Proactive Real-time Solution for Asthma Management

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***Abstract*—In recent years there has been an increased growth in the use of smart applications to better care and manage various medical conditions. Recent studies have concluded that the daily management via an application improves Asthma control compared to manual or paper based monitoring [1]. To this effect, this research aims to study existing Asthma applications and propose a holistic approach to Asthma care and management by developing a novel Android application that provides a real-time, multi-way communication between patients and providers (healthcare, insurance, food, drug, etc.). The current state-of-art smart applications are able to aid users send information to their physicians typically via email; but, healthcare providers still need to contact patients through traditional methods (phone, email or face-to-face appointments). Our proposed multi-way communication can eliminate phone calls, emails and appointment scheduling to save time and provide real time feedback to the patients. Furthermore, providers can monitor the health status of patients remotely by checking their patient specific journal entry and set new and/or modified action plans and also uploads those to the patient's smart devices. Providers can also send notifications to patients even if the device is in sleep mode. In case of emergency patients are able to call 911 or find the nearest hospital and pharmacy via a pre-programmed *one-click* method. Our pilot evaluation at a nationally recognized HIMSS Stage 6 regional trauma center (> 500 beds) and its affiliated 20 partner clinical practices has confirmed that the proposed application has the potential to significantly improve the quality of care while reducing the overall cost of care delivery for the target population.**

Keywords—Asthma; management; real-time; proactive; Android; multi-way communication

I. INTRODUCTION

Asthma is a serious chronic lung disease and affects over 235 million people in the world [2]. According to the Centers for Disease Control and Prevention (CDC), in the United States 1 in 12 persons (~25 million) have Asthma conditions [3]. This high percentage of Asthma costs nearly 100 billion in care and management over the country. There have also been various efforts at the federal and state level to address the problem. Notably, the Baltimore City Health Department has issued an agenda titled: *Healthy Baltimore 2015*, with the goal of promoting well-being in the Asthma affected population. *Healthy Baltimore 2015* defines the focus areas with the largest impact for improving quality of living and invites researchers, the health care industry, experts and individual citizens to be involved to help in the process [4]. Furthermore, the hospitalization rate for Asthma in 2010 in Baltimore was 419.2 per 1,000,000 persons. The City Health Department aims to decrease this rate by 15% by the end of year 2015. It is interesting to note that the second highest rate for this condition is for the 18-44 age groups. The inference is that they have developed this condition due to work environment or lifestyle change outside of the home environment. The City Health Department also aims to increase the discharge rate by 10% for the target population.

Fig. 1. One-way communication with physicians

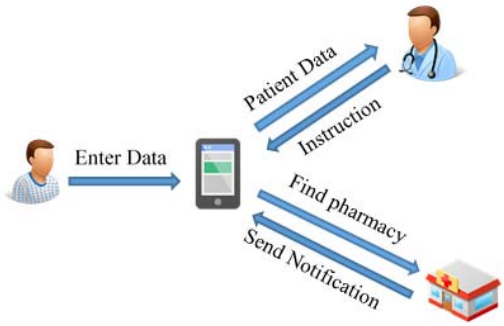

Fig. 2. Two-way communication with healthcare provider

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Asthma cannot be cured however avoiding triggers appropriately can control it. Patients need to record their symptoms and peak flow statistics and visit their physicians regularly. Moreover they must have action plans to be able to better manage the condition. The traditional method of controlling Asthma has been paper-based, but with the current era of technological advances (smart phone and hand-held smart devices) users can manage their condition in a more efficient manner.

In recent years, there have been many Android and iOS applications that can help patients to manage their condition, but are limited to the incomplete communication between patients and providers. Current solutions also lack real time feedback and multi-way communication between patients and care providers. Patients are able to enter their Asthma information and email their records to their assigned providers, but the providers need to use traditional methods via phone, email or face-to-face appointments to discuss the action plans as shown in Fig. 1. Moreover, effective appointment scheduling with reduced patient wait times and improved patient satisfaction along with ensuring physician efficiency is still a huge challenge. There are also uncertainty conditions in regards to late arrivals, cancelations and no show situations, which in turn affects appointment scheduling [5, 6, 7, and 8]. The method of telephone communication requires a good documentation in patients' medical record, which is a system limitation. In contract, the mode of electronic communication is self-documenting and can save time and improve resource usage [5].

To this effect, goal of this research is to:

- Conduct an extensive domain survey of applications for Asthma management

- Gather requirements from target users and providers to identify existing and new features necessary for a holistic application development

- Develop an Android application to manage Asthma and provides patients with real time feedback from healthcare providers (Fig. 2). The proposed multi-way communication method can eliminate phone calls and appointment scheduling and improve quality of care. The developed application immediately sends information to the appropriate healthcare provider. Also the provider is able to push the action plan back to the smart device of his/her patient.

- Conduct a pilot study (both patient and provider) at a collaborating nationally recognized HIMSS 6 regional trauma center with > 500 beds and its affiliated 20 partner clinical practices.

This paper is organized as follows. Section II presents the related work in the area. In Section III we discuss our proposed framework. The implementation details are discussed in Section IV. Section V discusses the evaluation and we present our concluding remarks in Section VI.

Table 1. Asthma applications information

Name	Version	Last Update	Price	Device	Votes	Rating	Multi User	Anonymous Data
AsthmaMD	2.1	Feb-13	Free	IOS	238	3.5	Y	Y
Asthmapulse				IOS				
MyFitness Companion	2.2.2	Aug-13	free gold silver	Android	158	3.6	Y	
Asthma Sense	1.1.1	May-13	Free	IOS Android	16/11	4 - 3.5	Y	
Asthma USA	1.1	Jul-13	Free	IOS		No Rating	Y	Y

Table 2. Asthma applications features

Name	Password	Encrypted Data Send	Location	Database	Graph	Medication List	Triggers	Feedback
AsthmaMD	Y	Y	Y	Google	Y	Y	Y	Y
Asthma pulse	Y	Y		Google	Y	Y	Y	
MyFitness Companion				Microsoft	Y			Y
Asthma Sense	Y			Asthma Sense	Y	Y	Y	NIST
Asthma USA	Y		Y		Y	Y	Y	Y

II. BACKGROUND AND RELATED WORK

It is estimated that 84% of U.S. adults own a smartphone, and more than 50% of that population uses various smart applications. Of all the application downloads, 29% are health management applications [9]. Research has shown that people are willing to use smartphones for managing their health condition and improving their lifestyle. The current Asthma management applications typically aid patients to enter their peak flow for a condition, set triggers, identify symptoms and input medication lists [1, 10, 11, 12]. Of the available English language based Asthma applications, 56 just provide some information about Asthma condition and only 47 applications are designed for user-managing Asthma and out of those only 29 of them include self-diaries [13]. Diaries could be different in capturing different information. One diary can capture symptoms, triggers and medication but not the best peak flow

[14]. Some diaries can also capture best peak flow only [15, 16, 17]. Although most of the applications require the user to manually enter data, only one has the ability to communicate with a peak flow meter over Bluetooth and record values [15] and only one other can read the data from a wireless enabled inhaler [13, 18]. We have identified PropellerHealth application, which can wirelessly record the time and location of last inhaler use. PropellerHealth sensor attaches to the top of the inhaler and by using the inhaler the sensor sends the information to PropellerHealth application over Bluetooth [19]. We noted that out of 29 applications with user-diaries, 57% lacked data validation; hence the user could enter out of range values. Only 4 of the 29 applications offered password protection and 5 of the 29 had an explicit confidentiality policy [13]. AsthmaUSA and AsthmaSense applications provided password protection. We needed to sample the applications mentioned above and conduct user studies to compare their functionalities and effectiveness to initiate the proposed application development plan.

We sampled out the applications that lacked data validation such as AsthmaCheck [13] and those that captured either Asthma symptoms or peak flow alone. We also did not consider applications without self-diaries. The type of feedback that the application typically provides is similar to a traffic light that displays green, yellow and red colors based on a threshold. In the Tables 1 and 2 we list the applications and important features, which should be supported by a comprehensive solution. To the best of our knowledge there is no solution that provides direct feedback from physicians back to the application. Our study concluded that there is a lack of a smart application that can provide both Asthma information and effective Asthma care and management. Additionally, we also conducted user studies and interviews at our partnering HIMSS 6 healthcare organization to establish the requirements and functionalities of a successful application. The analysis and interviews paved the way for our application development framework and identified the required functionalities for the application.

III. FRAMEWORK

The proposed system architecture consists of three components: the clients (patients), the server (Data center) and the healthcare providers as shown in figure 3. In the following paragraphs we will describe each component in detail.

Client [Patient]: Patients use smartphones to enter their Asthma information at any location and communicate with the healthcare provider over the Internet. The application must save all patient data on its local database, which must be password protected. To share data with physicians the application should automatically send a copy of all entered data to the central system through a secure connection and also check the central system for any new notification and/or action plan updates from the provider. In scenarios where there is no Internet connection available on the smartphone, the application should still save the entered data and wait until it is connected back and then synchronize with the database server.

Server [Central System]: The central system allows for data sharing and communication between physicians, hospitals, grocery stores, pharmacies and patients. It hosts the database that stores all patient information and any notification(s) and action plan(s) from physicians and other provider participants. It is necessary to make application-to-application interaction between different devices, typically via web services. Web services are communication models that allow data exchange(s) between different devices, such as a central database, an Android application, and a server hosted in a healthcare provider location. Web services provide increased security and confidentiality, as the application cannot directly access the central database. In circumstances where the application gets hacked, the central database remains safeguarded. It also provides higher performance and lower bandwidth usage than direct access to the central database.

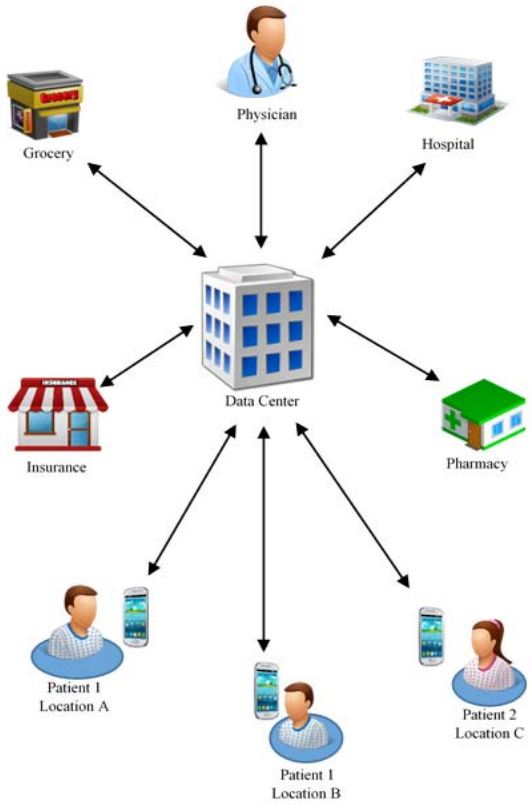

Fig. 3. Framework: Communication information between patient and provider

The healthcare provider can communicate with central system through a secure connection and check patient information and associated medical records. No information is stored

locally at the healthcare provider's device. The provider can use any computing device to connect to central system and obtain access to the most recent data of their patient. The following section describes in detail the implementation of our proposed application.

IV. IMPLEMENTATION

In order to develop the proposed framework we used the Android Software Development Kit (SDK) and Eclipse IDE for building the Android application. Microsoft SQL Server 2008 was used to store data on the server and Microsoft Windows Server 2008 R2 acted as the web server.

Communication Method: There are two main web service architectures for information interchange: namely, *Simple Object Access Protocol (SOAP)* and *Representational State Transfer (REST)*. Both architectures are suitable for data exchange; however, they both have some advantages and disadvantages. SOAP is the traditional and more complex technology and mostly used in enterprise applications. SOAP provides end-to-end reliability while REST assumes the application needs to address it [23]. Although SOAP takes slightly more time and bandwidth to transfer than REST, we used SOAP for implementation due to its higher reliability, security and platform independence features [23]. SOAP is an XML-based language. A SOAP message is an XML document that consists of an optional header and a mandatory body. The header contains the message infrastructure and the body contains the message payload. We convert messages such as Asthma information or notifications to *JavaScript Object Notation (JSON)* format that is a lightweight data interchange format, and use it as the payload with SOAP. JSON is a collection of name and value pairs that is faster than XML. The SOAP massage as shown in figure 4 is sent from smartphones to the web server that has web services enabled. On the other end of the communication, a JSON parser in the application converts the JSON message to a JavaScript object, which is then processed and stored on the database.

Security: Confidentiality of medical records is a big concern that must be addressed appropriately. The communication between the patient smartphone, central system and healthcare provider device needs to be encrypted to protect against eavesdropping. In the proposed approach all communication is via *Hypertext Transfer Protocol Secure (HTTPS).* HTTPS uses Secure Socket Layer (SSL), which is a cryptography protocol to provide secure communication by encrypting data over the Internet. The application is also password protected to keep data secure. Another important security concern is protecting users' passwords. The application and server use SHA-256 hashing algorithm for password protection in case there is a breach of the database and/or server. A hash function is a one-way algorithm that converts any amount of input into a fixed character set output, which is irreversible. On the server side a salt (random number) is added to the

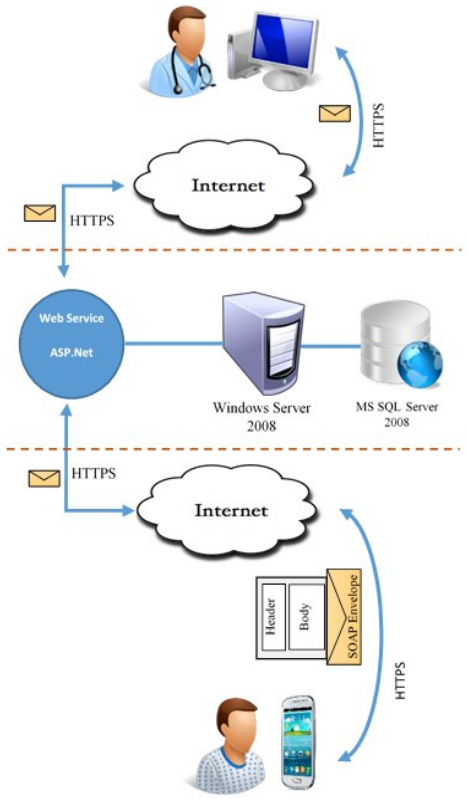

Fig. 4. Communication architecture

hashed password to prevent rainbow and/or dictionary attack conditions. Each time the application sends data to the server it must authenticate with a username and password. The application always sends data along with username and hashed-password. The server receives the data and if the username is valid it retrieves the users' salt and adds it to the received hashed-password and compares it with the saved salted-password. A match guarantees that the user is authentic otherwise the server would ignore and block the sender.

Peak Expiratory Flow Calculation: The initial access to the application allows the user to enter their best peak flow. This could be provided by a physician or computed by entering sex, age and height to calculate the predicted best flow value. The application uses *Wright McKerrow scale* to calculate best peak flow [24].

$$\text{PEF Female} = e^{((0.376*\ln(\text{Age}))-(0.012*\text{Age})-(58.8/\text{Height})+5.63)}$$

$$\text{PEF Male} = e^{((0.544*\ln(\text{Age}))-(0.0151*\text{Age})-(74.7/\text{Height})+5.48)}$$

The result of Wright McKerrow scale (W) is converted to European (EU) standard scale based on the following formula

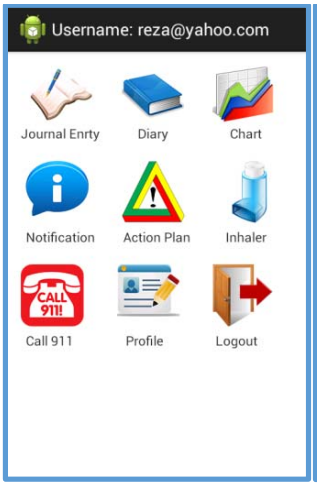

Fig. 5. Main window of the application

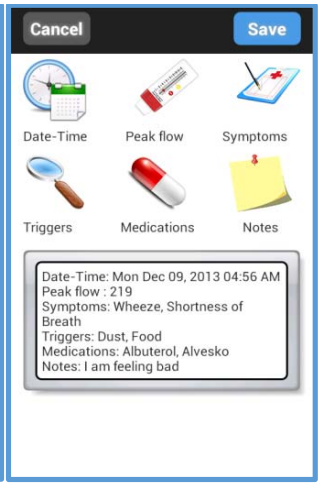

Fig. 6. Journal Entry window

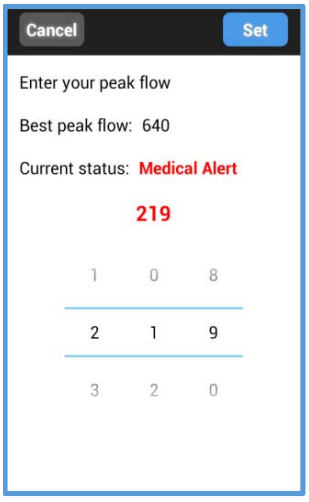

Fig 7. Peak flow entry window

Fig. 8. Action plan center

since it is more accurate and all new meters are based on the new scale [25, 26]:

$$EU = 50.356 + (0.4 \times W) + (0.0008814 \times W^2) - (0.0000001116 \times W^3)$$

The primary interface of the program is shown in Fig 5. This is a multiuser application that allows multiple users to use the same device without compromising confidentiality of any user data. Users can choose the Journal Entry feature to enter Asthma information such as date, time, peak flow, symptoms, triggers, medications, and notes as shown in Fig 6. While entering a peak flow value, the application compares it with the recorded personal best peak flow and displays the current status such as: "Doing *Well*", "*Getting Worse*" or "*Medical Alert*" with green, yellow and red colors

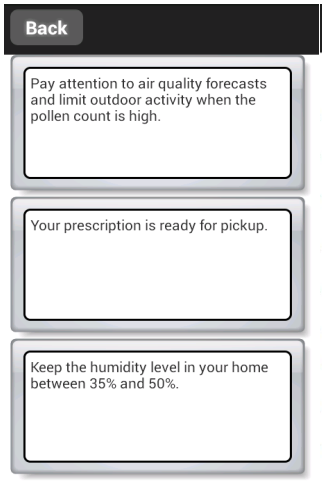

Fig. 9. Notification center

Fig 10. Nearest hospitals

respectively. Diary allows users to review existing Asthma data and Charts are used to view the graphic representation of the previous 'n' number of peak flows.

Action Plan: All target users with Asthma should have personalized action plans that are written directions by providers to better control their condition. Different users have different Asthma experiences and hence the design should be user-specific. Our developed application, ProCare, has the ability to receive new action plan(s) from physicians and set them in the application as shown in Fig 8. Physicians can monitor the status of patients remotely by checking their journal entry information and set new action plan(s) accordingly. The action plan is divided into three zones, green, yellow and red. Green zone indicates that the patient currently has no Asthma symptoms. Patients must continue taking their long-term control medications as prescribed. Yellow zone is a warning for the patient and displays that the patient has some increased symptom, such as shortness of breath and/or chest tightness and must follow the action plan such as taking quick relief medication to prevent a worse condition. Red zone is the most critical zone. In this, the patient has some severe symptoms. It is an alert condition that seeks serious action, such as an emergency call to the police department for help and hospitalization. The tool allows medical doctors to set action plans for each zone, and when the patient updates its respective journal entry, the application displays the appropriate action plan. The application also allows the user to call 911 via a *one-click method*. Users also have the flexibility to turn off the action plan alert separately for each zone.

Notification: The notification center is a feature for enabling multi-way communication between providers and patients as shown in Fig 9. It lists the last notification(s) received and/or feedback(s) that the healthcare provider sent to the patient.

The application checks the server regularly for any new/updated notification(s), even when the device is in the sleep mode.

Nearest Hospitals and Pharmacies: In case of emergencies patients might not be able to enable any typical location application on their smartphones. To help alleviate this problem, the application automatically includes the nearest hospitals and pharmacies via a *one-click method*.

V. EVALUATION

Three groups, namely, the *healthcare providers*, the *patients* and the relevant *IT personnel* at the target healthcare system conducted the evaluation of the application. The healthcare system is a HIMSS Stage 6 nationally recognized regional trauma center with over 500 beds and 20 partner clinical practices. It is important to note that the healthcare system houses a fully functional state-of-the-art data center addressing all functional, security, privacy and compliance requirements of the host hospital and the affiliated clinical practices. The evaluation of the application was for an initial 3-month period. We continue to conduct future evaluations over the upcoming 12-month period. The existing surveys were conducted via online anonymous survey questionnaires. The survey response was from 10 typical healthcare providers (lung specialists and/or primary care providers); 20 patients (age group: 18 years – 44 years; male: female ratio: 2:1); and 5 relevant personnel at the Information Technology group at the healthcare system. The questionnaire design was based on Asthma management; adoption by healthcare providers; patient's condition with Asthma and the IT personnel's evaluation of the proposed application. Respondents were asked to indicate their level of agreement via a *5-point Likert scale.* In the following we summarize the analysis of the survey results.

Patients' Evaluation: 20 typical patients aged 18 to 44 years with persistent Asthma condition used the mobile device for a period of 3 months. The questionnaire consisted of two parts; the first part was designed to evaluate patients and doctors communication method. The second part of the questionnaire was designed to evaluate the usability of the application. Of the 20 patients, 75% of them visited their healthcare provider for 5 to 9 times in the last 12 months, and 25% patients visited less than 3 times in the same time period. It is important to note that all patients contacted their healthcare provider in the last 12 months for a severe Asthma condition needing emergency attention. All this statistics indicates a high communication between patients and providers, leading to high cost and time consuming interactions. Additionally, a majority of patients reported that they usually forgot the prescribed action plan and indicated that the use of the proposed application aided them in keeping track and reducing the number of office visits and helped them better manage their condition. Most of the patients strongly agreed that the real-time feedback system used in ProCare was very useful. Overall the majority of the patients found ProCare very successful in their proactive Asthma management.

Healthcare Provider Evaluation: The group consisted of 10 typical providers, who were advised to use the application to communicate with their patients with Asthma condition and help them manage their condition for the evaluation period. An overwhelming 75% of the patients did not have an Asthma action plan prior to using the developed application. Nearly all the healthcare providers preferred to use the new communication method to remotely setup appropriate action plans for the patients via a secure mobile platform. The providers strongly believed that real-time feedback helps to improve the patients' Asthma condition. 80% of the providers indicated that ProCare reduced the number of office visits of their patients by over 50%. Most of the providers agreed that they trust and rely on the application to enter patient information. All this indicates a very positive and successful support for the developed application by the healthcare providers.

Information Technology Group Evaluation: The IT group at the hospital configured the necessary databases and web servers to incorporate the use of the application in their hospital and the affiliated partner clinical practices. Especially the group was queried on the security, privacy, usability and compliance requirement of the application operation. The IT group noted that the application to server communication was very secure and fast. There was no instance of the application instability and/or availability during the evaluation period. The result of the survey demonstrated that the IT group was quite satisfied with the overall performance of the application and the reliability of the host server.

VI. CONCLUSIONS AND FUTURE RESEARCH

We have identified the need to develop a multi-way communication Asthma care and management application with real-time feedback from healthcare providers. We have developed ProCare, the proposed mobile application, and conducted a pilot evaluation with our partner HIMSS Stage 6 healthcare organization and its affiliated partner clinical practices. The developed application eliminates manual methods of communication with a real-time proactive and automated approach to improve the quality and cost of care. The majority of the participants agreed that real time feedback from healthcare providers helped them to better manage their condition. Although we believe the closed loop communication between providers and patients can reduce the number of office visits and reduce cost, just 50% of the

patients agreed, and the rest still prefer face to face communication with their medical doctors. Furthermore almost all of the healthcare providers prefer to use the new technology to communicate with their patients, and a large number of the healthcare providers reported that the use of ProCare application reduced the number of office visits for their patients during the evaluation period. We plan to continue our evaluation over the next few months to gather more user evaluation data for analysis and to improve our proposed solution. The next step for our paper is to pilot the proposed application at various healthcare organizations and clinical practices nationwide.

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