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Web-Based Sharing of Electrocardiogram: A Framework for Information Publishing

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***Abstract*—Network-based data sharing is a current trend in medicine and healthcare. The search and retrieval architecture (SRA) we previously proposed for web-based sharing of electrocardiogram (ECG) facilitates the search and retrieval of ECG across hospitals via the Internet. The SRA has a triangle-like configuration including an ECG metadata registry, an ECG provider and an ECG querist. In this paper, we present a framework for ECG information publishing of an ECG provider. We also introduce a prototype of this framework, which was developed for an experimental scenario for assessment test based on MFER, an IEEE standard proposed from Japan. The assessment shows that the prototype of the framework can effectively publish the ECGs in a group of emulated MFER-conformant electrocardiographs, and the published ECGs can be successfully discovered and retrieved via the Internet.**

I. Introduction

SEQUENTIAL changes in a patient's electrocardiograms (ECGs) provide very important information for diagnosis of his/her heart diseases. So far there is no much common medical practice using sequential ECGs because easy access to a set of a patient's ECGs is not supported to a technically considerable degree. A patient's ECGs may reside in a variety of electrocardiographs, ECG Management Systems (EMSs) and Picture Archiving and Communication Systems (PACSs) of different hospitals where he/she took medical examination. It is therefore imperative to facilitate the sharing of ECGs across hospitals in such a way that a patient's ECGs can be discovered and retrieved among hospitals. An effective way to achieve this is integrating ECG data of different hospitals and providing web-based access to the integrated ECG data.

Our research group previously proposed a Search and Retrieval Architecture (SRA) for web-based ECG access. Based on the concepts derived from ebXML [1, 2], the SRA has a triangle-like configuration as depicted in Fig. 1, including an ECG metadata registry, an ECG provider and an ECG querist. The ECG metadata registry is deployed in the Internet and populated with the metadata of ECGs along with the links to their locations. The ECG metadata comprises the necessary attribute values for evaluation of query criteria, such as a patient's ID number, name and ECG acquisition date. The ECG provider is deployed in every hospital that participates in sharing of ECGs to populate the ECG metadata registry with the metadata and location links of the ECGs of the hospital. Then by means of an ECG querist, which is a web-based access application, medical and healthcare professionals can search the ECG metadata registry for a patient's ECGs and retrieve the ECGs from the ECG providers deployed in the hospitals that hold them.

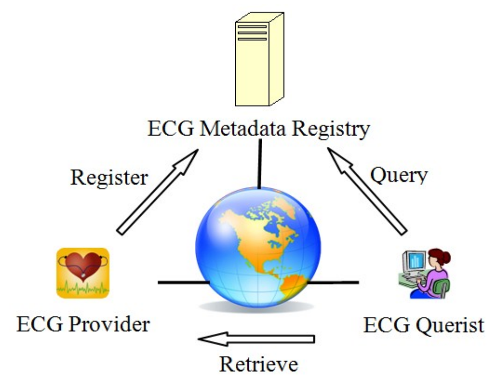

Fig. 1. Search and Retrieval Architecture for web-based ECG access

Successful implementation of the SRA has some challenges. One of them is designing a rational ECG provider. On one hand, an ECG provider is required to be able to register all the ECGs in the ECG sources in a hospital including electrocardiographs, EMSs and PACSs, regardless of what standards these ECG sources and ECGs conform to. On the other hand, an ECG provider has an obligation to apply privacy and security control to ECG access when providing services to ECG retrieval requests.

In this paper, we report a framework for ECG publishing of an ECG provider. The framework specifies a set of functional components of an ECG provider and the functional flows for major use cases, and some issues, such as the interoperability with various ECG sources which conform to different standards like DICOM [3] and MFER [4], and privacy and access control are taken into account.

II. Framework for ECG Publishing

In this section, we define the framework for ECG publishing of an ECG provider by specifying a set of functional components of an ECG provider and the functional flows for major use cases, discuss the interoperability with ECG sources and introduce some considerations on

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implementation of privacy and access control.

A. Functional Components

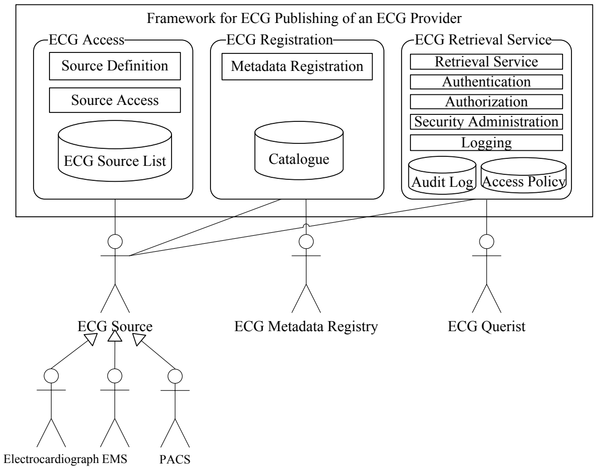

Fig. 2. Functional components of an ECG provider

According to the SRA, an ECG provider interacts with several different actors for different purposes. One is the ECG metadata registry, with which the ECG provider registers metadata of ECGs to be shared, and one is an ECG querist, to which the ECG provider renders ECG retrieval service. The others can be generalized into an ECG source actor that is simply an electrocardiograph, an EMS, or a PACS, from which the ECG provider acquires ECGs to be published for sharing. Fig. 2 depicts a collection of components that accomplish the functionalities which an ECG provider should provide to these actors:

ECG Access: supports definition of a set of ECG sources which hold ECGs and provides the capability to access ECGs from the ECG sources.

This functionality is accomplished by the Source Definition component and the Source Access component. The former aids a system administrator to define a collection of electrocardiographs, EMSs and PACSs as the ECG sources with the result that each ECG source has an entry in the ECG Source List to record its configuration information, such as source type (electrocardiograph, EMS or PACS), source name, IP address and so on. The later has the capability to access ECGs from a specified ECG source.

ECG Registration: acquires latest ECGs from the ECG sources, extracts the metadata of these ECGs and registers the metadata with the ECG metadata registry.

The Metadata Registration component performs this functionality, with each registered ECG appended to the Catalogue along with its source information, which is indispensably required when the ECG is retrieved.

ECG Retrieval Service: provides a web service for ECG retrieval to end users who are authenticated with the corresponding privilege.

This functionality is accomplished maily by the Retrieval Service component, which transmits the requested ECG from its source to an end user. The Security Administration component, the Authentication component, the Authorization component and the Logging component are for the purpose of privacy and access control of ECGs. The Security Administration component facilitates defining which users can obtain access to which ECGs. What is defined with the Security Administration component is stored in the Access Policy. The Authentication component verifies identity of an end user, and the Authorization component determines whether the end user is allowed to retrieve the ECG based on the policies in the Access Policy. The Logging component logs security relevant events in the Audit Log, which can be used to check whether the ECGs are protected in accordance to the defined policies.

B. Functional Flows

The following describes the functional flows of two major use cases:

ECG Registration: An ECG provider registers ECGs with the ECG metadata registry. (As shown in Fig. 3)

1) The Metadata Registration component acquires the configuration information of ECG sources from the Source List.

2) The Metadata Registration component calls the Source Access component to read the latest ECG data from each ECG source.

3) The Metadata Registration component extracts the metadata of all the latest ECGs.

4) The Metadata Registration component registers the metadata of each latest ECG with the ECG Metadata Registry.

5) The Metadata Registration component catalogs the latest ECGs along with their source information.

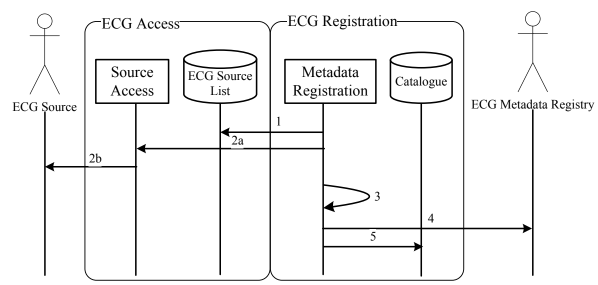

Fig. 3. Functional flow of ECG registration

ECG Retrieval: An ECG querist retrieves an ECG from an ECG provider on behalf of an end user. (As shown in Fig. 4)

1) An end user makes a request for the Retrieval Service to retrieve a certain ECG.

2) The Logging component logs relevant information from the request.

3) The Authentication component authenticates the end user. If the end user is not legitimate, the request is rejected.

4) The Authorization component finds the applicable policy in the Access Policy to apply to the request and determines whether the end user is permitted to retrieve the ECG or not.

5) If the retrieval is permitted, the Retrieval Service component looks up the source of the ECG in the Catalogue.

6) The Retrieval Service component calls the Source Access component to get the requested ECG from its source and creates a response message containing this ECG.

7) The Logging component logs relevant information from the response message.

8) The Retrieval Service component sends the response message to the end user.

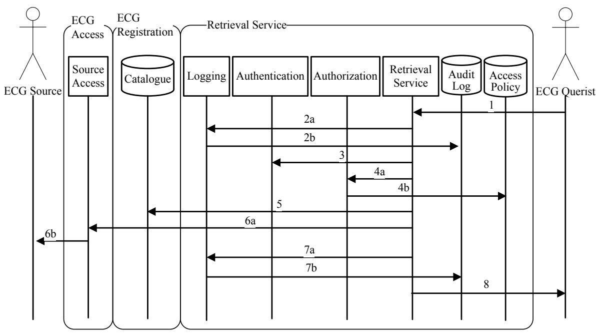

Fig. 4. Functional flow of ECG retrieval

C. Interoperability with ECG Sources

The processing procedures of the Source Access component and the Metadata Registration component depend on the information exchange protocol and the ECG file format that the ECG sources adopt. But there are differences in ECG file format and information exchange protocol between ECG sources which conform to different standards like DICOM and MFER. These differences therefore raise the issue of interoperability with ECG sources. We addressed this interoperability issue through the introduction of Generic ECG Source Layer (GESL) between the two components and ECG sources, as shown in Fig. 5. The GESL is further divided into the Abstract ECG Source (AES) sub-layer and the ECG Source Adaption (ESA) sub-layer. The AES sub-layer provides the two components with ECG source-independent function interface to access ECG files and ECG metadata, and the ESA sub-layer comprises a set of ECG Source Adaptors, such as DICOM-Adaptor, MFER-Adapter and so on, each of which provides an ECG source-specific implementation of the ECG source-independent function interface.

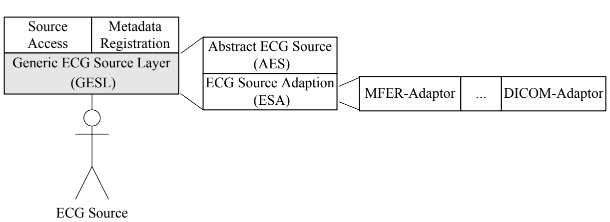

Fig. 5. Generic ECG Source Layer (GESL)

D. Considerations on implementation of privacy and access control

In the presented framework, the components Authentication, Authorization and Access Policy are responsible for privacy and access control. We implemented the privacy and access control using SAML [5] and XACML [6].

Because a user can request ECG retrieval service across hospitals, user authentication is based on federated identity and implemented following SAML IDP-initiated SSO Profile [5]. According to this profile, the Authentication component is implemented as the Assertion Consumer Service.

ECG access policies are based on Role-Based Access Control model [7] and represented as XACML policies. In accordance with XACML access control framework [6], the Access Policy component is implemented as PAP and the Authorization component performs the functionalities of PEP and PDP.

III. PROTOTYPICAL IMPLEMENTATION AND ASSESSMENT TEST

We implemented a prototype of the presented framework to publish the ECGs in a number of emulated electrocardiographs so that these ECGs can be discovered and retrieved via the Internet. The emulated electrocardiographs, which we developed as ECG sources, conform to the MFER, an IEEE standard proposed from Japan, and allow access to the ECGs through LAN.

In the prototype implementation, we developed a MFER-Adaptor for the emulated MFER-conformant electrocardiographs. The MFER-Adaptor can access a specified ECG file or the latest ECG files from a specified electrocardiograph and can extract the attribute values of a specified ECG by parsing the ECG file according to the MFER.

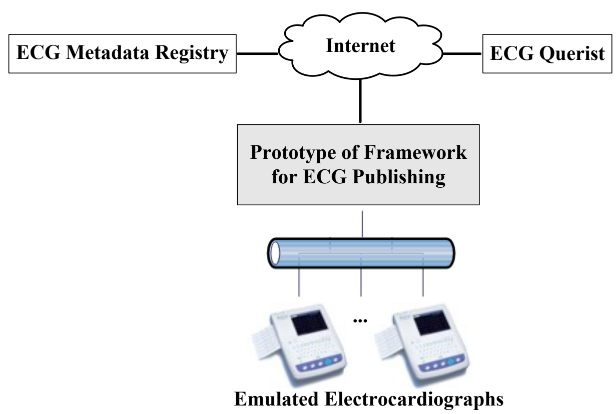

Fig. 6. Experimental scenario for assessment test

We further employed the prototype in an experimental scenario for assessment test of the presented framework. Fig. 6 illustrates this experimental scenario, where a group of emulated MFER-conformant electrocardiographs were connected to a LAN, and the ECG metadata registry and the ECG querist we had previously developed were deployed in the Internet. In order to publish the ECGs in the emulated electrocardiographs, we deployed the prototype of the presented framework in the LAN and connect it to the Internet. This prototype periodically acquired the latest ECGs from the electrocardiographs, registered the metadata of the ECGs with the ECG metadata registry, and meanwhile responded to the ECG retrieval requests from end users, who queried for and retrieved patient's ECGs through the ECG querist.

Fig. 7 shows a screenshot of the IE window where an end user queried for a patient's ECGs by his/her ID and succeeded in finding and retrieving the ECGs stored in the emulated MFER-conformant electrocardiographs.

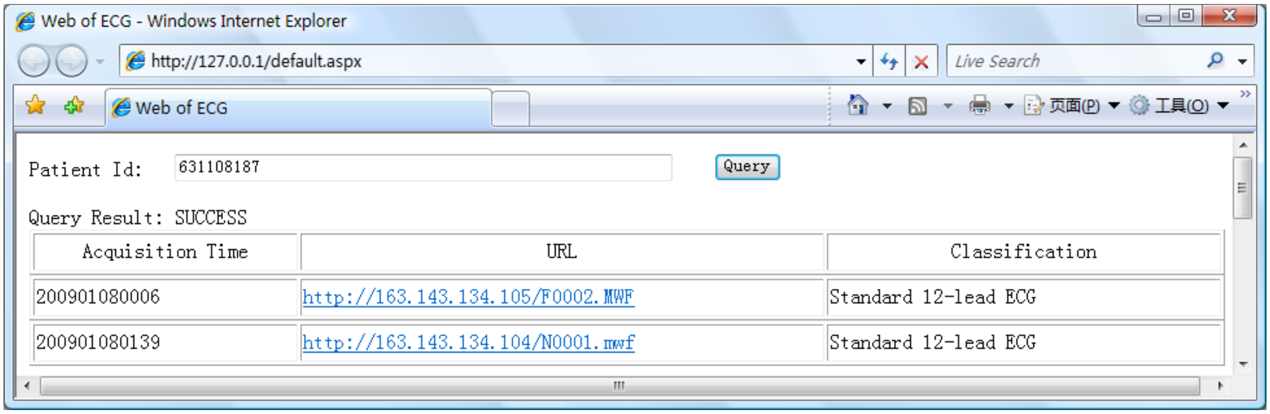

Fig. 7. Screenshot of querying interface

IV. Discussion

Although the prototypical implementation of our framework only involves the MFER-conformant electrocardiographs, we believe that the introduction of the GESL makes it viable for the framework to support a wide range of ECG sources through development and employment of corresponding Source Adaptors.

It should also be noted that in the experimental scenario, the ECG sources employed for assessment test are a group of emulated electrocardiographs which we assume able to access network and transmit ECG files in the same way as some network-enabled electrocardiographs do. So we think that the test result shows the effectiveness of this framework to a certain extent.

Other investigators have also developed some systems for web-based ECG sharing, but using these systems, only the ECGs that reside in database can be shared within or among hospitals. [8] and [9] are web applications, which enable the ECG database of a hospital to be queried and retrieved from different clinics. [10] facilitates ECG access across hospitals by setting up a national index-server with an index database containing information about the patients whose ECGs are available in the databases of the eight participating hospitals. In comparison with these systems, since an ECG provider of our presented framework can publish all the ECGs of a hospital no matter whether they are in electrocardiographs, EMS or PACS, what can be shared among hospitals is not limited to the ECGs in databases but can also be the ECGs in an electrocardiograph, EMS and PACS.

V. Conclusion

In this paper, we presented a framework for ECG information publishing of an ECG provider in the SRA. This framework may be applied to designing a system that publishes the ECGs in electrocardiographs, EMS and PACS of a hospital for web-based sharing. Through employment of our prototype of this framework, the ECGs in a number of emulated MFER-conformant electrocardiographs within a hospital can be effectively published, and the published ECGs can be successfully discovered and retrieved via the Internet.

For future work, we will perfect our prototype by developing various ECG Source Adaptors to support a wide range of ECG sources.

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