Continuous ECG Monitoring in the Management of Pre-Hospital Health Emergencies

F Chiarugi[1], D Trypakis[1], V Kontogiannis[1], PJ Lees[1], CE Chronaki[1], M Zeaki[2], N Giannakoudakis[2], D Vourvahakis[2], M Tsiknakis[1], SC Orphanoudakis[1,3]

[1]CMI-HTA, Institute of Computer Science, Foundation for Research and Technology - Hellas, ICS-FORTH, Heraklion, Crete, Greece

[2]EKAB, National Centre for Emergency Care of Crete, Heraklion, Crete, Greece

[3]Department of Computer Science, University of Crete, Heraklion, Crete, Greece

Abstract

For the last five years, a system for the management and coordination of pre-hospital health emergency has been in regular use at the Emergency Coordination Centre of Heraklion, as part of HYGEIAnet, the Regional Health Information Network of Crete. Approximately 20,000 emergency episodes per year are currently being logged in the system.

The need for better support of cardiac cases (about 20% of the total) prompted the extension of the system to include the continuous acquisition of 12-lead ECGs and their real-time transmission to the coordination centre for evaluation by an expert.

The 12-lead ECG module has been developed and integrated in the existing system with special attention to the provision of an easy user interface so that the extra work required to the ambulance personnel is negligible. The overall system has been carefully tested and is now in daily use.

1. Introduction

In the Emergency Coordination Centre of Heraklion a system for the management and coordination of emergency care has been in regular use for the last five years [1-2]. This system is part of HYGEIAnet, the regional health network of Crete, and includes components for ambulance scheduling, for the real time acquisition, transmission and management of a patient's vital signs to the coordination centre, as well as the automatic assessment of an episode's gravity based on the calculation of various scoring systems for pre-hospital health emergencies. Around 20,000 emergency episodes per year have been entered into a large database and classified according to gravity and specialty. According to these statistics about 20% of the overall episodes are classified as cardiology episodes: a significant proportion and one that is sufficient to justify their better clinical support. The overall system, in use for the last five years and before the inclusion of the 12-lead module, was composed of a call centre, an expert station and the ambulance subsystem (see Figure 1).

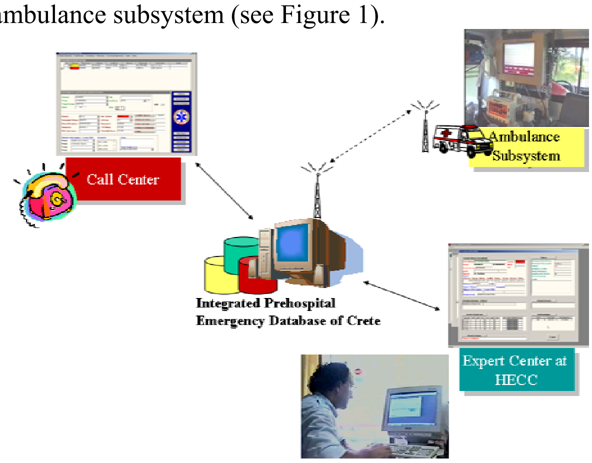

Figure 1. The overall Emergency Care Information System.

The operator at the call centre received an emergency call and decided, based on the first available information about the emergency episode (location, gravity, etc.) and the current location of the available ambulances, which ambulance to assign for the management of this episode.

The ambulance was alerted using the auxiliary wireless channel and the ambulance subsystem was started up, so that it received the new episode alert by the call centre operator system. Once the ambulance arrived at the episode site and the patient was taken on board, the vital sign monitor was connected to the patient. The patient's vital signs were then stored in the ambulance subsystem and transmitted to the emergency coordination centre using a GSM modem with a dedicated antenna. At the emergency coordination centre the vital signs could be displayed on the expert station and instructions could be relayed to the ambulance personnel.

In Figure 2 the interior of the ambulance with the pre-existing system is shown.

Figure 2. The interior of the ambulance before the installation of the new 12-lead ECG module.

The vital signs were shown both on the screen of the portable monitor and on the screen of the on-board panel computer. Information on the status of the GSM connection with the coordination centre was also available.

The expert at the coordination centre in real-time could view the transmitted vital signs and provide the ambulance personnel with useful information. The expert station at the Coordination Centre is shown in Figure 3.

Figure 3. The expert station at the coordination centre.

During the evolution of this system, a few years ago, some attempts were made to achieve the transmission of a 12-lead ECG, but the ECG module, after a period of test, was judged too complex to be put in daily use, mainly because the work required from the ambulance personnel for the acquisition and remote transmission of the ECG was excessive.

2. Methods

In our attempt to provide 12-lead ECG support we had to make some considerations [3]. The portable vital sign monitor installed in the ambulance was also able to record a 7-lead ECG so, like the majority of the vital sign monitors available on the market, it does not have the capability to record a 12-lead ECG. Another important consideration was that the users were quite satisfied with this monitor, so the attention was dedicated to an ECG device, or better, an ECG acquisition module sufficiently compact to be put in the ambulance, given that there was very little available space. Furthermore, to limit the clutter inside the ambulance, another main requirement was the use of the existing communication link for the transmission of the 12-lead ECG, without the need for installing a second GSM modem with another dedicated antenna. Our choice was a Cardio Control 12-lead acquisition module, able to acquire the ECG in real-time and to communicate via fibre optic with the USB port of an external PC. This ECG device is battery-powered and insulated by the fibre optic, so that all the patient safety requirements can be easily met. The user interface was custom developed with main focus to minimize the interaction of the user with the system. In fact, after power on, the system automatically connects to the open emergency episode (if any was assigned to the ambulance), establishes the link via GSM modem and starts the real-time acquisition from both the portable vital sign monitor and the 12-lead ECG acquisition module. The only manual operations required from the ambulance personnel, in case of cardiology episode, are: a) put the 10 disposable adhesive electrodes on the patient, b) switch on the ECG device, c) check the quality of the signal on the on-board panel PC monitor, d) push, on the touch screen monitor, the start button for the remote transmission of the real-time acquired 12-lead ECG.

In practice nothing was changed compared to the existing procedure for all the non-cardiology episodes (that are the majority), and very few operations, to be done just once at the beginning, were added to the system to enable the acquisition and transmission of the 12-lead ECG.

Due to the particular topography of Crete, which is very rich in mountains, currently there are several areas in which there is no coverage and no link can be established. So a major design choice was made from the beginning of the project and we decided to maintain a local copy of the data in the ambulance subsystem. A mechanism for database replication between the ambulance and the coordination centre has been established, and whenever the GSM link is present the data are transferred through the replication protocol in real-time to the coordination centre. If the ambulance is travelling through a no-signal area, the link is temporarily down, but as soon as it leaves this area the link is established again and all the data acquired during the missing-link period are replicated to the coordination centre [4]. This design choice assures the best property of all the acquired episodes and the collection of a high-quality database.

No significant modifications were made to the call centre operator module and in Figure 4 the user interface of this module is shown.

The procedure is not changed: the operator receives an emergency call and creates a new episode (with a new episode ID), assigning it to a specific ambulance that will set off on route to reach the emergency site. At the same time the on-board panel PC is powered on and through the GSM link the new episode ID is automatically received by the on-board database.

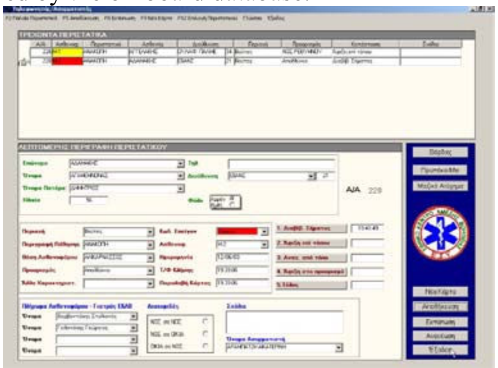

Figure 4. The user interface of the call centre operator module.

Once the emergency site is reached, the patient is loaded into the ambulance, the sensors for the vital sign acquisition are connected and the acquisition of the vital signs starts automatically. Figure 5 shows the internal setting of an ambulance with the panel PC and the vital sign monitoring. The ECG module is closer to the patient so that it can be easily connected to the patient in cardiac episodes.

Figure 5. The internal setting of the ambulance with the panel PC and the vital sign monitoring.

If the ambulance personnel decide that the specific episode requires the acquisition of the ECG, the electrodes are put on the patient and the 12-lead ECG acquisition module is switched on. At this point the appearance of the user interface is enriched by the real-time 12-lead ECG display, so that the on-board personnel can have the basic information for a first evaluation. In Figure 6 the user interface with the 12-lead real-time ECG is shown.

Clicking on the "Start" button (using the touch screen monitor) automatically enables the storage and the remote transmission of the acquired ECG.

Figure 7 shows the interior of the ambulance with a patient and all the sensors connected to him.

Due to the limited bandwidth available with the GSM link (9.6 kbps is the theoretical maximum), the uninterrupted transmission of the ECG signal is not possible, also considering that some amount of the available bandwidth is used for the vital sign transmission and for the overhead produced by the replication mechanism.

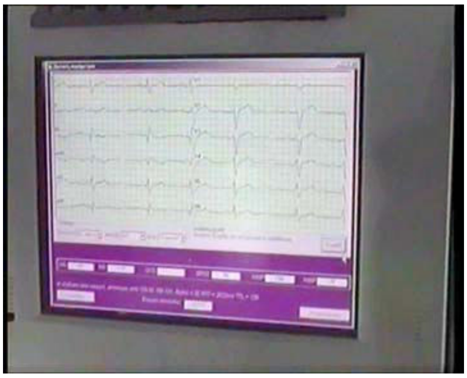

Figure 6. The user interface of the on-board PC during real-time ECG acquisition.

Figure 7. The interior of an ambulance during patient transportation and monitoring.

A logical and useful solution was the continuous transmission of ECG snapshots, so a snapshot interval was set up in the system with the possibility to be tuned during installation. Every 1, 2, …, 5 minutes the ambulance subsystem is able to automatically acquire 10 s of 12-lead ECG and to store it in the local database. The replicator automatically takes care of the remote transmission of the acquired ECG to the coordination centre database. During the first tests we verified that a snapshot interval of 2 minutes would be enough for providing valuable information to the coordination centre. This value was applied to the system that is now in daily use.

The 12-lead ECGs are received by the central database and listed in the expert station together with the vital signs. The expert can simply click on any ECG of the list to display the ECG signal with an appropriate ECG viewer. This ECG viewer also contains zoom capabilities and the possibility to make measurements on the ECG waveforms. Furthermore, the expert can open more than a single ECG, making a visual comparison of the received ECG signal and appreciating changes in the ECG waveforms more easily.

Figure 8 shows the user interface of the expert station during the real-time analysis of an ECG episode.

Figure 8. The expert station during the analysis of a cardiology episode.

Finally the expert station provides the capability of performing searches and reviewing the archived episodes.

3. Results

Many tests were made before deployment of the system as an upgrade of the existing one. During such tests live simulations were carried out with the collection of ECGs from the ambulance during the transportation of patients. The use of disposable adhesive electrodes was verified as absolutely necessary for the acquisition of a high quality ECG and the reduction of signal artefacts and electrode detachments produced by the very strong movements and accelerations experienced by the ambulance during patient transportation.

The final remarks of the users was that this system is a lot more friendly and easy to use than all the previous attempts made during the previous year and the extra effort required from the ambulance personnel was negligible. Furthermore, it could be very helpful in the support and in a better management of cardiology episodes, so finally the system was installed and put in daily use.

4. Discussion and conclusion

The availability in coming years of larger bandwidth communication channels for the mobile user (2.5G/3G mobile technology as GPRS, EDGE, UMTS), combined with a more extended coverage of the territory, should allow further tunings in the deployed solution, with the possibility of reducing the time between one ECG snapshot acquisition and the next. Also, other parameters can be easily adjusted, such as the replication interval and the sampling rate for the vital signs. In this way the overall time delay between the parameter acquisition and the parameter availability on the expert station with very simple settings can be adjusted for the best exploitation of the available communication channel.

A further improvement in the data rate could be also reached through the use of artefact filters and baseline-wandering filters able to stabilize the ECG signal so that specific techniques for beat classification and signal compression with reference beat subtraction and redundancy reduction methods could be applied. On the other side the availability of the original raw data is, at present, considered of extreme importance also for research purposes, so this possibility has not been investigated.

Acknowledgements

The work reported in this paper was supported in part by the OpenECG project (IST-2001-37711).

The authors would like to thank F. Kroon and M. Läkamp (Cardio Control NV) for their help and cooperation.

Furthermore, the authors would like to thank N. Papapostolou (Papapostolou Ltd.) for his support to ICS-FORTH research in eHealth and telemedicine.

References

[1] Leisch E, Orphanoudakis SC. HECTOR Solutions. 1st International Conference on Health Emergency Telematics. Seville, Spain, 1999.

[2] Leisch E, Orphanoudakis SC. The HECTOR Pilot System of Crete as Part of a Regional Health Telematics Network. 1st International Conference on Health Emergency Telematics, Seville, Spain, 1999.

[3] Giovas P, Papadoyannis D, Thomakos D, Soulis D, Stamatopoulos C, Mavrogeni S, Katsilambros N, Papazachos G, Rallidis M. Transmission of electrocardiograms from a moving ambulance. Journal of Telemedicine and Telecare, 1998;4 Suppl. 1:5-7.

[4] Chiarugi F, Spanakis M, Lees PJ, Chronaki CE, Tsiknakis M, Traganitis A, Orphanoudakis SC. Real-Time Cardiac Monitoring over a Regional Health Network: Preliminary Results from Initial Field Testing. Computers in Cardiology 2002;29:347-350.

Address for correspondence.

Franco Chiarugi
CMI-HTA,
Institute of Computer Science,
Foundation for Research and Technology - Hellas,
P.O. Box 1385 Vassilika Vouton,
GR 711 10 Heraklion, Crete
Greece
chiarugi@ics.forth.gr