A Web Service for Conformance Testing of ECG Records to the SCP-ECG Standard

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Abstract

The OpenECG network promotes interoperability and open standards in computerized electrocardiography. Since 2002, the OpenECG portal and its world-wide community have advocated open data formats for ECGs, facilitated the creation of vendor- and device-independent ECG databases, and stimulated the development of open source processing, analysis, and visualization tools. OpenECG offered the first on-line service for conformance testing of ECG records in the SCP-ECG format. This paper presents the design and evaluation of a web service providing SCP-ECG conformance testing to ECG tools. Two ECG viewers were modified to support this web service. The collection of ECGs submitted online for conformance testing was used to validate the web service and the viewers. Test results led not only to improvements in the stability and functionality of the viewers, but also to significant insight on strengths and limitations of the testing tools.

1. Introduction

Since 2002, the OpenECG portal [1,2] and its steadily increasing world-wide community, comprising 464 members in September 2005, have advocated open data formats for ECGs, facilitated the creation of vendor- and device-independent ECG databases, and stimulated the development of open source processing, analysis, and visualization tools. Currently there is a proliferation of 'standard' formats for ECGs. The annotated ECG format commissioned by FDA in 2002, and later adopted by HL7 in 2003, has formed the basis for XML formats promoted by large ECG vendors. At the same time, the SCP-ECG standard (EN 1064) became the official European standard for computerized electrocardiography in early 2005 [3]. SCP-ECG has been a standard format, notoriously difficult to implement consistently. Common errors include quality assurance mechanisms that have been embedded in the standard such as CRC codes and alternative ECG-specific compression mechanisms. A highly-compressed 10 sec SCP-ECG record can be up to 40 times smaller that the same ECG record stored in an uncompressed XML format! This difference makes SCP-ECG particularly attractive for smart cards and other portable or wearable devices, where space is limited and/or the communication channel is narrow.

On the other hand, existing implementations of SCP-ECG by vendors or integrators differ significantly and, in some cases, are erroneous. In this context, a major breakthrough was the first on-line conformance testing service for ECG records in the SCP-ECG format. The validation tools used in conformance testing (a format checker, a content checker, and a sample ECG data set including records with and without compression) were developed by BIOSIGNA [4]. Since their initial release, peer review by the OpenECG community has resulted in frequent updates of both the testing tools and the ECG data set.

The online conformance testing service has been available at the OpenECG portal since September 2003. Any authenticated OpenECG member may submit an ECG record for conformance testing. The results of conformance testing provide insight on the content and format of the ECG record. The contents report accounts for parsing the ECG record according to the SCP-ECG specification. The format report lists warnings and errors resulting from a basic format checking of the ECG file. All submitted ECG files are stored in a database at FORTH/ICS together with conformance testing results. Currently this database has grown to include more than 600 ECG records some conforming (others not) to the SCP-ECG standard. Using the service on-line, several integrators were able to combine different dialects of SCP-ECG into robust third-party viewers.

Responding to member requests, a web service that allows direct integration of the conformance testing functionality in third-party tools was developed and validated. Two viewers were adapted to incorporate the

[*] The creative, energetic, and resourceful spirit of Christoph Zywietz has driven the OpenECG work on conformance testing. He left too early in the middle of many exciting projects.

web service: a multi-vendor ECG viewer developed at FORTH/ICS [5] and the Cerversato/De Odorico open source ECG viewer [6] that won the first prize in the OpenECG programming contest. 485 ECGs from the collection of ECGs submitted for conformance testing were used in a two-phase validation. The results of the first phase were used to enhance the functionality of the viewers and also to identify strengths and limitations of the testing tools.

The design of the web service, the evaluation methodology, and the results obtained appear in sections 2 and 3 below. Then, section 4 discusses aspects of conformance testing that facilitate interoperability such as open source, web services, and standardization, while section 5 presents our conclusions.

2. Methods

The web service interface to conformance testing has been implemented in PHP using the existing infrastructure for on-line conformance testing through a programming interface. This interface allows the user program to configure four parameters, namely the web server and port offering the service, e.g. www.openecg.net:80, as well as the username and password of the OpenECG member (see fig. 1). Using the web service, a program submits the ECG file to the selected server (e.g. www.openecg.net) for automatic testing when an internet connection is available. The client (viewer) gets back a response with the testing results: the number of errors and warnings, the URL to retrieve the posted ECG file, as well as URLs to retrieve the full content and format reports. The format of the response is HTML, unless the client specifies in the *Accept HTTP* header *xml* (setting it to *application/xml*) or *csv* (setting it to *text/csv*).

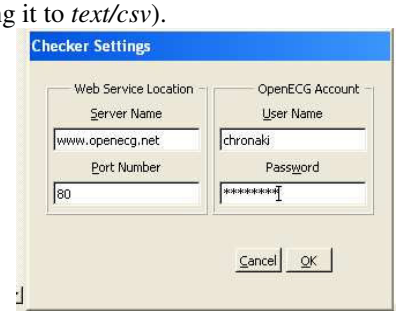

Figure 1: Configuration settings for conformance testing.

Web service integration: The web service has been integrated in two programs: (a) the Cervesato/De Odorico viewer that won the OpenECG programming contest for the best open source SCP-ECG viewer in 2004 and (b) the FORTH/ICS ECG viewer that recognizes and displays ECG records from at least 7 ECG vendors.

A new menu was added to both viewers. When the first menu item is selected, a window appears in which the web service configuration parameters can be set or modified. The other menu item prompts to browse, select, and submit an ECG file for conformance testing. This functionality has been implemented as a shared library using the *cURL* open source package [7]. The extended viewers appear in fig. 2 and 3.

Phase 1 - testing of ECGs records: The extended viewers were used to check the conformance of specific ECGs. In the absence of conformance errors, ECG display was requested in each viewer. Besides validating the web service, the ultimate goal was to improve the stability and functionality of the ECG viewers.

An ECG database maintained at FORTH/ICS includes all ECGs records submitted for conformance testing since September 2003 and is available to all OpenECG members. In June 2005, it numbers more than 600 records submitted by 35 members. Following a primitive screening for duplicates and reference/test ECGs, we selected 485 ECGs that were submitted by 33 members of the OpenECG community.

Testing the conformance of the 485 files using the web service revealed that: (a) 105 ECG files passed conformance testing without any errors, (b) 2 ECGs caused an unknown error and the web service returned no results, and (c) the remaining 378 ECG files raised a number of errors and warnings.

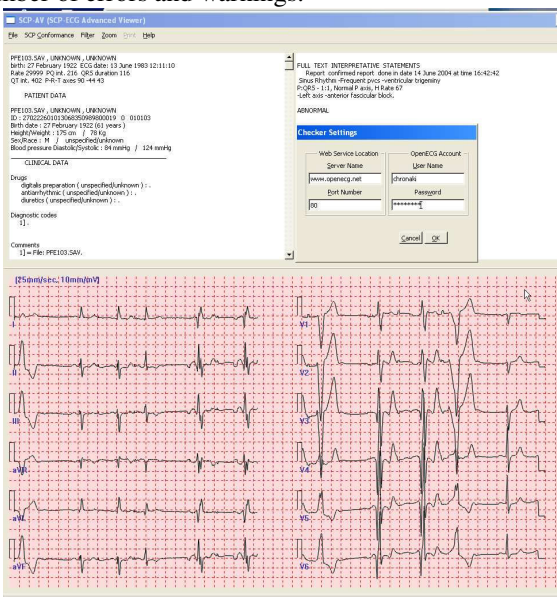

Figure 2: The extended Cerversato/De Odorico viewer available in open source at the OpenECG repository.

As shown on Table 1, the Cerversato/De Odorico viewer displayed only 40 out of the 105 ECG files that passed conformance testing without any errors. On 29 ECG records, the viewer did not display the ECG signal and simply returned a warning. In the remaining 36 ECG records, the viewer crashed.

Table 1: Each of the 485 ECG files was opened using both viewers to check SCP-ECG conformance and to validate the ability of the program to display a conforming ECG correctly.

	Viewer crashed	Viewer Warning	ECG displayed correctly	Web service failure	Conformance errors/ warnings
Cerversato/ De Odorico Viewer	36	29	40	2	378
FORTH/ ICS Viewer	0	85	20	2	378

The FORTH/ICS viewer did not crash on any of the 105 files for which the conformance testing service returned no errors. However, the number of ECG records that were successfully displayed was significantly lower. That is a policy issue, as the FORTH/ICS viewer refrains from further parsing an ECG file, unless it references in section 1, tag 14 a recognised vendor. Recognised vendors are maintained in an internal white list.

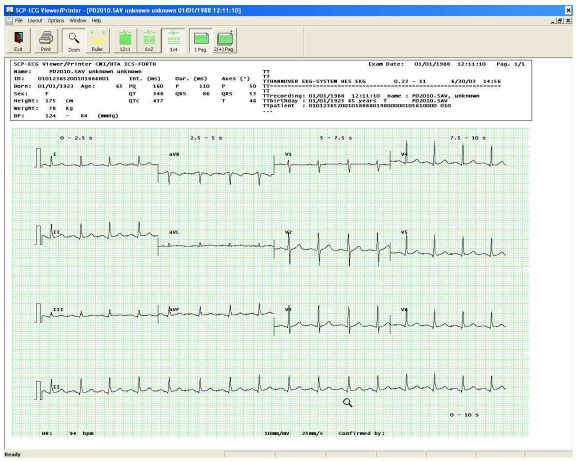

Figure 3: After revision, the extended multi-vendor viewer of FORTH/ICS is able to read ECG records from 9 ECG vendors.

Phase 2 - testing of ECG records: In phase 2, the content of each ECG file that passed conformance testing and could not be displayed, was individually inspected.

In 15 ECG files of the 29 cases where the Cerversato/De Odorico viewer returned a warning and did not display the ECG signal, the files included 2, 3 or 6 leads, while both viewers only allowed the display of 8 or 12 leads. That raised a warning and the ECG signal was not displayed. Additionally, an effort was made to investigate other cases where the Cerversato/De Odorico viewer crashed or exited with warnings. Following a debugging session, it was verified that the viewer failed to parse several ECG files due to data structure limitations. The viewer was amended and now 35 of the 36 ECG records where the viewer crashed and 4 of the 29 ECGs where it raised a warning are displayed correctly.

The manual inspection of the ECG records that the FORTH/ICS viewer failed to display revealed ECG records from 2 vendors that were not in its white list. The white list has been updated and now the FORTH/ICS viewer is able to display the corresponding ECG records. Also initially it did not display ECG signals less than 10 sec long (a CSE criterion for diagnostic ECG). The results of the second validation phase appear on Table 2.

Table 2: After code revision, each viewer was tested on each of the 105 ECG files for which the testing tools raised no errors.

	Viewer crashed	Viewer warning	ECG displayed correctly	Web service failure	Conformance errors/ warnings
Cerversato/ De Odorico Viewer	1	15+10	77	2	378
FORTH/ ICS Viewer	0	15+6	84	2	378

Evaluation of the testing tools. The current version of the testing tools (1.3a) carries out more than 400 tests including global format checks such as CRC, record length, and presence of mandatory sections and fields. Section-dependent checks for sections 0 through 6 are also performed. However, current tests do not involve cross-checking of information in different sections or checks that involve the reconstruction of the rhythm data especially in case of high compression with Huffman decoding, bimodal reconstruction of residual signal, and reference beat addition. Thus, "passing" conformance testing does not mean that the SCP-ECG file is fully conformant to the SCP-ECG specification in terms of quality assurance. Although the current version of the testing tools did not raise any errors, detailed inspection of 105 ECG files that the viewers were not able to display revealed that in 10 cases the ECG records were not fully conformant to the SCP-ECG specification. Problems with ECG files that passed unnoticed by the testing tools were:

a) Section 4 is absent where section 5 is present, thus the length of the reference beat is undefined.

b) Section 7 (global measurements) does not include "QRS type information" and "extra measurements."

c) Huffman decoding when applied to the residual signal does not produce the same number of samples on all leads.

3. Results

The web service for conformance testing that was designed, developed, and validated as part of two viewers one of which is available as open source in the OpenECG repository, increased the stability and enhanced the functionality of the viewers. In a two-phase validation, the web service gave us enough introspection into the available ECG records, to modify the Cerversato/De Odorico viewer in a way that almost all conforming ECG

records could be displayed. Initially, some SCP-ECG files raised a warning or crashed the Cerversato/De Odorico viewer. These bugs were discovered and the viewer was amended. The revised version of the Cerversato/De Odorico viewer has been released back in open source.

ECG records from manufacturers not accounted for in the multi-vendor viewer of FORTH/ICS were discovered among conforming ECG files and were used to improve the usefulness and vendor "coverage" of the viewer without compromising its robustness. The number of supported ECG vendors has increased from 7 to 9.

Finally, the identification of 10 ECG files that passed conformance testing without actually meeting the SCP-ECG specification pinpointed issues that should be taken into account in the next version of the validation tools.

4. Discussion

The creation of a web service enabled the integration of conformance testing to third party or open source viewers improving their robustness. The collection of ECG files submitted for online conformance testing allowed us to intensively test two ECG viewers through the web service. Furthermore, the fact that the web service is the only interface of the members to the tools facilitates their transparent update. Thus, every time that a member uses the service by default the newest version of the tools is used. There is no need to recompile or in anyway, automatically or otherwise, update the tools.

The new version of the Cerversato/De Odorico viewer is now available for downloading at the OpenECG repository. The role of open source is noteworthy, since it allowed us to update the viewer and offer an improved version to the OpenECG community. This is to stress once again the power of the community in collaboratively developing, testing, and promoting tools.

An obvious limitation of conformance testing available online or as a web service is that it cannot verify the accuracy of compressed ECG data, since the original raw data are not available. This is feasible in off-line testing of ECG devices, where a standard data set is used. On the other hand, the web service can provide early feedback on the correct implementation of the standard.

The current version of the SCP-ECG standard allows too many options to the implementers, and that presents a problem to integrators that wish to leverage many dialects of the standard [5,8]. Furthermore, the existing four conformance levels do not adequately address the most frequent scenarios where the standard is useful, namely electronic health record, intrahospital, ambulatory, and homecare scenarios. At this time, CEN/TC251 WG IV is working on a technical amendment to address the reduction of conformance levels in the SCP-ECG standard, and further facilitate interoperability.

5. Conclusions

Online conformance testing was originally created to drive interoperability of SCP-ECG implementations by ECG device and software vendors. This web service is a step further towards robust user-accepted vendor-neutral software systems with SCP-ECG support, advancing interoperability and quality control. It supports the practical set-up of electronic health records with digital ECGs and the wide adoption ECG analysis procedures such as serial comparison, promoting personalized health management.

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