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A Novel Web-enabled Healthcare Solution on HealthVault System

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Abstract Complicated Electronic Medical Records (EMR) systems have created problems in systems regarding an easy implementation and interoperability for a Web-enabled Healthcare Solution, which is normally provided by an independent healthcare giver with limited IT knowledge and interests. An EMR system with well-designed and user-friendly interface, such as Microsoft HealthVault System used as the back-end platform of a Web-enabled healthcare application will be an approach to deal with these problems. This paper analyzes the patient oriented Web-enabled healthcare service application as the new trend to delivery healthcare from hospital/clinic-centric to patient-centric, the current e-healthcare applications, and the main backend EMR systems. Then, we present a novel web-enabled healthcare solution based on Microsoft HealthVault EMR system to meet customers' needs, such as, low total cost, easily development and maintenance, and good interoperability. A sample system is given to show how the solution can be fulfilled, evaluated, and validated. We expect that this paper will provide a deep understanding of the available EMR systems, leading to insights for new solutions and approaches driven to next generation EMR systems.

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Introduction

Electronic healthcare (e-Healthcare) is defined as "a way of delivering and achieving better health outcomes through effective and innovative use of health information" according to University of La Trobe [1]. This way has been evolved for decades with the traditional healthcare providers such as hospitals, medical centers, laboratories and doctors' offices appearing [2]. Under a hospital-centric healthcare model, our traditional healthcare facilities are focused on how to meet healthcare providers' needs and how to manage doctors and other healthcare staff [3], and so do most of the e-Healthcare systems, such as hospital management systems, billing systems and scheduling systems. However, this traditional "face-to-face" way for accessing to healthcare services has been changed a lot with the great evolution of the Internet technology. Then, the Web-enabled healthcare service is emerging as a new healthcare delivery trend, increasing and empowering "e-Patients" or "e-Customers" to seek healthcare information and purchase healthcare services through the Internet in an effective cost and efficient way.

According to the Wall Street analysts [4], the recent web-enabled healthcare delivery industry has been fostered to be a market. However, when we are using "e-Healthcare" to search the Internet, we can hardly find the real online healthcare services except for websites of selling vitamins and books, etc. There is a big gap between the limited number of healthcare service providers and the huge number of consumers. The main reason is that most of the existing e-Healthcare back-end platforms, EMR Systems, are too complicated for those Web-enabled healthcare service providers, who are

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normally the independent healthcare professionals and expected to donate more time on illness curing rather than participating an IT project programming. Finding a well designed EMR platform with easily understood and used programming interface, developing a understandable and rapidly implementable Web-enabled system model with good security, interoperability and low maintenance cost for those independent healthcare givers are the key point to deal with this trouble. In this paper, through summarizing the two-layered Web-enabled application infrastructural model and comparing the main back-end EMR systems, we propose a novel Web-enabled healthcare solution by using Microsoft HealthVault EMR [5] system and a sample online pharmacist services system based on it is to show how it deals with the trouble in rapid implementation, interoperability, security, and maintenance.

The rest of the paper is organized as following. "Background" describes the background about healthcare information systems and gathers contributions for the proposed Web-enabled healthcare solution, such as, the two-layered infrastructure model, the main back-end EMR systems, and the customers' applications. On "Web-enabled healthcare solution on HealthVault EMR system", through analyzing healthcare application users' requirements, a novel Web-enabled healthcare solution on top of Microsoft HealthVault EMR back-end system is proposed. "Sample system implementation" and "Sample system evaluation and validation" present a sample system, a pharmacist online service application, and how it is evaluated. The conclusions are drawn on "Conclusion".

Background

This section focuses on some background about health information systems and gathers contributions for the proposed Web-enabled healthcare solution. As we know, Canadian healthcare system is a publicly funded system and it can be split into two levels, the Primary healthcare services based on clinics and the Secondary services based on hospitals [6]. The major health care services and the way they are delivered have been changed from a reliance on hospitals and doctors to alternative care in clinics, primary health care centers, community health centers and so on [5, 7]. Normally, these healthcare providers are working independently and operating privately. For them, it is almost impossible to invest huge amount of money to hire a professional development team with healthcare domain experience, which can be very expensive and prefer customizing their existing system rather than build a new one according to the new requirements; or to invest big amount of time to work with programmers. These are the main trouble that blocks the Web-enabled health care services being delivered. A time and cost effective solution with necessary security and interoperability will be their best choice.

On the rest of this section, we elaborate on a two-layered infrastructure model, the main back-end EMR platforms, and the customers' application on the front.

The two-layered infrastructure model

In order to provide Web-enabled healthcare solutions for millions of e-Patients, a two-layered model can be provided to turn them into a reality. This model may consider the E-healthcare back-end platform layer and the e-Healthcare customer applications layer. This infrastructure can ensure that medical givers can devote more time to their patients, patients' health records can be accessed safely, and the healthcare services can be delivered more efficiently with lower costs and shorter waiting times. Figure 1 displays the structure of this two-layered model.

The e-Healthcare customer's applications can be either the applications used in hospitals and clinics or the Web-enabled e-Healthcare services desired by millions of e-Patients. The former applications can be accessed through a local networking or the Internet by the authenticated users, such as, doctors or staff working in hospitals or clinics. The latter is normally deployed through the Internet and works online. E-Patients are able to access to them through the Internet. Both of these two kinds of e-Healthcare applications must connect to the e-Healthcare back-end platform based on the EMR system, which electronicalizes all the private and sensitive medical information and provides some related services [8].

The e-Healthcare back-end platform

The e-Healthcare back-end platform is based on EMR systems, which is a longitudinal record of patient health information generated by one or more encounters in any healthcare delivery setting [9]. Patient demographics,

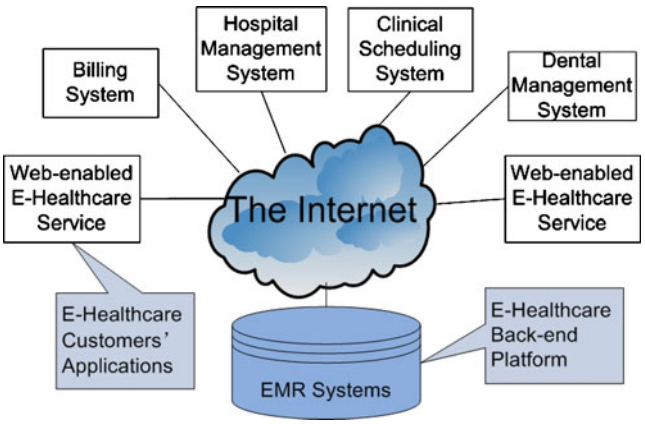

Fig. 1 E-Healthcare two-layered infrastructure model

progress notes, problems, medications, vital signs, past medical history, immunizations, laboratory data and radiology reports are all included in it. It forms the platform to support the daily clinical workflow and the other care-related activities directly or indirectly via its interface. This interface sets the standards for all customers' applications on the top. Following, several available solutions are described and discussed in the context of the goal of this contribution.

1) *Enterprise EMR systems* [10]*:* Nowadays, many companies provide proprietary EMR systems for hospitals and clinics. As Dorenfest [11] and HIMSS [11] Analytics have tracked since 2002 [10], the major enterprise/EMR vendors, for example, Medical Information Technology, Inc (MEDITECH), Siemens Medical Solutions, McKesson Provider Technologies, Cerner Corps., had got 88.82% of the market in 2005. They provide complex and comprehensive EMR systems for those big hospitals. Some small venders respect to those top ones we just mentioned, such as, eClinicalWorks [12], MedComSys [13] and Medinformatix [14], provide some EMR systems with small scale and flexible functionality, they may benefit large and medium medical group practices, including community health centers, small and solo provider practices.

Hospitals normally use complex EMR systems developed on the legacy computer system, and the doctors often need to connect to hospital's Virtual Private Network (VPN) server firstly, then they can have access to the system. The hospitals in the same health authority normally use the same EMR system. For instance, the hospitals in FraserHealth [15], which is the largest health authority in British Columbia, Canada, uses MEDITECH EMR system; but the hospitals in the other authorities, such as, Vancouver Coastal Health [11] and Provincial Health Services Authority [15], use different ones, which are most probably designed by different companies, based on different hardware platforms, and have different interfaces. Clinics also use various EMR systems, which compete against each other. Doctors often use a local network system in the clinics, but most of them also can access to the record remotely after work. Most of these EMR systems can work individually but hard to cooperate, which have caused the big problem in system resource wasting and interoperability [16]. On the other hand, as above-mentioned, these systems are often developed on legacy hardware and software platforms, which makes them really hard to find qualified developers and causes high developing cost and maintaining trouble.

2) *Free/Open EMR systems:* In order to deal with the high cost and interoperability of EMR systems, the open source community has developed a free EMR system named the OSCAR [17]. This EMR system includes the full billing capabilities, chronic disease management tools, prescription module, scheduling, and many other features. It can run locally in an office or be accessed through the Internet. The main benefits for users to choosing this free EMR system are described as the following:

- Affordability—total cost of ownership of the OSCAR EMR system and its data is usually dramatically less than proprietary EMR systems. The only fee we have to consider for building an OSCAR EMR system is to buy a suitable server box, the installation services, and/or monthly maintenance services.
- Sustainability—costs of proprietary products can dramatically escalate over the next several years as the industry moves to narrow the vendor field and system requirements increase. This will create an even more captive consumer market with proprietary systems and for those whose systems are not compliant with newer standards, it may mean a significant loss of investment and data.

However, OSCAR also presents three main disadvantages to turn it more widely used. Firstly, getting to know and use an OSCAR system for a doctor without full IT knowledge is very time consuming. There are no organizations or companies to provide pre-sale services to doctors and independent developers. The OSCAR website is the only way to get the related information. Secondly, even with the help of IT engineers, system customization is still quite difficult. The OSCAR system is driven by the open source community and developed by millions of different developers, then the source code can be piled up without full documentations and the system structure can be quite complicated. Finally, it is impossible for an independent developer without any OSCAR developing experience to add new features on it during a short time. The services provided are limited regarding installation and maintenance, and there are few people understanding the system programming and can be dependable at all times.

3) *Microsoft HealthVault EMR system:* Microsoft HealthVault [5] is a system in the middle of the both above-mentioned. It is a healthcare back-end platform based on EMR system, plus a set of services for creating an application ecosystem that lets consumers collect, store, and share health information online. This well organized and maintained platform provides a privacy-enhanced and security-enhanced foundation that can be used to store and transfer information between a variety of e-healthcare customer's applications, hospital applications and healthcare devices.

This system has three major advantages. Firstly, it presents a low cost solution in developing and maintaining. Contrast to the first two platforms that users have to purchase or download an EMR copy, to get the suitable hardware, and to worry about the network bandwidth, database performance and access security. The HealthVault EMR system is always running somewhere of Microsoft datacenter with probably the best IT engineers in the world taking care of their security and performance. The only pay, which is much more less than purchasing software, hardware, and maintenance, is the joining fee for becoming a HealthVault application. Second, it is finely designed and used advanced technology. HealthVault system is the latest EMR system among the three we have mentioned above. It is designed by Microsoft experts and adopts the newest software engineering, database, information security, networking communication, and hardware technologies, which ensure that millions of front-end applications (the e-Healthcare customer's applications) can be successfully supported. Another important issue is sustainability. Healthcare industry as the 4th largest industry in the world has been attracting Microsoft for a long time [4]. HealthVault EMR system is the core platform for Microsoft to enter this market, as we have noticed that HealthVault system is running in the United States and still beta testing in Canada. The HealthVault team is still working very hard to improve the whole system and add more features, better performance and higher security can be expected to be coming. Finally, the system offers an easy customization. With sufficient documents and sample codes in Microsoft MSDN website [5], any interested individual with some experience in programming language C# [18] and ASP.NET [19] can develop a customer application on top of HealthVault. New development solutions and models are also published on MSDN or through yearly conference. Online discussion can also be accessible on HealthVault developing forum.

The e-Healthcare customers' applications [20]

All the healthcare applications on top of the EMR platform can be named as e-Healthcare customer's applications. They can be divided into two categories, the hospital/clinical-oriented and the e-Patient-oriented. Hospital/clinical-oriented applications are traditional and have been involved for decades. Almost all the hospital healthcare system and part of clinical healthcare system in developed countries can be categorized into this sector [10]. They are legend and cost a lot in updating and maintaining. More than 80% of them are based on proprietary EMR systems [10]. The interoperability has become one of the biggest issues [15]. E-Patient-oriented applications are also called Web-enabled healthcare services. In recent years, they are emerging as the result of healthcare delivery changing from hospital-centric to the Internet-based [7]. They also can be subdivided into two types, one for health care consumers to manage their own healthcare records and the other for health care givers to provide healthcare services. MyHealthVault [5] and MyOscar [17] provided by Microsoft and open source community belong to the first sector. Individuals can logon them and review/manage their health records. The Web-enabled services provided by healthcare providers are the most needed not only by e-Patients but also by the wellness concerned. Fully closed and opened back-end platform are too complicated for common healthcare actors such as family doctors, dentists, and pharmacists, to build their own Web-enabled healthcare services. Microsoft HealthVault system can be a good choice with low cost, necessary security, and rapidly development tools to create a small and middle sized Web-enabled healthcare service.

Web-enabled healthcare solution on HealthVault EMR system

As above-mentioned, with the ways by which people access to all kinds of services are being significantly changed by the Internet, the traditional "face-to-face" healthcare delivery may not fully meet the new requirements from trillions of "e-Patients" or "wellness-concerned" [4], who may sit at home seeking healthcare consultant or help online instead of lining up hours just for ten minutes talking with doctors in hospitals or clinics. However, the reality is that fewer of the healthcare online services can be found currently. The main reason is that most of the EMR systems widely used today, as the core back-end platform for front-end healthcare applications, are those products based on previous trends, which put their focus on hospitals and clinics rather than patients. Such kind of the back-end platform has very complicated structure and the interface is not shared. There is hardly a way to evolve it to the new trend, "patient-centric" web-enabled healthcare services, which normally needs to do the system redevelopment according to the EMR platform interface and provided by independent healthcare providers. In the rest of this section, a novel Web-enabled healthcare solution based on HealthVault EMR platform will be discussed through analyzing the system requirements, the system design, and the data model.

System requirements

The common Web-enabled healthcare services are provided by independent healthcare providers, and facing the wellness and patients concerned. So such kind of applications is normally small application, and its providers and consumers are all individuals, who may or may not have IT

technology and programming background. Such kind of applications has several features.

- Cost effective. Since this kind of applications is small, and its owners and consumers are individuals, we cannot expect them to spend huge money in building such kind of application or buying a service through it.
- User friendly. The user interface must be extremely friendly and easy to use. Both services providers and consumers are not IT technical oriented, and the most important is that we may be able to train the providers but never have chance to train our consumers, once they get confused, they never come back again.
- Easily developing, deploying and maintaining. As we above-mentioned, the providers are individuals, they may not have deep IT technology. The typical case is that they hire a couple of helpers to do the developing, deploying and maintaining. With the limited budget, we cannot expect the helpers have deep domain knowledge and comprehensive system design skills. A simple system design, rapidly development model, less work in deploying and maintaining are what they want.
- Information security. Any information related to individual's healthcare record is privacy and sensitive. How this information is stored and accessed should be privacy-enhanced and secure-enhanced is a big concern. In addition, customers might need to access to such kind of Web-enabled healthcare services to buy a healthcare service, the information about online paying also should be privacy-enhanced and secure-enhanced. Based on the related literature and the system requirements, next section will focus on proposed system design.

System design

As discussed in previous sections, a Web-enabled healthcare service must be built on top of the EMR systems. In this proposed solution, we are going to employ Microsoft HealthVault EMR system instead of any other existing EMR systems used in hospitals or clinics because of its low cost, sophisticated architecture, and enhanced security. The whole solution involves Microsoft Internet Information Server (IIS) [21] web server, Microsoft HealthVault system [22], and MySql [23] database where some necessary help information may be stored locally. The workflow of our solution is shown in Fig. 2.

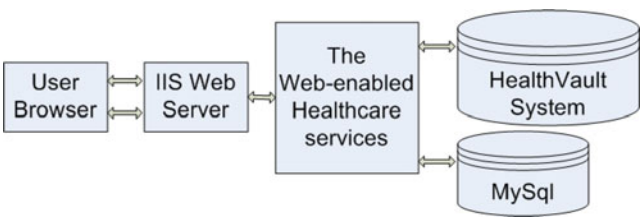

Fig. 2 The working flow of the proposed solution

In this system, we have two types of users, (*i*) healthcare customers and (*ii*) healthcare givers. Healthcare customers may go to our web pages to browse the free healthcare information as well as login to web-enabled healthcare services to purchase some healthcare advances, such as pharmacy consultant, weigh-lose guidance, fitness advances, or chronic disease watch. Healthcare givers can review the healthcare information, which has shared by its owner and give some answers through our system. The main functions include the following main functionalities: (*1*) users login and logout; (*2*)healthcare information share/retrieve/update/delete for login customers; (*3*) Shared healthcare information retrieve, advices give for login givers; and (*4*) bill paying. The whole system architecture is depicted in Fig. 3.

As the back-end platform, HealthVault system works as a database to store all the EMR information in a proper way in which any user cannot only add/update/delete/retrieve their own records but also share the records to the healthcare providers. The HealthVault system interface APIs are such kind of ways to be used to interact with HealthVault EMR system. All the APIs are programming in C# [22], so all the web pages on the top must be written in ASP.NET/C# [22] to easily call the APIs. Beside HealthVault system in the back-end, we also can find Mysql database in Fig. 3. It is used for storing the user information and HealthVault visiting information so that only the authenticated customers can use the healthcare services and only those records shared by an authenticated customer can be visited by the healthcare provider who is given the right by that authenticated customer through this proposed application. In this proposed design, we suggest to use Mygeneration [23], which is a free database mapping tool, to map MySQL tables into classes to avoid from writing the boring Structured Query Language (SQL) [24] sentences and their testing Fig. 4.

From all the above-mentioned, a rapidly implementable and cost effective design has been proposed. By using

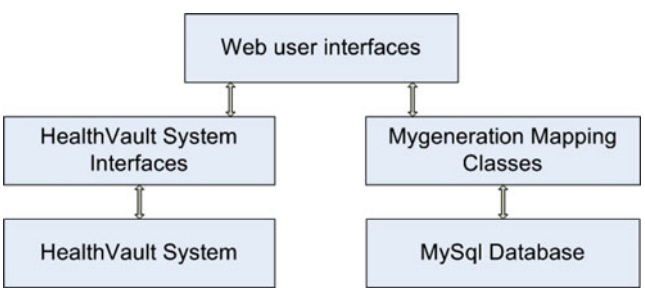

Fig. 3 The architecture design of the proposed web-enabled healthcare service solution

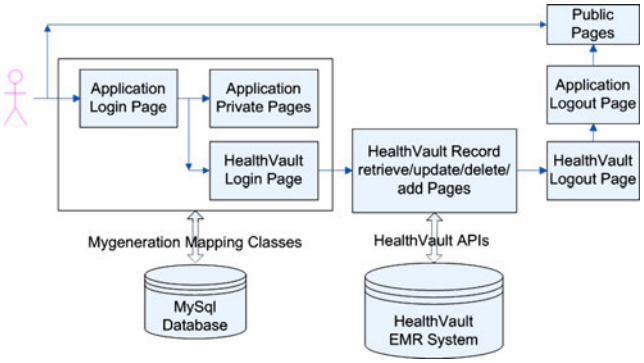

Fig. 4 The sample system architecture

HealthVault EMR system as the back-end platform, application developers inherit a free EMR platform with open interfaces, sample codes, documents, and even sample projects. The MySQL database and Mygeneration mapping tool are also free and save lots of energy for developers in database testing. C# and ASP.NET programming languages are very handy and understandable for all developers with basic programming skills. Next section will present the data model to see how the healthcare information is organized in the HealthVault system.

Health data schemas

Microsoft HealthVault EMR System has a generic data model to hold the possible health related data and provide methods to access them. All the health data records in HealthVault are described in Extensible Markup Language (XML) [25], they are structured in a flexible way. This section will discuss how these health records items are designed and how to access them by introducing the most important class, HealthRecordItem Class [26].

1. *Microsoft Health Records Items:* A health record item is a single piece of data in a health record that is accessible through the HealthVault API. All the healthcare related information can be organized into different kinds of health record items. Figures 5 and 6 are two pieces of codes copied from the definition of the HealthRecordItem Class [26]. As shown in Fig. 5, we can see that a health record item can be structured into the type-common information and type-specific information. In HealthRecordItem Class, the type-common information is described as HealthRecordItemKey, the unique identifier of the type of which the item is an instance; HealthServiceAudit, the audit information associated with the creation of this health record item; the DateTime, the date and time that the health record item data was taken; the HealthRecordItemPermissions, the effective permissions on the item granted to the person retrieving; the TypeId, the type identifier for the health record item type; the TypeName, the name for the health record item type; and the other common item data, such as the notes, sources and extension in the ComonItemData part. On the other hand, different type of health records has different type of contents. The TypeSpecificData is used to describe this type-specific health content as shown in the Fig. 6. About 100 XML schemas [27] have been provided to describe almost all the different health record items. The bold statement in the following is one piece the XML descriptions of Weight Measurement type item, it is retrieved by using the GetItemXML() method of HealthRecordItem Class from our sample project, which is going to be proposed in "Sample system evaluation and validation". This piece of XML document shows how the weight information is structured and the data is stored in HealthVault. But if you still cannot find the suitable

Fig. 5 Part of HealthRecordItem Class definition

```
public HealthRecordItem(Guid typeId, IXPathNavigable typeSpecificData);

public CommonItemData CommonData { get; internal set; }
public HealthServiceAudit Created { get; }
public DateTime EffectiveDate { get; internal set; }
public HealthRecordItemPermissions? EffectivePermissions { get; internal set; }
public HealthRecordItemFlags Flags { get; internal set; }
public Collection<HealthRecordItemSignature> HealthRecordItemSignatures { get; }
public bool IsDownVersioned { get; }
public bool IsImmutable { get; internal set; }
public bool IsPersonal { get; set; }
public bool IsUpVersioned { get; }
public HealthRecordItemKey Key { get; internal set; }
public HealthServiceAudit LastUpdated { get; internal set; }
public OtherItemData OtherData { get; set; }
public HealthRecordItemSections Sections { get; internal set; }
public HealthRecordItemState State { get; internal set; }
public Collection<string> Tags { get; }
public IDictionary<string, XmlDocument> TransformedXmlData { get; }
public Guid TypeId { get; internal set; }
public string TypeName { get; internal set; }
```

```
public IXPathNavigable TypeSpecificData { get; set; }

public string GetItemXml();
public string GetItemXml(HealthRecordItemSections sections);
public string GetItemXml(string elementName);
public string GetItemXml(HealthRecordItemSections sections, string elementName);
public int GetSizeInBytes();
public bool IsSignatureValid();
protected virtual void ParseXml(IXPathNavigable typeSpecificXml);
public void Sign(X509Certificate2 signingCertificate);
public void ValidateCertificate();
public virtual void WriteXml(XmlWriter writer);
```

Fig. 6 Another part of HealthRecordItem Class definition

item type to hold your data, a new type can be easily created by using some API provided.

"<thing><thing-id version-stamp=\"229b66d3-baff-4d74-a5a4-36b65d163d4c\">34c6ee9c-4f30-43d2-8915-af2504308add</thing-id><type-id name=\"Weight Measurement\">3d34d87e-7fc1-4153-800f-f56592cb0d17</type-id><thing-state>Active</thing-state><eff-date>2009-02-19T20:47:10.484Z</eff-date><data-xml><weight><when><date><y>2009</y><m>2</m><d>19</d></date><time><h>20</h><m>47</m><s>10</s><f>484</f></time></when><value><kg>0.328547354009257</kg></value></weight><common/></data-xml></thing>"

2. *The related access Methods:* In order to access to the data stored in the TypeSpecificData, some generic XML methods are provided, such as GetItemXml() is to get the XML representation of the health record item; ParseXml() is to parse the type-specific XML data for the item; WriteXML() is to write the XML for the type-specific data of the item to the specified XmlWriter, through which the XML data is finally written back to the health record item. By defining the HealthRecordItem Class, Microsoft HealthVault EMR system provides a generic data model to describe the different healthcare related information. This data model is structured because every type of item has the same sub-items, and it is also flexible because the type-specific health data is described in TypeSpecificData sub-item by using the type-specific XML schema. This type-specific XML schema can be modified and rewritten, so that the different health data standards can be complied with and the interoperability can be supported.

So far, we have discussed what are the system requirements for a HealthVault based Web-enabled healthcare solution and how this kind of system can be designed. More important is that by analyzing the health data schema used in HealthVault we have illustrated that HealthVault can be generic back-end EMR system to support varied front-end applications. Next section a sample implementation will be presented to show how this proposed approach can be used.

Sample system implementation

Using the proposed approach, we have implemented a Web-enabled pharmacy service which provides pharmacy related consultants online. Figure 4 shows the sample system architecture. This sample system has multiple web pages including public pages and private pages. The public pages contain some general information about healthcare news, event, and the service provider. They can be browsed by anybody. The private pages consisting of the information related to a specific customer can only be accessed to by that login customer. The HealthVault records pages as a part of the private pages containing all the sensitive healthcare information have to be accessed to through the cutomer's Windows live account. As above-mentioned in the previous section, the whole system runs on top of HealthVault EMR platform and MySQL database. HealthVault EMR APIs and Mygeneration mapping classes are used to interact with the back-end EMR system and database to save developing and testing time.

Figures 7, 8, 9 depict the basic functionalities for each type of users. As above-mentioned in the previous section, there are two types of users, customers (public or login) and doctors (login). The public customers can browse the free healthcare information through the web page. The login customers can review/modify/share their private healthcare

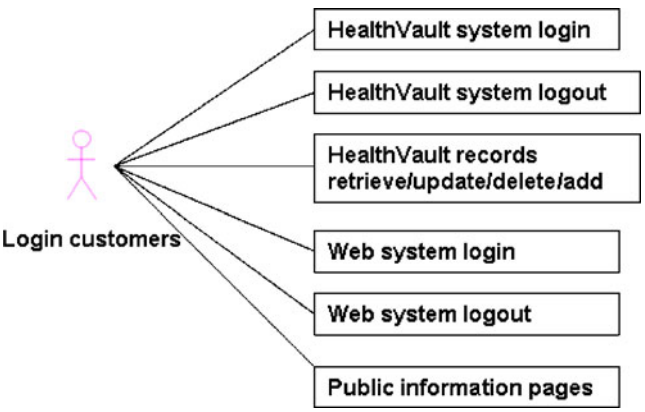

Fig. 7 The basic functionalities for login customers

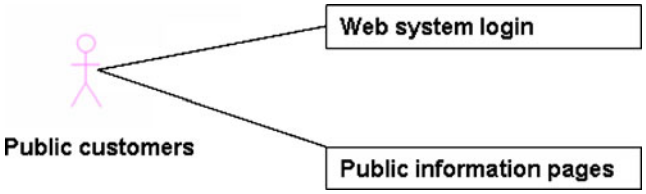

Fig. 8 The basic functionalities for public customers

records stored in HealthVault system through our system and ask for healthcare giver's advices. The healthcare providers can login to our system, review the customer's shared information and give the advices. A paying service also can be implemented according to the needs.

The sample system runs on Microsoft windows XP, using an ASP.NET [19] platform and IIS web server. It can be run on the main web browsers, such as Internet Explorer 7+ and Firefox2+. Secure Socket Layer (SSL) [28] service [29] also can be easily set up through IIS for some pages related user private information, which is expected to be security-enhanced.

This sample information system (IS) was developed on Windows XP + SP2 + Visual Studio.NET 2005 + HealthVault Development Kit. ASP.NET/Javascript and C# are the web programming languages to deal with the web programming. All the HealthVault API will be programmed in C# and integrated into the related web pages.

Several public healthcare information pages including, such as, home page, services page, about us and contact us, to provide some general healthcare information should be available to the public for free. Some features, mainly used by login users to access to the Web-enabled online health care service are the following: (*1*) User Login to our sample system/HealthVault system; (*2*) Customer Retrieve/Update/Delete/Add the his/her health information in HealthVault; (*3*) Providers Retrieve/Add information to a specific customer's health record; and (*4*) Logout from HealthVault system, Logout from our service.

Sample system evaluation and validation

This sample system adopts the proposed system model in "Web-enabled healthcare solution on healthVault EMR system", meets the basic requirements discussed in "Sample system evaluation and validation" and was implemented under the proposed design. The whole system is done in 2 months, 1 week's requirement collecting, 1 week's system designing, 1 week's Web page programming, 3 weeks' HealthVault system integrating, 1 week's testing and 1 week's deploying by an experienced ASP.Net/C# programmer but without touching any HealthVault API before. In contrast with any other solutions based on the private EMR system and free EMR system, which may have a experienced C++ or Java programmer at least 6 months to review their interfaces and get to start, it can be a time effective solution. It is also cost effective in terms of its short development period, lower programming skills which means lower human being resource cost, free HealthVault system including software and data space, and Windows developing/operating environment with cheap server box. The other solutions cost a lot, either to purchase the EMR license and high-end server box or to find a qualified developing and maintaining team.

In the rest of this section, we will firstly present this sample system, and then discuss its interoperability, security, and performance.

Sample system presentation

This sample system is a pharmaceutical online service application, which is one of the typical Web-enabled healthcare systems desired by individual healthcare providers and e-Patients. In this section, we present some screenshots to show how this application works. Figure 10 is the Home Page. As the above-mentioned, there are several public pages and private pages. All public pages are

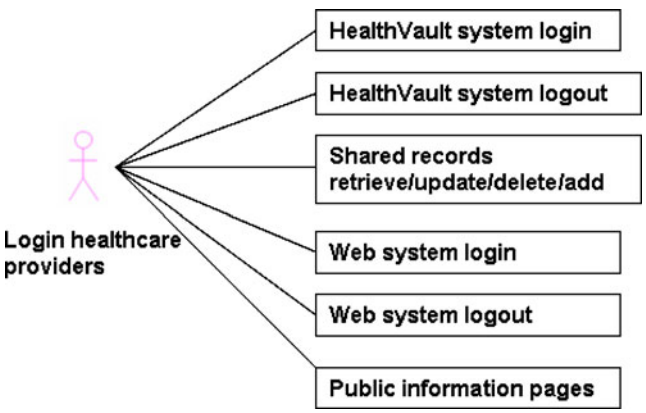

Fig. 9 The basic functionalities for login healthcare providers

Fig. 10 The sample system Home Page

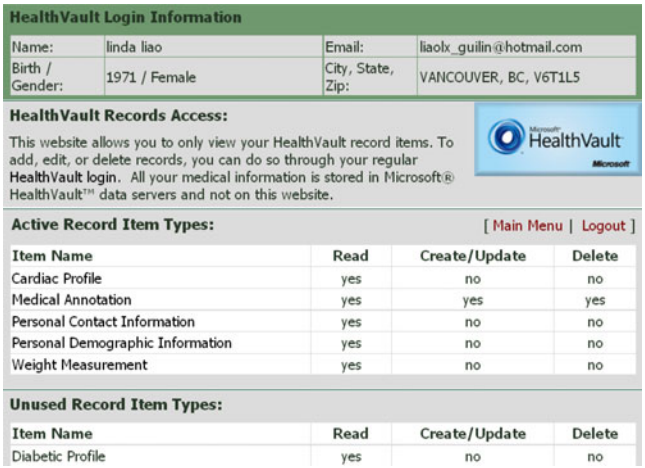

Fig. 11 HealthVault item page for e-Patient

showed in the main menu bar. The private pages only can be accessed to through *Client Login* page.

As above-mentioned in last sections, we have two types of login users, one is login *e-Patient* and the other is login *healthcare provider*. When an e-Patient logs in, he/she will see some of his/her information stored in HealthVault system. Figure 11 displays the page that a login *e-Patient* finally sees. This e-Patient's basic information will be showed on the top of the page, and following two tables show the items which have records in and the empty ones. Every item in the first table is a link, which links to a new page contains all the records of this item in remote HealthVault system. Figure 12 is the page showing all the records in Weight Measurement Item of this login user (the data is used by testing and not meaningful). When the *healthcare provider* logs into this application, he/she, also as the owner of this sample application, has two tasks, one is to manage the e-Patients and the other is to review the e-Patients' health records and give advices. Therefore, this sample system provides a page, which is depicted in Fig. 13, to direct the healthcare provider to either review healthcare records or to manage system users. The healthcare provider can select an e-Patient who is listed in the top table in Fig. 13, and open a page which is almost as same as the Fig. 11 is showed. Picking an item in the first table, for example, weight measurement item, we get a new page in Fig. 14. No delete button in this page because the

Fig. 12 Weight measurement item page

Fig. 13 Login healthcare provider page

healthcare provider in this sample system only has the right to review e-Patients' records, and the medical annotation [30], which is also one of the HealthRecordItem in the HealthVault, is added to let the provider to give advices.

Interoperability, security and performance

As we have mentioned in "Background", interoperability has been the biggest issue [15] to bother e-Healthcare industry for decades because most of EMR systems have their own system data model, they hardly follow the same standards [15]. However, it is not able to be a big deal to our proposed solution any more since XML schema is used to describe the health record type and stored the record values are stored. The data model for HealthVault is flexible. A health record type can be redefined and a health record data can be restructured without toughing any other health record items. HealVault has already provided the XML schema for almost of the main existing EMR standards in the world [31]. If unfortunately the EMR format used in other application that our proposed system is willing to interoperate with is not in HealthVault system, a new XML schema can be easily created by calling HealthVault API. In this sense, a Web-enabled service based on HealthVault can share and transfer healthcare records with

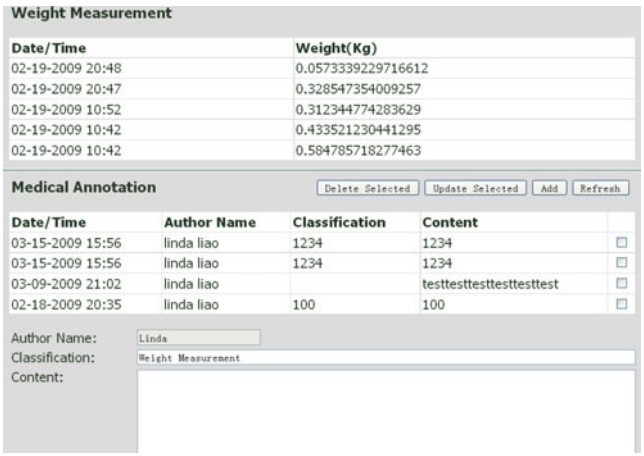

Fig. 14 Weight measurement item page for the login healthcare provider

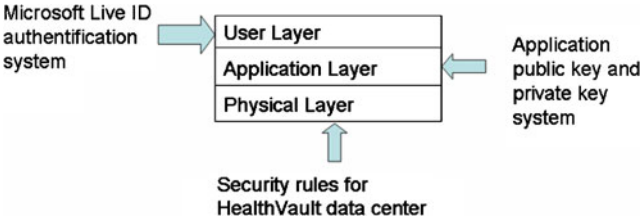

Fig. 15 The security model of the sample system

any other application based on any other EMR platform. For those applications based on the same HealthVault system, they can interoperate automatically since they share the same back-end system.

Since e-Healthcare system deals with the private and sensitive healthcare information, system security is another big issue that has to be considered. In this proposed system, all the sensitive data are stored in the remote HealthVault system except the application user account data, which are stored in the local MySQL database but only used for login to the application not to the HealthVault system (it can be accessed to by using users' Windows live account). Therefore, how secure a user can access to and share his/her sensitive data through this proposed system is the key to evaluate the security of this system. Figure 15 depicts a three-layer security model used in this proposed approach.

The layer in the bottom can be all the security rules for the remote HealthVault data centers [31], which are taken care of by Microsoft IT expert and can be expected to be securer than any hospitals' computer rooms or clinics' computer rooms. The middle layer is the Application Layer, which is provided by HealthVault system through an asymmetric encryption mechanism [31, 32]. Every application based on HealthVault system will be required to get a certificate from Microsoft, through this process, HealthVault system creates a private and a public key for this particular application and deliver the public key to it. When a user tries to connect to HealthVault system through this application, HealthVault system will authenticate this application and open the resource in a proper way which has been approved when this application applies for the certificate. It can be what kinds of items in HealthVault and they can be read, written, or both. This public key is called application ID in the *web.config* file of the application solution. Figure 16 is a part of the *web.config* file showing how to write the application ID.

The top layer is the user authentication layer. As above-mentioned, the user's healthcare information stored in HealthVault system can only be accessed to by using his/her Microsoft Live ID [33]. The local application can leave the whole authentication process to Microsoft Live Service, which has enabled over 300 million potential online users to access their applications [33].

```
<appSettings>
  <add key="ApplicationId" value="05a059c9-c309-46af-9b86-b06d42510550" />
  <add key="ShellUrl" value="https://account.healthvault-ppe.com/" />
  <add key="HealthServiceUrl" value="https://platform.healthvault-ppe.com/platform/" />
```

Fig. 16 Application ID in web.config file

The performance should be considered more about the back-end EMR system since the solution's target is to provide some services related to EMR information. Therefore the whole solution's performance turns to be the performance of the back-end EMR system and the way how you integrate it. It is reasonable to believe that the HealthVault system as the newest EMR platform will employ the most advanced technologies to manage this system. For this proposed sample system, the most time consuming page is the page showing all the items with records and the empty ones because a for loop has been used to traversal all the items in HealthVault system to get a name list for all the item, and then another for loop to be used to split it into a record one and empty one. It should have a better way to get the lists and can be improved in the future.

Conclusions

HealthVault based Web-enabled healthcare service solution is a novel e-healthcare solution to deal with the quickly increasing e-Paitent's needs. With security-enhanced and privacy-enhanced HealthVault system in the back-end, this type of applications provides not only a time effective, cost effective but also interoperable, secure and well-performed solution for those independent healthcare providers. The proposed sample application presents the general requirements, system design and its capability in rapid development, and low cost. This system was evaluated and validated in a real-like scenario. Its good interoperability, security and performance mostly rely on the back-end HealthVault system, a newest generation EMR system. In this paper, the scalability is not discussed and evaluated since it is not a hard requirement for such kind of small-scale applications. However, how the way that the front-end uses to fetch the data from the back-end HealthVault XML datacenter does affect the performance of the applications a lot. Therefore, to investigate the performance and scalability of such a XML database in a highly concurrent circumstance will be our and Microsoft's future work.

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References

1. E-Healthcare Definition: University of La Trove, http://www.latrove.edu.au/telehealth/consortium/whatis.php
2. Rodrigues, J. and Vaidya, B., Health information systems: concepts, methodologies, tools and applications. In: *Multi-volume publication Health Information Systems: Concepts, Methodologies, Tools and Applications*. *IGI Global*, 2010.
3. The MITRE Corporation,"Electronic Health Records Overview", April, 2006/
4. Goldstein D., E-healthcare: harness the power of internet, e-commerce & e-care, *AN ASPEN PUBLICATION*, ISBN 0-8342-1365-6.
5. http://msdn.microsoft.com/en-us/healthvault/default.aspx
6. http://www.hc-sc.gc.ca/
7. http://www.infoway-inforoute.ca/
8. Gunter, T. D., and Terry, N. P., The Emergence of National Electronic Health Record Architectures in the United States and Australia: Models, Costs, and Questions. J. Med. Internet Res. 7 (1), 2005.
9. "Broad issues to address in the successful implementation of an Electronic Health Records system" *e-Mzanzi Information Socie ty,* http://www.pnc.gov.za/, vol. 3, No. 07.
10. "The Clinical Systems Hospital IT Market", *Himss Foundation*, 1998-2005.
11. http://www.himss.org/foundation/histdata.asp/
12. http://www.eclinicalworks.com/
13. http://www.medcomsys.com/
14. http://www.medinformatix.com/
15. http://www.health.gov.bc.ca/socsec/
16. Grace, S., The Road to EMR Interoperability http://www.physicianspractice.com/, Nov 2009.
17. http://www.oscarcanada.org/
18. http://msdn.microsoft.com/en-us/vcsharp/default.aspx
19. http://www.asp.net/
20. Yang, G. Body Sensor Networks, *Springer*, ISBN: 978-1-84628-272-0
21. http://www.iis.net/
22. http://msdn.microsoft.com/en-us/healthvault/default.aspx/
23. http://www.mygenerationsoftware.com/portal/default.aspx/
24. http://www.mysql.com/why-mysql/topreasons.html
25. http://www.w3.org/XML/
26. Microsoft.Health.HealthRecordItem.cs, Microsft HealthVault Kit
27. Microst Health Schemas, http://developer.healthvault.com/sdk/docs/index.html
28. "SSL Protocol: Version 3.0," Netscape's final SSL 3.0 draft, November 1996.
29. http://www.microsoft.com/technet/prodtechnol/WindowsServer2003/Library/IIS/56bdf97714f8-4867-9c51-34c346-d48b04.mspx?mfr=true/
30. Medical Annotation, http://developer.healthvault.com/pages/types/type.aspx?id=7ab3e662-cc5b-4be2-bf38-78f8aad5b161
31. http://channel9.msdn.com/shows/Microsoft+Conversations+with+J/A-conversationwithSeanNolanchiefarchitectforHealthVault/#351062
32. Pfleeger, C., and Pfleefer, S. Security in Computing. *Fourth Edition, ISBN: 0132390779*.
33. http://msdn.microsoft.com/en-us/library/bb288408.aspx/