

Communication and Storage of Compressed Resting and Exercise ECGs Using the Revised SCP-ECG Standard

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Abstract

Exercise ECG testing is one of the clinical routine examinations which produces a large amount of data if full disclosure records shall be provided. We describe a system for XECG analysis which takes advantage of the data compression procedures and the data format of the standard SCP ECG Protocol. Processing the XECG data in consecutive 10 s data sections results in six SCP blocks per minute. Over a test set of 20 XECGs with various test durations a median compression ratio of 11.1 has been achieved. We have also investigated the influence of noise on the compression ratio. 50 μ V RMS may reduce the compression ratio from ~ 17 to ~ 8 .

1. Introduction

Information integration and communication is to date the paramount assignment of computer applications in medical care. To promote information exchange in Electrocardiology the European Commission has supported in 1991 within the Advanced Informatics in Medicine Program – AIM – (project # A1015) the development of a Standard Communication Protocol for Computer assisted Electrocardiography. During this project an inventory on ECG compression methods and on existing protocols has been made [1]. A new compression scheme with defined error limit specifications has been developed. Also format specifications and a low level messaging scheme for cart to cart communication was designed [2...5]. After a final workshop with experts from Europe, United States, and Japan a final report was prepared which became the basis for the standard proposal. In 1993 the CEN Pre-Standard ENV 1064 [6] has been published. This pre-standard did have its roots in the Universal Protocol of the American Veterans Administration Hospitals. It has been during the past years within a subcommittee of AAMI re-evaluated, slightly revised and clarified and successfully balloted. During these discussions the question was brought up whether the SCP-Protocol could be used for Exercise Electrocardiography since the originally design was directed towards Resting Electrocardiography. We present here a solution for generation of SCP records from Exercise Electrocardiograms (XECG).

2. HES XECG processing

Figure 1 depicts the layout for the HES Exercise ECG Analysis System.

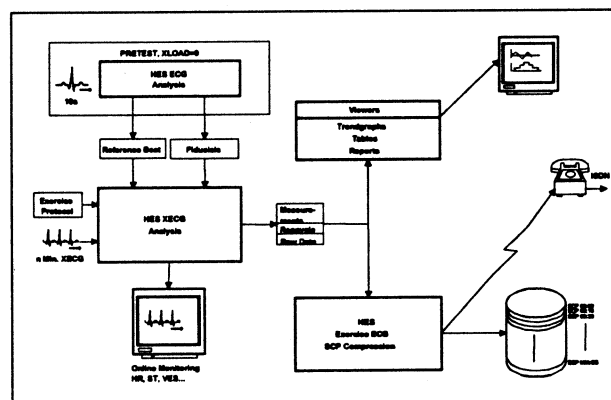


Figure 1. HES Exercise Analysis System

There are the following program modules:

(a) The HES ECG Analysis Module for processing a baseline ECG with re-located limb leads and zero exercise load. The reference beat and a couple of sensitive measurements are transferred to the Exercise ECG Analysis in order to refer all exercise induced ECG changes to their reference measurements.

(b) The Exercise ECG Analysis Module for processing continuously 10 s XECG data sections throughout the whole exercise and recovery period. This module provides all relevant XECG analysis results, e.g., heart rate, ventricular premature beats and other rhythm information and sets of Standard ECG measurements such as multiple ST-T values for all leads etc.

(c) Viewers for the ECG data as well trendgraphs allow monitoring of the exercise process, of the heart rhythm, ST-T changes etc.

(d) The HES Exercise SCP Compression Module processes all subsequent ten-second data sections following the SCP compression scheme. In case of significant arrhythmia the exercise data are redundancy reduced otherwise median beats and rhythm data are encoded as specified within the SCP Standard.

Figure 2 depicts the HES Exercise ECG Processing Sequence in more detail.

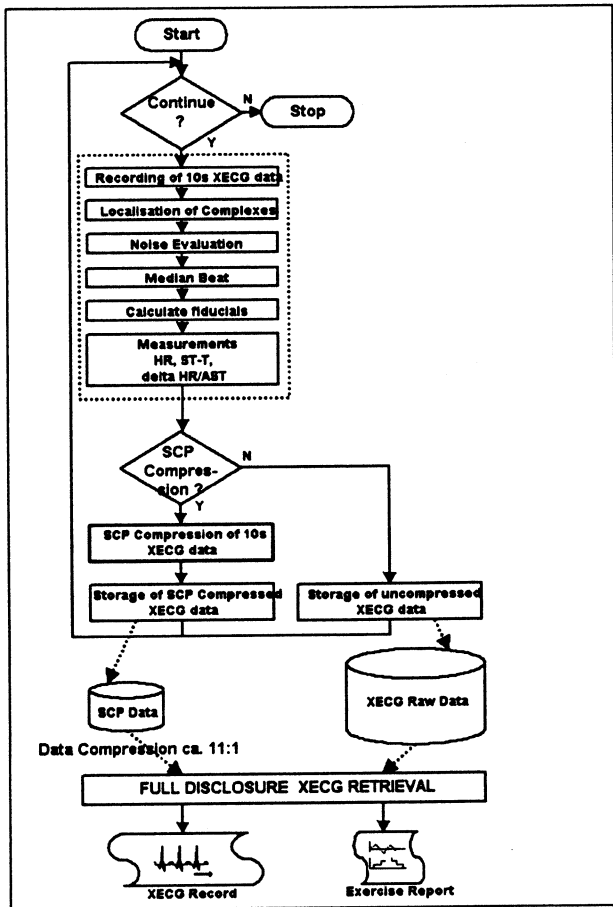


Figure 2. HES XECG Program Structure

Processing speed and capacity of presently used PCs does allow to acquire, to display, to process, to compress, and to store all data in real time. At the end also a full disclosure XECG report may be printed out or retrieved.

The XECG Processing includes the following steps:

1. After acquisition of a first 10 s data section without exercise load but with for the exercise test re-located limb lead electrodes these data are analyzed in detail by means of the Resting ECG Analysis module.

2. Fiducials, ST measurements and the reference beat are transferred to the exercise analysis module.

3. For all subsequent 10 s data sections ECG complexes are localized, the noise is estimated and a median beat is processed by means of the XECG analysis module. Fiducials are calculated and a set of measurements is made.

4. If the ECG shall be compressed the median beat is used and the last 10 s data section is compressed as specified within the SCP Standard. We use only the default Huffman table and produce SCP data blocks (as shown in Figure 4) up to the end of the exercise test.

Figure 3 depicts as an example the display with representative cycles at minute 6:00, 7:00, 8:00, 9:00 for the leads V2, V4 and V6 with QRS fiducials and the ST-T measurement marked

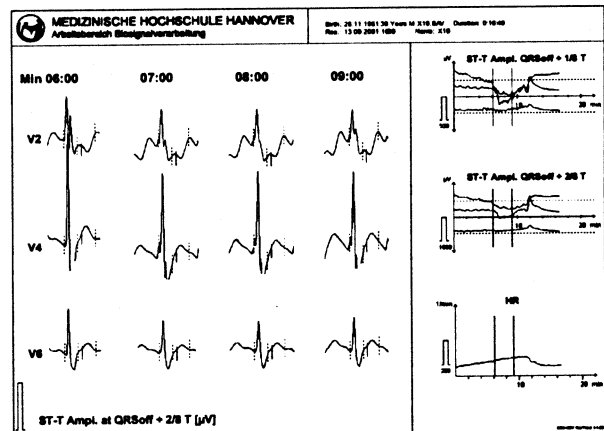


Figure 3. Sample of a HES Exercise ECG Report

On the right hand side of this display trendgraphs for the heart rate and ST-T amplitudes can be seen. The vertical lines indicate the window within the exercise test for which the representative cycles are given.

Figure 4 depicts the structure of the XECG SCP record data blocks. Each data block starts with the global CRC checksum and the global size followed by the SCP mandatory data sections zero and one with the pointers and the header information.

Within the subsequent eight sections the ECG lead definitions, QRS locations, the encoded beat data, the residual signal data, global measurements, textual data, and HES processing specific data are stored. The length of one SCP compressed 10 s data block is approximately 1/10 of the uncompressed data block size.

GLOBAL CRC CHECKSUM AND GLOBAL SIZE
(Section 0) POINTERS TO DATA AREAS IN THE RECORD
(Section 1) HEADER INFORMATION - PATIENT DATA/ECG ACQUISITION DATA
(Section 2) STANDARD HUFFMAN TABLE IDENTIFICATION
(Section 3) ECG LEAD DEFINITION
(Section 4) QRS LOCATIONS
(Section 5) ENCODED REFERENCE BEAT DATA
(Section 6) "RESIDUAL SIGNAL" AFTER REFERENCE BEAT SUBTRACTION IF REFERENCE BEATS ARE STORED, OTHERWISE ENCODED RHYTHM DATA
(Section 7) GLOBAL MEASUREMENTS
(Section 8) TEXTUAL PROCESSING RESULTS
(Section 128 Manuf. Specific) EXERCISE PROTOCOL AND ST-T MEASUREMENTS

Figure 4. Used SCP Sections for compressed XECGs

3. Results on ECG compression

The efficiency of SCP compression depends: a) to some extent on the heart rate, b) on the noise content (which may be influenced by the exercise load), c) on the signal properties itself.

To get insight of the noise effects on compression we used the artificial CTS/IEC ECG ANE 20000 [7].

NOISE		ANE20000 compressed in kB	SCP Files in kB	CR data	CR file
HF RMS	BL 0,3 Hz				
-	-	102.1	174.7	23.5	13.7
50 Hz	-	133.0	205.7	18.0	11.7
-	1mVpp	125.8	198.5	19.1	12.1
25 μ V	1mVpp	147.1	220.0	16.3	10.9
50 μ V	1mVpp	233.5	306.4	10.3	7.8
25 μ V	-	159.8	232.6	15.0	10.3
50 μ V	-	231.2	304.0	10.4	7.9

Table 1: Noise Influence on Compression Ratio

We added to this ECG 50 Hz line frequency noise, 1 mVpp 0.3 Hz baseline noise (BL), and HF noise up to 50 μ V RMS. The compression ratio for these data dropped down with increasing noise levels from 23.5 (without noise) to 10.3 at 50 μ V HF and 1mVpp baseline noise. A file of originally 2400 KB could be compressed to 233.5 KB.

Figure 5 depicts heart rate and data compression in patient X10 (one of the 20 Exercise ECGs analyzed in this study).

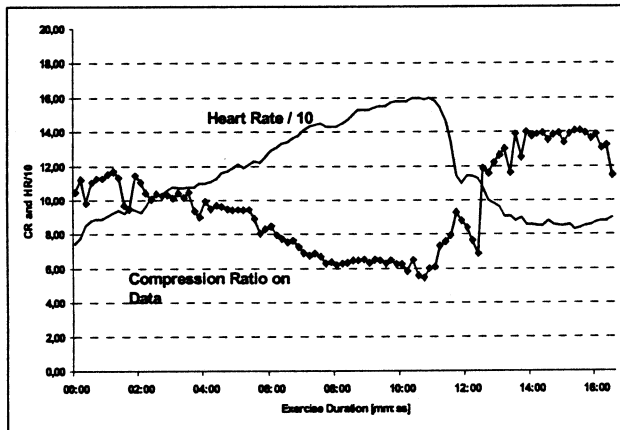


Figure 5. Heart Rate and Compression Ratio

While the heart rate continuously increases up to minute 11 the compression ratio decreases at the same time continuously while during the recovery phase up to minute 11 the heart rate drops and the compression ratio rises up to 14. Reason for this is most likely both, the changing signal characteristic and the increased noise

during high exercise load.

Figure 6 depicts the distribution of compression ratios for the 1812 10 s intervals of the 20 XECG data sets investigated.

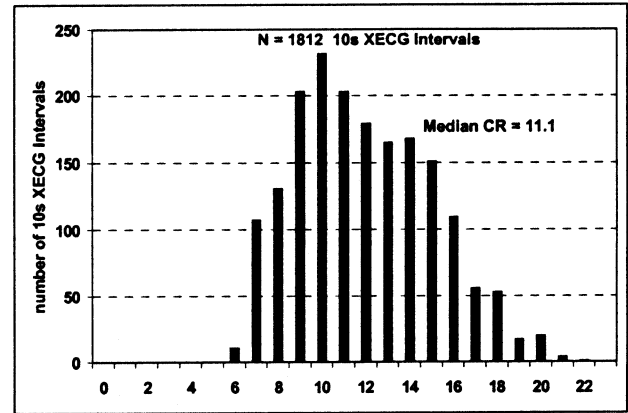


Figure 6. Distribution of 10 s XECG intervals according to the compression ratio.

A median compression ratio CR of 11.1 has been reached. For 90 % of the 10 s intervals a compression ratio between 8 and 18 has been achieved.

To investigate further the influence of noise we have analyzed the noise levels in the 1812 10 s intervals of the data set. Figure 7 shows the distribution of 10 s XECG intervals in noise classes from 5 to 80 μ V RMS.

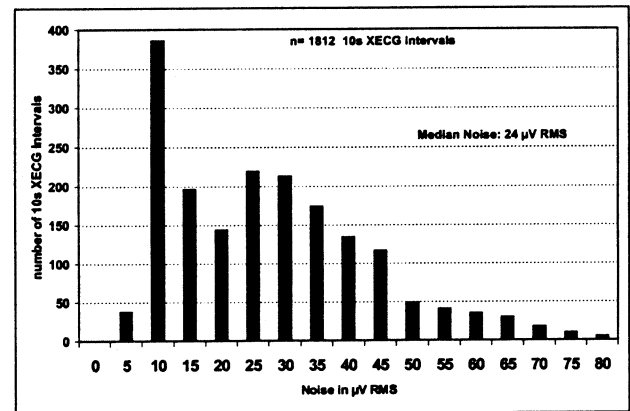


Figure 7. Distribution of 10 s XECG intervals according to noise level classes.

As can be seen the distribution is highly skewed. 90 % of the intervals have noise levels between 10 and 60 μ V RMS.

Figure 8 depicts directly the interdependence between compression ratio and noise levels analyzed by ordering the data according to noise level and compression ratio for each of the individual 10 s intervals. For all noise levels the compression ratios for the associated 10 s

intervals have been drawn on the vertical axis in figure 8. The regression line shows the drop of the compression ratio from 16 to approximately 6 with the increasing noise levels.

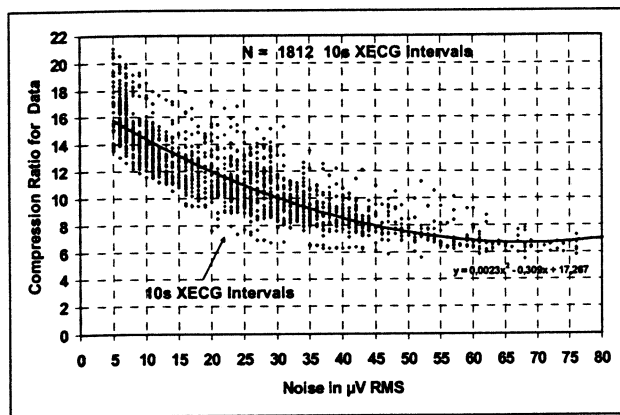


Figure 8. Interdependence of Noise and Compression Ratio

For a noise level zero we obtained for the artificial ECG in table 1 a compression ratio of 23.5 and at 50 μV noise a CR of approximately 10. Two conclusions may be drawn from these figures. (a) Adding 50 μV noise reduces the compression ratios by approximately 2.5. (b) Not surprisingly is the compression ratio for the biological ECG signals approximately 1/3 lower than for the absolutely smooth artificial ECG ANE 20000.

Figure 9 shows transmission durations of a 20-minute XECG where the original data amounted to 10.56 MB while the SCP files covered only 1.58 MB.

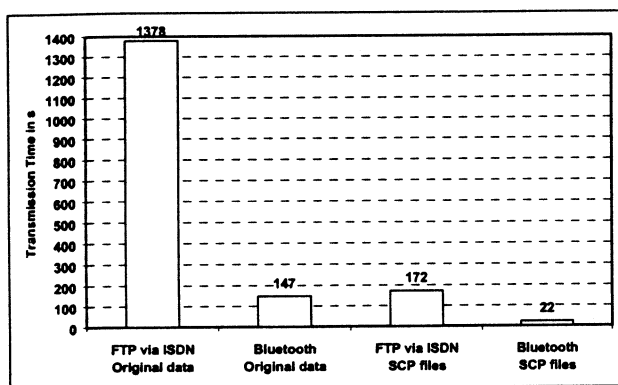


Figure 9 : Transmission Duration of a 20 Minute XECG

FTP transmission via ISDN of the original data would take 1378 seconds, that is approximately the full time of the exercise test. Transmission of the original data via Bluetooths would take 147 seconds while FTP transmission via ISDN of SCP files would take 172 seconds. Bluetooths transmission of the SCP files would only take 22 seconds.

4. Summary and conclusion

1. Our work has shown that the SCP/ECG protocol and its compression method can be successfully applied during real time processing of XECGs.

2. A substantial data reduction was possible despite the fact that we have used only one Huffman table. Using optimized Huffman tables depending on the noise spectrum results in only marginal compression effects.

3. The SCP/XECG compression makes possible to retrieve or even to transmit electronically a full disclosure exercise record which is demanded in many health care situations.

4. Despite the lengthy discussions on SCP Protocol revision 1.3 some simplifications of the SCP Protocol are possible and could promote its general acceptance.

References

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