are distributed across the patient's skin in a standard manner. After removing the unit from the patient, the recording is dumped over a visualization program on a PC, which allows the analysis of the stored ECG. The power, ease of use and diagnosis speed of these programs are ever increasing. Having obtained the parameters needed for the final diagnosis, the results are printed out.

Holter-sysem technology has experienced a considerable advance, and thus both safety and speed in processing the stored information have improved. Furthermore, the computation power and diagnostic help provided by the analysis system have notably increased. Nevertheless, the protocol ruling the operation of the global system remains essentially unaltered.

B. GSM Standard

The mobile telephony standard currently implanted in Europe is the GSM system [2]. GSM endows its users with a voice and data channel and the possibility of sending short SMS messages to other terminals.

A few important features of GSM are set out below:

- Maximum transmission speed of 9.6 Kbps (TCH/F 9.6 GSM)
- Convolutional coding.
- Coverage of 98% of the territory.
- SMS of around 150 characters
- Compatible with PTN and integrated services digital network (ISDN).

Noise constitutes one of the major problems of GSM technology for ECG transmission, making the use of error correcting codes necessary. New third generation standards,

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Abstract

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such as GPRS and UMTS, will present further advantages and allow higher transmission rates.

II. PROPOSED DESIGN

The proposed system entails a new design philosophy. In contrast to all existing equipment, several monitoring protocols are supported, and interactivity is enabled by means of recorder-analyzer communication. Value is added to all the functionality and usefulness provided by conventional Holter systems through the possibility of patient's monitoring anywhere, anytime. Advantages shown by both systems are integrated in a single piece of equipment. Hence, the patient can be monitored 24 hours per day without inconvenience other than that of traditional Holter. This functionality is currently feasible via the GSM system only.

In 1999, our research group (Bioingeniería y Telemedicina, BET) proved and demonstrated that current technology is sufficient for the required specifications. Tests of ECG transmission over GSM were carried out, a simulator of the software and hardware to be implemented was developed on a PC, and multiple error correction techniques were studied [3].

The present contribution describes the hardware prototype designed and implemented. Apart from traditional Holter typical capabilities, the new system presents additional features, both in automatic analysis (processing in the Holter itself) and in the communications interface (GSM transmission). The system has been developed bearing in mind the validation of the equipment by the medical community, both on the recordings received via GSM and those stored in memory. In this manner, an *a posteriori* analysis of the system operation was made possible.

The system presents the following main functionalities:

- 2 to 3 lead acquisition.
- Solid-state memory card storage.
- Real-time analysis of the acquired signal.
- ECG transmission via GSM.
- Full-duplex communication with the medical center.
- Geo-positioning.
- Error control.

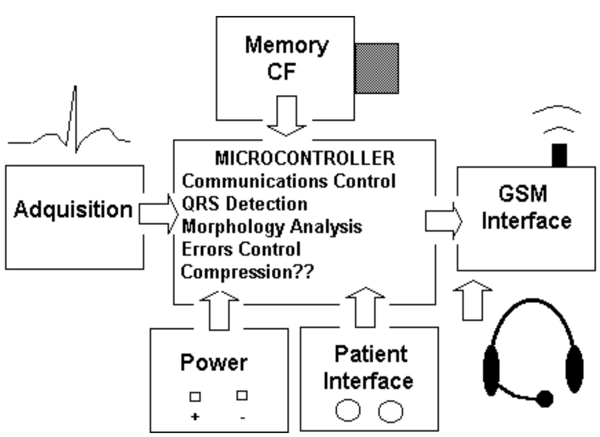

Fig. 1. Architecture of the proposed GSM-based Holter system.

A. Signal Acquisition

Signal acquisition allows a customized configuration for each patient and situation. The system is able to select between 2- and 3-lead recordings. The second option provides the medical team with an increased diagnosis capacity, since 3 leads make the 3 analysis basic planes available. In addition, the physician has 2 leads available, in case any of the electrodes presents a high noise level, a situation rather usual in practice. The system gain is configurable as a function of the acquired signal strength. On the other hand, common-mode (50 Hz) noise rejection techniques have been included [4], such as an optional 50-Hz filtering. The input signal bandwidth lies between 0.2 and 62 Hz, and digitization is carried out with an 8- to 10-bit resolution, which may also be configured by the system.

B. Data Storage

Compact Flash cards [5, 6] have been chosen for storage. The signals are to be stored in non-volatile solid-state memories with high capacity and reduced size. All these characteristics are presented by Compact Flash memories, which also provide scalability, since they possess 32, 64 and 128 MByte capacities.

C. Real-Time Processing

The proposed equipment in this paper intends to introduce the novelty of real-time processing in Holter systems. In conventional Holter, calculations are not computed or, at most, are computed *a posteriori*. The adopted solution is based on a new 16-bit microcontroller, incorporating an ADC, 3 UART, a 20- Kbyte Flash program memory. All these features endow the equipment with sufficient resources for its use.

The computations made by the microcontroller are variable in functionality and complexity as required by the case under consideration. Processing as basic as QRS-complex detection [7] and cardiac-rate estimation and as complex as morphologic algorithms [8] for ECG signal structure analysis is implemented. A balance between computational cost and effectiveness has been reached in the introduced algorithms, supervised by the medical community.

The proposed system prioritizes a "possible anomaly" at the expense of false alarms, in a bid to avoid a decrease in the test's diagnostic power. In other words, detection sensitivity is primed over specificity. As soon as an anomaly is detected, it is transmitted via GSM through a prior programmable buffer.

D. GSM Transmission

The implemented prototype utilizes a GSM modem available in the market (Wavecom). The modem can be operated by the microcontroller by means of straightforward Hayes (ATA) commands, which follow the ETSI GSM 07.07 standard [9]. Using those commands, all functionality provided by a GSM terminal (voice, data, SMS) can be exploited. Available in the market are several GSM modems weighing less than 20 gr. and smaller than a matchbox, which allow system reduction and integration.

The GSM-Holter has been endowed with 2 main buttons. The first one allows a voice call towards the medical center, which can give the patient advice on a particular situation or calm them down when facing an alarm. Communication can also be initiated by the medical control center. The GSM-Holter features a simple audio kit which can be connected to the equipment as soon as a voice communication is established. A call reception activates a ringing sound that calls the patient's attention. The other button is to be used in the event of an emergency, allowing the Holter to act as an event recorder, just as any of the systems available in the market but via GSM. The patient can press the button as soon as they note an anomaly, making the microcontroller send the appropriate ECG segment to the control center, so that a suitable diagnosis may be made therein. Therefore, transmission can occur for a variety of reasons:

- Alarm button (patient).
- Anomaly detection (Holter).
- Remote petition (control center).
- Regular intervals (automatic).

Transmission of the whole of the stored recording is redundant, since it is kept in memory. Only those segments useful in making an adequate diagnosis are sent. Both voice and data communications are totally full duplex.

Data transmission is accomplished through ISO´s OSI-layer compliant protocols [10]. In particular, the 3 basic layers are available: physical level (FL), data-link level (DLL) and application level (AL). This latter is only present in the control center. On the other hand, the 9.6 Kbps speed enables real-time transmission of the 2 or 3 acquired leads.

E. Positioning and Location

The system also allows the positioning and location of the patient in emergency situations. The use of GPS technology has been discarded, due to the latest advances in terminal localization through passive triangularization over GSM. GSM presents the drawback that localization errors are cell-size dependent. In urban environments, characterized by smaller cells, errors from 50 to 100 m error are typical, but may be much larger in rural scenarios. In the GPRS and UMTS standards, computations for patient's localization will be more accurate than at present, without resorting to a GPS system.

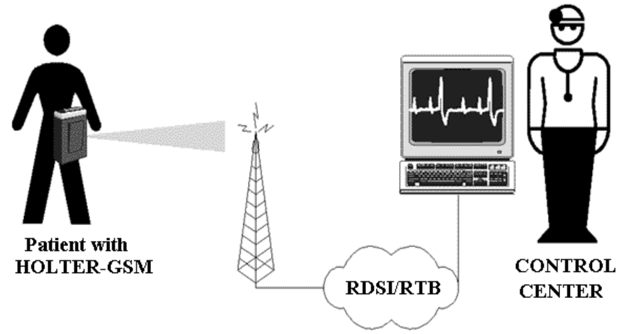

Fig. 2. Schematic diagram of ECG transmission from patient's recorder to control center.

F. Error Control

To guarantee a received ECG signal free from noise, a cyclic redundancy code such as Hamming (15,11) error correction coding has been used. This choice is supported by a number of tests, including comparisons and analyses by a medical team. Hamming codes are computationally simpler than convolutional codes. With the aid of different digital Holter signals, it has been tested that the minimum bit error rate (BER) for acceptable quality is of about 10^{-4}. The selected coding scheme achieves these results, and even improves them with the further application of a median filtering.

G. Power

Power supply is a critical part of the design. Currently available Holters do not implement internal processing and data transmission, thus keeping consumption low. By contrast, GSM transmission increases power consumption in the suggested system. Several techniques have been used in a bid to minimize power consumption. In any case, Ni-MH or Ni-Cd batteries are necessary, whose cells provide a 1.2 V tension and a capacity between 750 and 1250 mAh. The light weight and high charging capacities of these batteries allow the system to work within the desired specifications.

H. Compression?

The possibility of including compression processing in order to increase the performance of both the card and the transmission is currently under study, Several algorithms are being considered. The algorithms must be efficient and should not consume too many system resources. Their pros and cons when implemented in the system are being analyzed. Tested algorithms are linear and also pattern-based,

Fig. 3. ECG representation in Holter mode, in which the physician can observe each lead separately. All leads can be seen in normal mode.

since transform-based compression requires excessive computations.

III. CONTROL CENTER

The medical equipment simultaneously monitoring different patients is found in the control center. The control center is in the hospital, and is composed of a number of computers and modems connected to the PTN or ISDN.

Implemented software includes the basic procedures of the traditional Holter analyzer. The main part of the medical center is formed by the program in charge of the reception, visualization and analysis of the transmitted record fragments. Once connection is established, the visualization program graphically displays the ECG on the screen.

The code for ECG visualization and reproduction has been implemented in Visual C++ with event-based programming. The choice of this language has been based on the fact that it easily handles objects and allows the rapid development of efficient, robust applications.

IV. CONCLUSIONS AND FUTURE IMPROVEMENTS

This contribution has described the design of a novel Holter monitoring system which relies on GSM technology. The benefits of the proposed scheme are manifold. In the first place, the patient can be monitored over the whole recording without any additional inconvenience, conveying security and trust. The mobility in the monitoring process is continuous, and the system can act as Holter and event-recorder at the same moment. Also, the physician can interact with the patient at all times, including voice calls, emergencies, reconfigurations, advice, etc. The patient can easily be localized, which may be crucial in an emergency, and a great number of patients can be monitored from the same station or computer network. In addition, the equipment is able to detect anomalies and it is simple to adapt to future standards such as GPRS and UMTS.

The system can be further improved in several aspects. Once the system requirements have been clearly defined, the hardware can be optimized, specially regarding its size, weight and consumption. Together with clinical analyses, the protocols to optimize the system performance should be established. New technology such as Bluetooth, GPRS and UMTS could also enhance the performance of the final product.

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