An XML Format for Storing Body Surface Potential Map Recordings

RR Bond, DD Finlay, CD Nugent, G Moore

University of Ulster, Belfast, United Kingdom

Abstract

Current ECG formats such as SCP-ECG and HL7/aECG mainly support popular acquisition methods such as the 12-lead ECG. These formats do not, however, provide support for less prominent methods such as the Body Surface Potential Map (BSPM). As an attempt to address this shortcoming, this study introduces an XML based format for storing all multi-electrode BSPMs. The proposed format has been successfully tested by storing both the Lux 192-lead dataset and the Kornreich 117-lead dataset.

1. Introduction

In recent years the interoperability of clinical documents within and between heterogeneous Hospital Information Systems (HIS) has been a major area of research [1]. One of the main drivers towards solving the issue of interoperability has been the development of open standard formats for the storage and intercommunication of medical data between systems. According to Fischer et al. [2], cardiological information is progressively being introduced into the Electronic Patient Health Record (EPHR). As a result, a plethora of ECG storage formats have been developed over the last two decades. The three prominent ECG storage formats are the Digital Imaging and Communication in Medicine ECG (DICOM-ECG) format; Health Level 7 Annotated ECG (HL7/aECG) and the Standardised Communication Protocol ECG (SCP-ECG) format [3-5].

The DICOM standard was originally created to store radiographic images using a pixel based raster format [3]. At present DICOM aims to support all diagnostic modalities, which is why DICOM waveform supplement 30 or DICOM ECG was introduced in 2000. DICOM ECG enables raw medical waveform data storage, which in effect stores the actual ECG waveform values instead of a raster image.

The HL7 in collaboration with the US Food and Drug Administration (FDA) created a format based on the eXtensible Markup Language (XML) for storing ECGs [4]. This format was named the Annotated Electrocardiograph (aECG) and was accepted as a standard by the American National Standards Institute (ANSI) in May 2004. The aECG format was created to standardise the administration tasks in clinical trials.

The SCP-ECG standard is a binary encoded format which has been the official European standard for the storage and transmission of ECGs since 2005 [5]. SCP-ECG has been supported by the European funded OpenECG consortium since July 2002. The OpenECG network is a body of organisations dedicated to working towards solutions in the domain of interoperability in digital electrocardiography.

Within the current research, the three aforementioned ECG formats along with other formats have been examined. The main observation has been that none of the current ECG formats support the storage of Body Surface Potential Maps (BSPMs). It was found that ECG formats concentrate on supporting popular ECG acquisition methods and in particular the 12-lead ECG. In fact, these formats may lack BSPM support because the requirements for storing a BSPM compared to the 12-lead ECG are largely different. It is also difficult to develop a standard for an acquisition method that is, in itself not standardized. For example, the 12-lead ECG utilizes 10 electrodes placed at standardized anatomical landmarks, whereas a BSPM can utilize anywhere between 32 and 213 electrodes placed at custom anatomical positions [6]. This versatility and customization of acquiring a BSPM is the reason why current ECG formats lack BSPM support.

To store BSPM data, the format must support an arbitrary number of unipolar leads and store their associated electrode positions. (Given that all leads in a BSPM are unipolar, the terms electrode and lead can be used interchangeably). Nevertheless, it could be said that SCP-ECG supports the storage of BSPMs since it can store up to 255 leads, but these leads are predefined i.e. V7, V8 etc. It could even be said that a simple amendment to HL7's XML schema would enable support for an arbitrary number of leads. This amendment still leaves the problem of retaining electrode positions. Electrode positions must be stored, not just to support all BSPM electrode layouts, but also for clinical reference, post processing and for contour plotting. According to Hoekema et al. [6] there are at least 11 international BSPM electrode layouts a BSPM format must support.

Before we present our format for storing BSPM data, a number of interesting observations have been made from analysing trends in current ECG formats. In terms of implementation, Figure 1 indicates a steep trend in XML based ECG formats as opposed to binary encoded formats. Figure 2 indicates an increase in ECG formats that exclusively support one particular ECG acquisition method, in comparison to formats that support multiple ECG acquisition methods. These trends indicate a global realisation of the strength of XML and specialised formats.

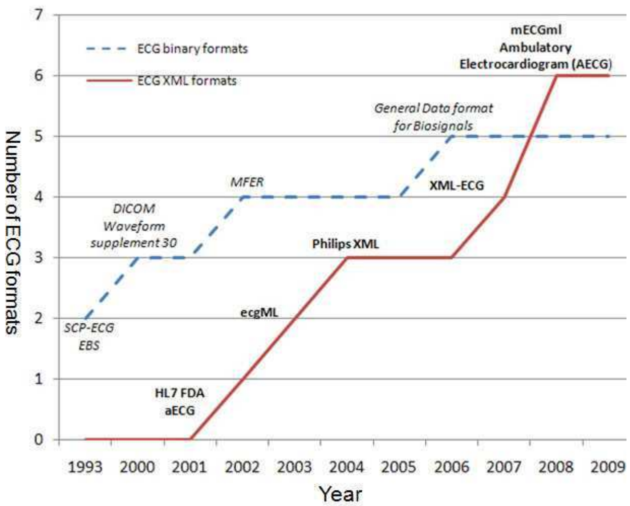

Figure 1. The number of formats implemented using XML (dashed line) and binary (solid line).

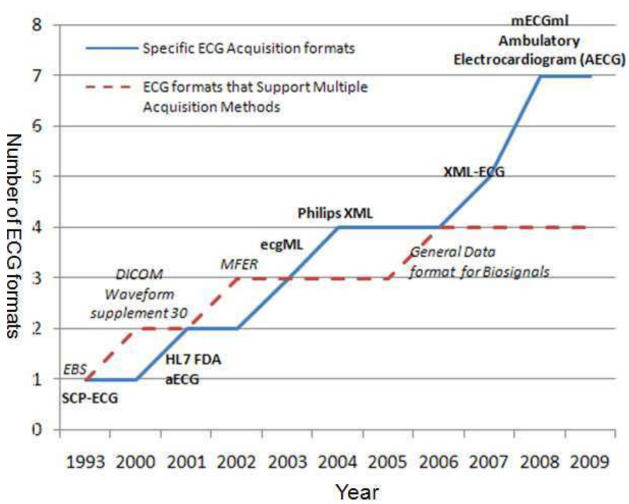

Figure 2. The number of formats that support multiple acquisition methods (dashed line), in comparison to formats that support just one (solid line).

2. Methodology

Following these ECG formatting trends, an XML based format has been developed within this research for specifically storing BSPMs. Figure 3 is a tree diagram illustrating the XML structure of this format.

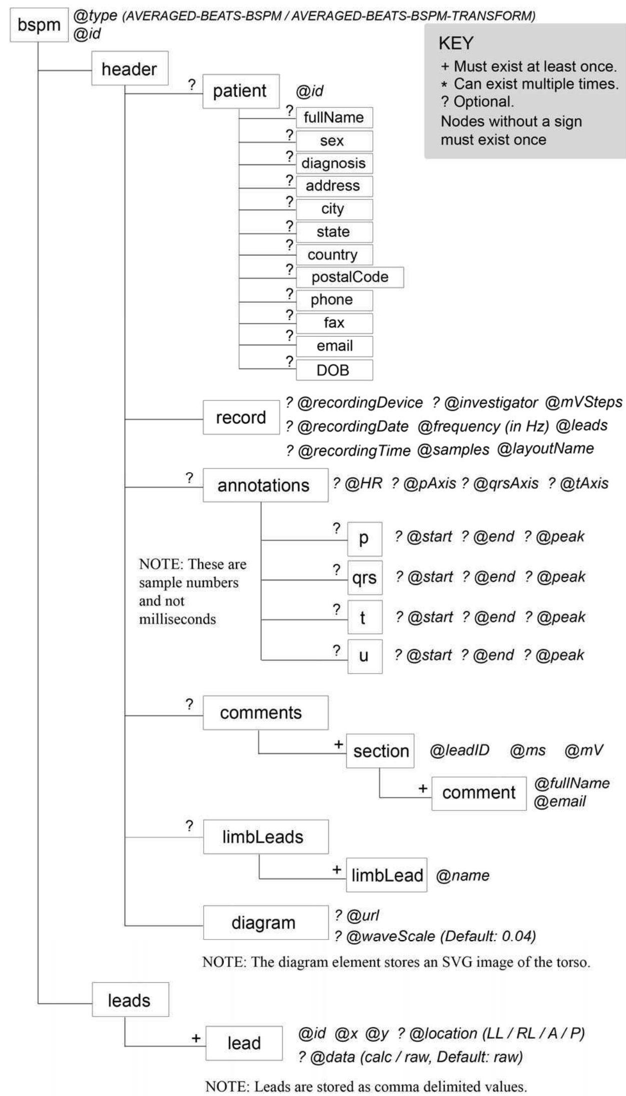

Figure 3. Tree diagram of the BSPM XML format

The root element *bspm* stores a required attribute called *type*, which can be one of two values. The value *AVERAGED-BEATS-BSPM* indicates that all stored leads contain raw data values, whereas the value *AVERAGED-BEATS-BSPM-TRANSFORM* indicates that some leads contain raw values and some leads store equations, which, when executed, calculate pseudo leads. This format currently only supports the storage of averaged beats, since several existing BSPM datasets are stored in this way. The *bspm* element also stores an *id* attribute which is useful for unique identification and database collaboration. There are two further elements within the *bspm* element called *header* and *leads*. As the name suggests the *header* element stores information about the data which is being stored, for example patient demographics and the recording settings. The *leads* element stores the actual BSPM lead data. Both these elements have sub elements which are described below.

2.1. The *header* element

The *header* element currently has six sub elements i.e. *patient, record, annotations, comments, limbLeads* and *diagram*. The *patient* element contains a further 12 elements (*fullname, sex, diagnosis address* etc.) as listed in Figure 3. These items provide all the basic information required to identify a patient. The *patient* element also has an *id* attribute (*@id*) which is a unique identifier that has been included to facilitate the integration with an EPHR. The *patient* element itself and all its sub elements are optional, as in some cases this record may be integrated with other storage formats or databases which may already contain patient demographics.

The *record* element stores information about the recording settings that were used to record the data stored in this file. This element does not have any sub elements but does have a number of attributes. Attributes have been chosen instead of elements because they improve the readability of the document. The *record* element is not optional, as all valid recordings will contain most of this information.

The annotations element stores waveform parameters that may have been identified by the recording apparatus or a human observer. The four elements contain the wave annotations for the various ECG wave components, *p*, *qrs*, *t* and *u*. Each wave element has three attributes which allow the storage of the location of the wave onset (*@start*), offset (*@end*) and *peak* (*@peak*). Each attribute value stores a sample number, as opposed to milliseconds for defining a point in the waveform. For example, one could include a sample number for the p wave onset (*@start*) and offset (*@end*). These annotations are required for drawing contour maps, for example, the ST40 isopotential map. Nevertheless, this information is optional, since such data may not, as of yet been observed or calculated.

The *comments* element can be used to store textual information inserted by a human or a classification system. This element must contain at least one *section* element. The *section* element has three attributes (*@leadID @ms* and *@mV*) which specify exactly what instant on what lead each sub *comment* is referring to. The *section* element can be repeated to facilitate multiple comments that refer to different leads. The *section* element has a sub element called *comment*. This element contains the actual textual comment itself, and it too can be repeated. This *comment* element also has two attributes (*@fullName* and *@email*). The *fullName* attribute stores the name of the author and the *email* attribute can be used for both correspondence and as a unique identifier. These comments can be used for collaboration and knowledge sharing amongst BSPM researchers and/or clinicians.

The *limbLeads* element is not a requirement, but is available to store the limb leads that were used to calculate the Wilson Central Terminal (WCT). The *limbLeads* element has a sub element called *limbLead* which stores the actual comma delimited data values. This element has one required attribute called *name* (*@name*), which identifies the name of the limb lead, e.g. VL (left arm), VR (right arm) or VF (left foot). Storing limb leads may prove useful for post processing.

The *diagram* is a required element which stores an unrolled torso schematic using Scalable Vector Graphics (SVG). This *diagram* element has two optional attributes (*@url, @waveScale*). The *url* attribute stores a Uniform Resource Locator (URL) that links to an SVG file, that either resides on a local network or on the internet. This is an alternative approach to embedding SVG markup within the *diagram* element. The attribute *waveScale,* stores a decimal number between zero and one. This attribute defines the proportional scale at which each waveform (lead) should be drawn on top of the torso diagram. If this attribute does not exist, the value defaults to 0.04 which is 4% of the actual size. This default value was chosen because it is proportional to torso diagrams that are approximately the size of an A4 piece of paper.

2.2. The *leads* element

The *header* element mainly stores information relating to the BSPM, whereas the *leads* element stores the actual BSPM data. The *leads* element must contain at least one *lead* element. It is the *lead* element that stores the actual comma delimited values. This *lead* element has five attributes, three of which are required *(@id, @x* and *@y*) and two that are optional *(@location* and *@data*). The *id* attribute identifies the lead number. The *x* and *y* attributes store coordinate values that define the electrode position derived from the top left hand corner of the SVG torso schematic that is stored within the *diagram* element. The *location* attribute defines which portion of the torso that particular lead is derived from. This attribute can have one of four abbreviated values (*RL*: Right Lateral, *LL*: Left Lateral, *A*: Anterior, *P*: Posterior). Storing a *location* attribute gives a computer program (BSPM viewer) the option to visually distinguish between for example, the posterior and anterior leads, i.e. using colour. The *data* attribute can store one of two values (*raw* and *calc*) and is used to distinguish between a lead that contains raw data and a lead that contains an equation. This attribute is only used if the *type* attribute in the *bspm* element has a value of *AVERAGED-BEATS-BSPM-TRANSFORM.*

3. Results and discussion

The torso illustration in Figure 4 is the visual representation of the BSPM format following software processing. This diagram illustrates how each *lead* defines and then derives its electrode location, with reference to the SVG torso diagram. The advantage of XML based formats compared to binary formats is that, they have a plethora of related technologies such as SVG. SVG provides a non-verbose method for storing images when compared to JPEG. To investigate this concept further, sample torso diagrams were drawn for the purposes of this study. One simple SVG torso diagram was just one kilobyte in size, whereas the rasterized (JPEG) equivalent was 50 kilobytes. As of yet, there has been no standard torso diagram proposed for displaying BSPMs and as a consequence, researchers usually draw their own custom diagrams. The proposed BSPM format within this study facilitates the ability to integrate custom SVG diagrams.

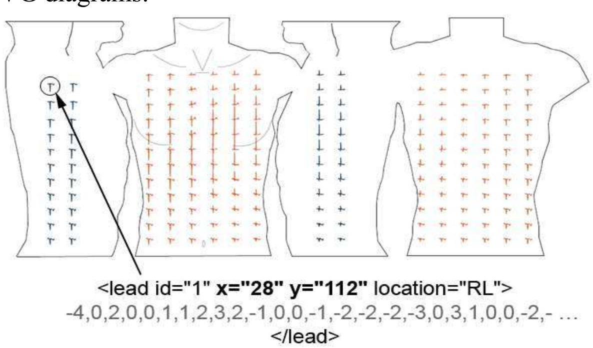

Figure 4: Torso diagram displaying BSPM leads.

To examine the utility of this format, a BSPM was recorded using the Lux-192 lead set and was stored as 291 kilobytes using this BSPM format. This file was later reduced to 76 kilobytes using a basic compression technique. This is a compression ratio of almost 4:1. This BSPM format has also been used to store the Kornreich dataset, which consists of 117 leads and three limb leads. The proposed BSPM XML format within this work supports all forms of multi-electrode layouts including the 11 published by Hoekema et al. [6]. Nevertheless, one main caveat exists. The proposed format requires an intricate viewer to visualize the BSPM data, given that the format relies on SVG rendition and calculated leads.

4. Further work

The format proposed within the current work requires further testing, with regards to the storage of calculated lead sets such as the Lux-32 layout. In the near future, the format may include novel features, such as the ability to store custom equations within the *header* of the format to transform the BSPM into other lead sets such as the 12-lead ECG and the vectorcardiogram. Moreover, this format may be further altered to facilitate the storage of continuous data as an alternative to storing averaged beats. A Rich Internet Application (RIA) is also underdevelopment for visualizing BSPM data, given that the real power of a format can be best demonstrated through the use of a viewer [7-8]. Other work may include a BSPM to SVG converter, a validation service and possibly an online warehouse, where users can share and download BSPMs. In conclusion, this research provides some initial ground work for a complete BSPM management system.

References

[1] Sfakianakis S, Chronaki CE, Chiarugi F, Conforti F, Katehakis DG. Reflections on the role of open source in health information system interoperability. Year book of Medical Informatics. 2007:50-60.

[2] Fischer R, Chiarugi F, Zywietz TK. Enhanced integrated format and content checking for processing of SCP ECG records. Computers in Cardiology, 2006:413-416.

[3] Hilbel T, Brown BD, de Bie J, Lux RL, Katus HA. Innovation and advantage of the DICOM ECG standard for viewing, interchange and permanent archiving of the diagnostic electrocardiogram. Computers in Cardiology, 2007:633-636.

[4] Brown BD, Badilini F. HL7 aECG Implementation Guide. Available from: http://www.amps- llc.com/UsefulDocs/ aECG_Implementation_Guide.pdf.

[5] Chronaki CE, Chiarugi F, Sfakianakis S, Zywietz C. A web service for conformance testing of ECG records to the SCP-ECG standard. Computers in Cardiology, 2005 2005:961-964.

[6] Hoekema R, Uijen GJH, van Oosterom A. On selecting a body surface mapping procedure. Journal of Electrocardiology, 1999;32:93-101.

[7] Bond RR, Body Surface Potential Viewer. Available from: http://bspmviewer.raymondbond.com.

[8] Bond RR, Finlay DD, Nugent CD, Moore G. A compressed XML format and a Rich Internet Application for processing and visualizing Body Surface Potential Maps. Northern Ireland Biomedical Engineering Society, 2009:29:21

Address for correspondence

Raymond Bond (Room 16J26),
University of Ulster, Shore Road, Newtownabbey,
Co. Antrim, BT37 0QB, bond-r@email.ulster.ac.uk