Integrating SCP-ECG files and patient records: an ontology based approach

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Abstract—**Health care standards like SCP-ECG (Standard Communication Protocol for Computer Assisted Electrocardiography) aim at enhancing interoperability of digital electrocardiography. However, the complexity of information included in such a file limits the wide adoption of SCP-ECG as the default standard in the field, and restricts its integration with the corresponding EHR (Electronic Health Record). In the present work, focusing on the integration between the ECG-related information and EHR, we have developed SEIA (SCP-ECG Integrated Access), an integrated environment for managing ECGs and other medical information originating from disparate sources. The SEIA system consists of an SCP-ECG Ontology defining SCP-ECG file structure, a query mapping ontology, the database used to retrieve relevant patient data, and a GUI environment used to register SCP-ECG files, pose queries, retrieve results and visualize ECGs.**

I. Introduction

ADVANCES in medical technology generate huge amounts of non textual information (e.g. biosignals, images), along with textual ones. All this information is kept in heterogeneous distributed hospital computer systems, in different file formats which are mainly proprietary. Keeping track of a single patient's medical history within a hospital, introduces many difficulties originating mainly by the diversity of data and systems. However information is only valuable to the extent that it is accessible easily retrieved and addresses the user's needs. It has been realized that added value is not gained merely through larger quantities of data, but through easier access to the required information at the right time and in the most suitable form [1]. Thus, there is a strong need for improved means of facilitating information access.

Interoperability between medical devices and between host systems is a key requirement for the establishment of integrated electronic patient health record. A prerequisite for interoperability is standardization of message formats and of messaging protocols. For computer assisted electrocardiography a specific standard: SCP-ECG has been developed in 1993. This standard specifies the interchange format and a messaging procedure for ECG cart-to-host communication and for retrieval of SCP-ECG records from the host (to the ECG cart) [2]. Since its inception, SCP-ECG has evolved resulting in various versions. Although a lot of work was put into its development, it has not yet been adopted as widely as its creators would like. The binary format that is not human readable, the degrees of freedom in its implementation that lead to misinterpretations are some of the reasons why SCP-ECG has not yet become the default standard in digital electrocardiography [3].

The above mentioned problems still challenge current approaches towards medical data integration. Patient management has become a rather complicated procedure as it consists of querying retrieval and organization of combined medical information. An example scenario that reveals the complexity of the situation is to search for both the ECG file of a patient whose name is X and the results of his laboratory examinations. The first obstacle derives from the binary format of the ECG files that is not human readable and therefore not easily searched and the second by the diversity and heterogeneity of the desirable information.

Our approach addresses the problem of integrated management and organization of SCP-ECG files, along with the query and retrieval of combined ECG and other types of medical information located in the various health systems. For that purpose we have developed an SCP-ECG OWL (Ontology Web Language) ontology to provide a formal representation of the structure and content of SCP-ECG files, in order to make it comprehensible by both humans and machines and therefore promote the interoperability and integration of medical information in a broader context like the Web. An OWL database is used to store instances of SCP encoded data, thus keeping classes and instances separated, in order to provide modularity and scalability and effectively handle a possible evolution of the system. A set of automatic store and conversion, query and retrieval services has been accommodated around the aforementioned ontologies to provide the user with the ability of handling textual and non textual data. A Java based application allows the user to read and visualize SCP-ECG records and register their parts in the ontology repository. A friendly user interface facilitates knowledge acquisition in the form of simple or more complicated queries, like "*Show all Patients and ECGs with diagnosis arrhythmia*" or "*Show all SCP files of patients over 60 years old, with diagnosis atrial*

Manuscript received July 6, 2006. (Write the date on which you submitted your paper for review.)

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fibrillation, whose medication includes Clonidine and Quinidine and have Hypertension". In order to have access to combined medical information originating from a commonly used health care system used for patient management, a mapping mechanism is consolidated in our architecture for mappings between the various fields of SCP-ECG and the aforementioned database. The user can then have access to integrated information concerning patients' medical history in a seamless way.

II. MATERIALS AND METHODS

A. *Electrocardiography*

Introduced in 1902 by Einthoven, electrocardiography is the graphical display of electrical potential differences of an electric field originating in the heart as recorded at the body surface. As a record of electrical activity of the heart, it is a unique technology that provides information not readily obtained by other methods. In fact, recording of the resting 12-lead ECG continues to be the most commonly used laboratory procedure for the diagnosis of heart disease.

There are numerous potential clinical uses of the 12-lead ECG. The ECG may reflect changes associated with primary or secondary myocardial processes, metabolic and electrolyte abnormalities and therapeutic or toxic effects of drugs or devices. In many cases, diagnosis is made by inference based on extensive studies correlating the ECG tracings with variety of clinical, pathological and experimental states. Therefore there is a need to develop solutions for integrated access to differently formatted medical data in order to improve accuracy in diagnosis and research in cardiology domain [4]**.**

In this scope, the present work focuses on an integrated presentation of the textual information incorporated in SCP-ECG format as well as in patient's electronic health record (EHR), such as diagnosis and medication, along with the actual biosignals and their main morphometric features, i.e. the QT, RR, etc. In this way, overall information can be retrieved in a consistent manner.

B. *Ontologies for semantic representation*

In order to achieve semantic interoperability in heterogenenous systems, ontologies have been widely used. Ontologies are used to capture knowledge about some domain of interest. An ontology describes the concepts in the domain and also the relationships that hold between those concepts. Different ontology languages provide different facilities. We have chosen OWL, the most recent development in standard ontology languages developed by the World Wide Web Consortium (W3C). OWL makes it possible to describe concepts but it also provides new facilities [5]. It has a richer set of operators - e.g. and, or and negation. It is based on a different logical model which makes it possible for concepts to be defined as well as described. Complex concepts can therefore be built up in definitions out of simpler concepts. Furthermore, the logical model allows the use of a reasoner which can check whether or not all of the statements and definitions in the ontology are mutually consistent and can also recognise which concepts fit under which definitions. The reasoner can therefore help to maintain the hierarchy correctly. This is particularly useful when dealing with cases where classes can have more than one parent [6].

TABLE I
SCP-ECG STRUCTURE

Type	Description
M	2 bytes - checksum - CRC - CCITT over the entire record (excluding this word)
M	4 bytes - (unsigned) size of the entire ECG record (in bytes)
M	(Section 0): pointers to data areas in the record
M	(Section 1): header information - patient data/ECG acquisition data
O	(Section 2): Huffman tables used in encoding of ecg data (if used)
O	(Section 3): ECG lead definition
O	(Section 4): QRS locations (if reference beats are encoded)
O	(Section 5): encoded reference beat data if reference beats are stored
O	(Section 6): "residual signal" after reference beat subtraction if reference beats are stored, otherwise encoded rhythm data
O	(Section 7): global measurements
O	(Section 8): textual diagnosis from the "interpretive" device
O	(Section 9) : manufacturer specific diagnostic and overreading data from the "interpretive" device
O	(Section 10): lead measurement results
O	(Section 11) : universal statement codes resulting from the interpretation

Among various examples of existing ontologies in both the medical informatics and medical information integration domain, the following are worth mentioning:

- GLIF. Referring to the medical knowledge, as coded in guidelines, an effort has been paid towards a specification for structured representation of guidelines, named GLIF [7]. An example of GLIF has been already implemented for hypertension, and can be a basis for medical knowledge representation, especially in relation with hypertension treatment.
- OpenEHR. In order to share the knowledge between the different and heterogeneous medical information systems, within the framework of a federated information system, OpenEHR ontologies [8] can contribute to interoperable electronic health records.
- TAMBIS project: Aims to provide transparent access to disparate biological databases and analysis tools,

enabling users to utilize a wide range of resources with the minimum of effort. A prototype system has been developed that includes a knowledge base of biological terminology (the biological Concept Model), a model of the underlying data sources (the Source Model) and a 'knowledge-driven' user interface. Biological concepts are captured in the knowledge base using a description logic called GRAIL [9].

In the present work, focusing on the integration between the ECG-related information and EHR, we have developed SEIA (SCP-ECG Integrated Access) an integrated environment for managing ECGs and other medical information originating from disparate sources. The idea is to adapt the querying mechanism, either using ontologies as intermediates when needed (e.g. in flat-file sources) or using standard SQL (in structured databases) and then unify the retrieved information from the distributed sources. Our system consists of an SCP-ECG Ontology defining SCP-ECG file structure, a simple query mapping ontology, the database used to retrieve relevant patient data, and a GUI environment used to register SCP-ECG files, pose queries retrieve results and visualize ECGs.

C. SEIA Architecture

An overview of SEIA system architecture is depicted in Fig.1 and consists of five main components:

- The SEO Repository Ontology and the EHR Database (knowledge base)
- Two Core Ontologies, SEO and Mapping Ontology
- The SCP to OWL Transformation Module
- The Query Handling Module
- A series of tools to assist the user exploit SEIA's capabilities.

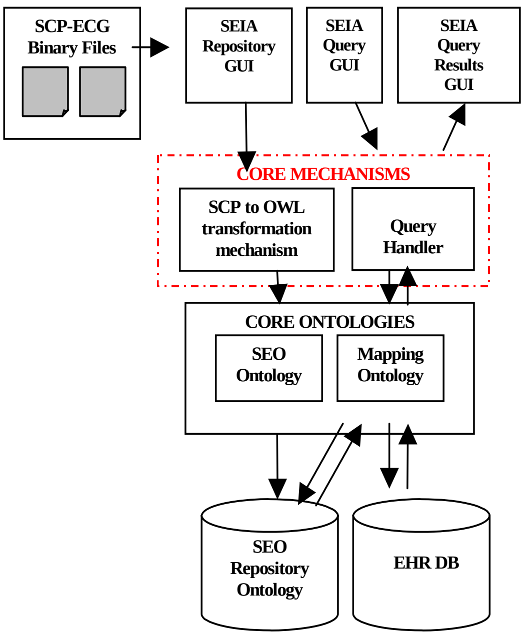

Fig. 1. SEIA Architecture overview.

D. SCP-ECG Ontology (SEO)

The aim of the SCP-ECG ontology (SEO) is to provide a commonly agreed vocabulary with formal definitions that can be used to represent ECG biosignals and the information that is encompassed in SCP-ECG formatted files. SCP-ECG standard, as defined by the TC251 committee, specifies that information is to be structured in data sections, as shown in Table I [10]. Besides the actual time-series, various types of information regarding the patient and the medical procedure are included, either as mandatory or optional fields. SEO ontology is imported by an initially empty ontology, which acts as a repository of the contents of SCP records. The user just loads SCP files in SEIA Repository GUI and a Java-based SCP to OWL mechanism mediates between the user interface and the ontology to automatically create and store instances in the repository [11]. This ontology is then queried in order to satisfy user-defined criteria synthesized in the SEIA query interface. All the queries are parsed to the ontology in SPARQL Query Language and are then combined with query results originating from the EHR database, in order to provide the user with an integrated view of patient medical information.

E. Merging SCP-ECG with the EHR

The database used to retrieve additional patient medical data originates from a commonly used health care system used for management of patients with chronic heart disease. Patient data and ECGs are stored in different computer systems and the only accurate correlation between them (except from the combination LastName FatherName FirstName) is their Patient Id Number. In order to be able to define cross queries between the ontology and the database, we developed a query mapping mechanism which transforms the imposed queries to match the combined underlying data.

For that reason we have built a second ontology to handle the query mappings and transformations. This ontology holds database and SEO ontology metadata, meaning, data about the database and the ontology describing their schema and other relevant technical information. The mapping ontology has been manually populated with instances concerning the databases, although our final aim is to automate this process and encapsulate other relevant ontologies as well. The mapping ontology is used by the query handler to transform and merge query results stemming from data contained in both the ontology repository and the EHR Database.

As already mentioned, SEO Repository Ontology stores information about SCP-ECG files in the form of instances while EHR data are stored as SQL records. Our main aim was to create a scalable solution where queries would be dynamically created. The mapping ontology maps the differences and the similarities between the ontology and the databases. Fields, tables and attributes, classes having the same context are mapped with each other in the mapping ontology. When a query is imposed, the user actually chooses the conditions to be satisfied by selecting the appropriate fields or entering the desired criteria into SEIA Query Analyzer software tool. A query is dynamically synthesized based on information extracted by the ontology and the user entered criteria. For example if patientId is selected as a criterion, our software tool can directly extract the field name or attribute name of such a parameter along with the name of the table or class it belongs. This contributes to the scalability of our approach as source code will not have to change if more databases are incorporated into the system.

As already mentioned, an SCP-ECG file not only contains ECG biosignal data, but other relevant medical information as well, which is also contained in the EHR demographic information, thus being typically common in both repositories. As far as laboratory measurements (for example systolic and diastolic blood pressure), and/or Medical Information (Diagnosis, Medical History, Drugs) are concerned, inconsistencies may arise between the two repositories. Our current approach towards this possible problem lies in the presentation of the requested information. Specifically, in the relevant interface, namely the Query Results table, results originating from both repositories are presented together, however differentiated by the colour of each row and the field origin defining the location of the data.. More sophisticated filtering and meta-analysis methods can be developed in the future.

A set of automatic store and conversion, query and retrieval services has been accommodated around the aforementioned ontologies to provide the user with the ability of handling textual and non-textual data. SEIA SCP-ECG Repository GUI uses SEO ontology to create SCP-ECG instances of ECG files corresponding with patients whose data are stored in the database.

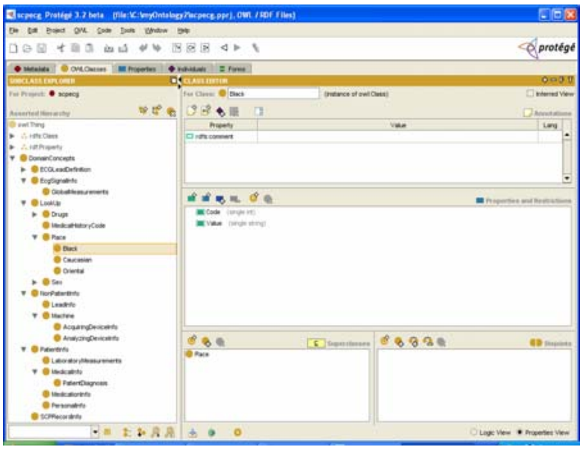

Fig. 2: Partial view of SEO ontology.

F. Implementation issues

The ontologies are written in OWL language, which is the most recent development in standard ontology languages [5]. Protégé 3.2 beta version including Protégé OWL Plugin was used as ontology editor [12], and. Racer as Description Logic Reasoner, to check the consistency of the ontology and automatically compute the ontology class hierarchy [13]. The implementation of the graphical user interface was performed with Protégé OWL API, which is an open source Java library for the Web Ontology Language and RDFs. The database (MySQL) is accessed directly via JDBC. The queries addressed to the ontology are written in SPARQL. SPARQL is a W3C Working Draft towards a standard query language for the Semantic Web. Its focus is on querying RDF graphs on triple level. SPARQL can be used to query an RDF Schema or OWL model to filter out individuals with specific characteristics [14]**.** Finally the software tool that was chosen for the project's development and deployment was Eclipse 3.2 using compiler Java[tm] 2 Platform.

The SCP-ECG viewer encompassed in the above mentioned application was developed as an entry to the openECG programming competition on February 2003. The results along with the source code of the application are published in OpenECG's web site. SCP-ECG viewer is a Java based application developed with open source tools. It offers two main functionalities: SCP-ECG viewing and writing. Specifically, the application can read SCP files and visually display their content (both alphanumeric and signal parts), as well as update it. Furthermore, a raw ECG file can be read and converted to the SCP format [15]**.**

Fig. 3: SEIA Repository/Browser.

III. RESULTS

A series of tools have been implemented to facilitate the automatic creation of ontology instances of SCP-ECG records, and query/retrieval of combined information related to both ECG and EHR data. The presented tools are SEIA Repository/Browser, SEIA Query Analyzer and SEIA Results Panel.

A. *SEIA Repository/Browser*

The SEIA Repository/Browser, as shown in Fig. 3, consists of a GUI through which the user can load SCP-ECG files, visualize their content –both the textual and biosignal data- and finally make any necessary alterations to the files. In order to transform the file to ontology instances and register them to SEO Repository the user just presses the button “Add to ontology” and the system automatically creates a number of relevant instances for each loaded file. These instances are named by class name + file name for every class of the ontology that is present in the file.

The first instance to be defined concerns information about the file and is registered to the Class SCPRecordInfo. The remaining instances refer to information contained in the file, such as patient demographic data, diagnosis, drugs etc. The relations between the different instances are implemented with two inverse object properties: “isRelatedTo” and “fileContains”. When an instance of an SCP file is created, the property “fileContains” is assigned with one value for each one of the series of instances that will be created for that file while the instance of the file will be assigned to the property “isRelatedTo” once for each one of the above mentioned instances

Some of the classes within SEO Ontology that are used to store these instances are:

PersonalInfo contains information of general interest concerning the patient, such as demographic data (e.g. patientID, lastName, etc.) contact information (e.g. Address, etc.) and permanent characteristics of the individual (e.g age, height sex and race). PatientDiagnosis class contains the physician’s diagnosis of the patient, while class InterpretiveStatements contains a textual version of latest ECG diagnostic interpretation.HeartDiseases. Class DeviceData is subclassed to MachineAcqDevice and MachineAnalDevice classes, which contain data related to the ECG acquisition and analysis device respectively. Medication class contains patient's medication. MedicalHistory concerns patient's medical history and PatientExams class consists of properties like systolic and diastolic blood pressure. Look up class is used to store all the encoded fields of SCP-ECG protocol. A class has been created for each concept and is subclassed according to data structure. These Classes have been instantiated before the first population of the ontology. Sex class which is subclassed to Female Male Unknown and Unspecified classes respectively and Race class comprising of Caucasian, Oriental, Black and unknown subclasses, constitute a part of LookUp Class hierarchy. MedicalHistory, Diagnosis and Drugs adhere to the protocol’s coding and hierarchy scheme. Although the protocol states that diagnosis is a free text field, our ontology has been annotated with terms and descriptions concerning heart diseases deriving from UMLS(tab of Protégé ontology editor).

B. *SEIA Query Analyzer and SEIA results Panel*

After a number of SCP files have instantiated SEO Repository ontology the user is ready to use SEIA Query Panel. As shown in Fig.4 the panel includes two subpanels. The upper one consists of four tabs where the user enters the criteria for the query to be performed. Each tab represents a different thematic category of criteria related to the patient and ECG.

In the first tab, named *Demographics,* the user can enter criteria related to patient demographics such as race, age, sex etc. The second tab includes conditions about the ECG biosignal like “QRS duration > < = than N msec”, “Heart rate > < = than N msec” etc. *Diagnosis and Drugs* (Fig. 4) is the third tab, where the user can enter criteria related to multiple diagnosis and medication. Finally, the tab *Clinical Info(Fig. 5)* comprises of data concerning the existence of Hypertension, Allergies, Diabetes, Hyperlipidaemia, thyroid condition, whether a patient smokes or not and laboratory measurements such as SBP, DBP values.

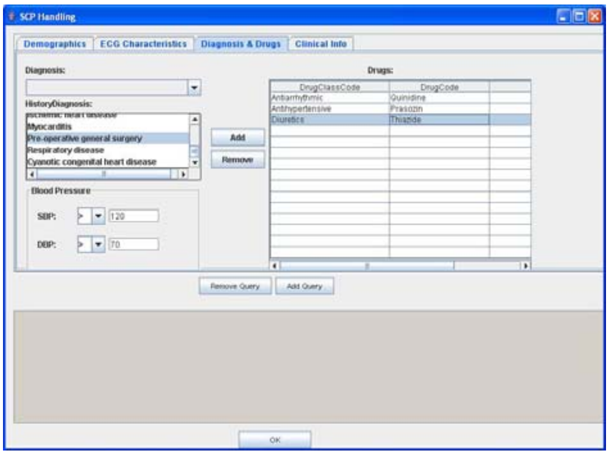

Fig. 4: SEIA Query Analyzer, Tab: Diagnosis & Drugs.

After the user has entered the desired criteria, the lower part is activated by pressing button *Add Query.* A query in natural language form concerning the previously entered conditions is displayed in the lower panel. “*Patients <Female> AND <Caucasian> < with age > 60> AND Diagnosis <Heart Failure> AND <SBP >128> AND <DBP >84> AND <Has Hypertension> AND <Smokes>AND <Has Allergies>”* is an example of an imposed query. Information extraction is performed from both EHR and SEO ontology repository.

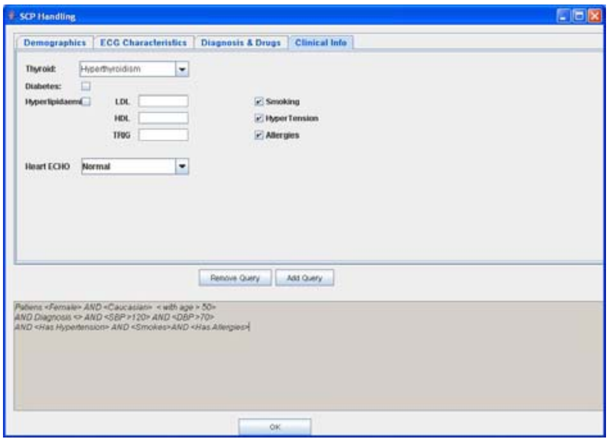

Fig. 5: SEIA Query Analyzer, Tab: Clinical Info.

The results window consists of two panels as shown in Fig 6. On the left hand side the user can see the results of the previously submitted query in the form of PID numbers and ECG filenames. The example results presented show patients' PIDs and the corresponding ECG filenames that match the aforementioned criteria, ordered by PID and date of ECG acquisition.

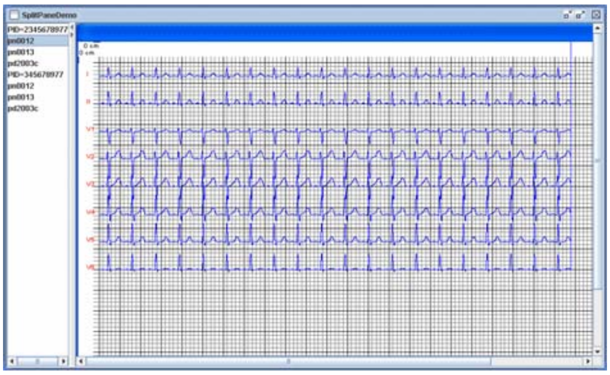

Fig. 6. SEIA Results Panel depicting a patient's ECG.

The ECG waveform, is rendered in the right panel when the user clicks on each ECG filename as shown in Fig. 6.

To facilitate the integration of information and avoid any inconsistencies deriving from the diversity of sources, textual results are presented in a table, in the right hand panel, in which each row is differently colored depending on the source of data origination. When the user clicks on PID, the right hand panel displays a table which consists of 7 rows: date, Drugs, SBP, DBP, Heart Rate, Diagnosis, ECG. For each patient the user can see the date of visit or ECG acquisition, and all the above mentioned column values, extracted either by the EHR or the SEIA repository. Empty ECG field means that data originate from the EHR, while an ECG filename denotes that data are extracted directly from SEIA repository, enabling the user to compare the presented results and resolve any possible incosistencies.

IV. DISCUSSION

Electrocardiogram (ECG) data have been traditionally generated by multiple software applications on various platforms. Furthermore local data storage and distribution uses different formats and structures. These data modelling and distribution tasks should consist of flexible and inexpensive tools to enhance pattern recognition and visualisation capabilities of humans and machines. There is an increased need to promote the development of standards in order to support a seamless exchange and migration of ECG data as well as the native integration into Electronic Patient Records (EPR) and medical guidelines. Such models should be platform-independent, flexible and open to the scientific community. In the case of ECG data interpretation, an important pre-requisite is a comprehensive data description independent of the number of channels, instrumentation platform and type of experiments. Additionally, an ECG record should include annotations relating to the acquisition protocols, patient information and analysis results [13].

An interesting effort is being made by openXDF which is an open standard for the digital storage of time-series physiological signals and annotations. The primary focus is on electroencephalography and polysomnography. OpenXDF is based on XML. Separating the descriptive data from the binary waveform data also allows multiple waveform files to be linked together under one OpenXDF header file. XML files are human readable by design, but this feature is not always desirable for security reasons [16].

Another interesting effort is the use of "ecgML: Tools and Technologies for Multimedia ECG Presentation". Based on advantages of XML technologies, ecgML has the ability to present a system- application- and format-independent solution for representation and exchange of ECG data. Moreover, a distinct separation of content and presentation (among other components such as links and semantic) exhibits a remarkable advantage over existing systems where information is merged and intertwined with its representation format [17].

The system presented in this work consitutes a proposal for integrated EHR and SCP-ECG based medical information. It provides an environment of structured SCP-ECG file representations, and can be used as a repository of ECG files, where the user can pose queries based on the textual information they contain. Furthermore, the implementation of the SCP-ECG ontology provides an explicit representation of the semantic and lexical connections that exist between information carried in the fields of SCP-ECG files. A mapping mechanism facilitates the unified querying and presentation of information originating in EHR and SCP-ECG repositories.

One of our future intentions is to provide an integrated platform, where the different formats of ECG recordings will be converted to SCP-ECG files and further enrich our repository. As far as the mapping mechanism is concerned, we consider the extension of the mapping ontology in order to include more databases and eventually automate the process of instantiating the ontology with database schema information entered by the user, aiming at a more scalable solution. A further enhancement of our system would be a filtered display of query results, presenting a merged view of valid and consistent information. Furthermore some meta-analysis of the results will help the user reason over the imposed queries.

V. CONCLUSIONS

The collection and integration of all medical information, distributed in different files, encoded in different formats, originating from different systems, is a hard and time-consuming procedure.

The proposed work, following the widely adopted ontology–based computing, is believed to contribute towards promoting the consistent use of SCP-ECG standard. Furthermore it constitutes a step towards the integration of medical information, by enabling a reusable representation of SCP-ECG based information, and by proposing a mechanism for synchronous querying and presentation of EHR and SCP-ECG based medical information.

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