ReTiHA: Real Time Health Advice and Action using Smart Devices

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***Abstract*— In this paper we have explored the novel services that can be engendered with the use of Real Time Health Advice and Action (ReTiHA) through continuous monitoring of the patient for vital parameters, real time prognosis and medical advice. Our services are aimed at providing healthcare services in remote areas where rigid healthcare systems are unavailable through implementation of cost effective mechanisms. With the advent of wearable sensors, improved mobile communication technologies and powerful on-board processing capabilities in smart devices, the data collected from the patient and the surrounding environment can be utilized to monitor the patient for various anomalies ranging from a simple rise in body temperature to complex situations including organ failure. The data from sensors are processed on the device itself or sent to a remote server for computations depending on the amount of data handled and the level of emergency associated with the same. The patients are registered on the cloud with organized storage of medical history, vital parameters along with possible emergencies and symptoms. We have emphasized on the introduction of various value-added services in which the immediate family of the patient can receive real time updates, push notifications for medicinal intakes, feedback from patients as well as real time advice in times of emergency. These services are designed to reduce reaction time for an emergency allowing possible prediction of occurrence at a lower level of emergency for patients.**

Keywords—E-health monitoring; Smart devices; Wireless sensor networks; Remote health advice.

I. INTRODUCTION

Wireless Sensor Networks have been the backbone of health care systems for patient monitoring, be it monitoring the vital parameters of the patient or be it the surroundings including ambient temperature, humidity and other parameters. Starting with systems using simple unobtrusive sensors to monitor the health of the patient, with subsequent systems have been designed to track the location of the patient, various complex parameters like ECG, heart rate and oxygen levels[1][2]. Mobile devices have played a major role in the research to report changes in parametric values or about emergencies [3]. However, the processing capabilities have remained limited till the recent growth of smart devices. Smart devices are equipped with memory and processing speeds capable of performing complex computations swiftly. In this paper we have exploited this feature of smart devices to bring about novel services optimizing the utilization of a smart device.

In previous monitoring systems, the roles of mobile devices were limited to sending messages, creating alarms and performing minor comparisons. However smart devices can be used to receive and store values from the sensors locally and interpret the situation from the raw values using intelligent algorithms. The smart devices may be also used to send data collected from the sensors to the cloud where larger and complex computations may be executed. The camera as well as the GPS sensor can be utilized to monitor the location of the patient and to track the surroundings of the patient as well.

Security of the data collected from the sensors is a point of major concern as well. The data collected should be visible only to authorized people including the doctors, caregivers and the relatives of the patient. Using the ability to access the internet, we have developed a secure system which requires the user to login to the secure cloud servers to access the data of the patient. This information is available only to those registered to receive updates and information regarding the patient.

With improved mobile communication technologies including 3G and 4G services, the spontaneity of receiving the computed values from the cloud servers have also been reduced hence adding to the real time aspect of the monitoring system. With the computation capabilities of the server, we can furthermore use image and audio processing techniques to further refine the health scenario of the patient and hence improve the accuracy and latency for health advice.

In rural regions of developing countries, proper health care centers are a rarity due to lack of rigid healthcare systems, proper infrastructure, stable power supply and various other factors. However with the penetration of mobile communications even in rural areas, providing patients with proper healthcare can be realized using wearable sensors for collecting raw data concerning the patient and performing computations using smart devices as well as on server processing on the cloud. In these regions where doctors are also not available immediately ReTiHA can provide real time health advice for certain pre-defined emergencies associated with the patient.

Our ideas in this paper are subsequently illustrated in the following sections. In section II, we have discussed about the architecture of the system for implementing ReTiHA along with the parameters we are monitoring, utilization of each layer for monitoring and the communication process between various entities. Section III illustrates the design aspect of the ReTiHA module based on storage, security, services offered along with alerts and updates. We have discussed the operational flow for ReTiHA in Section IV which illustrates the working block diagrams of the system. Section V provides an example of a Use Case for the ReTiHA system. Section VI gives an insight into the ongoing research in remote health monitoring systems. Future prospects and further improvements have been discussed in the conclusive section.

II. ReTiHA System Architecture

The system architecture of ReTiHA is discussed with a top down approach comprising of three primary layers, the registration layer, the middleware layer and the e-health application and services layer. The higher layers use information or data from the lower layers to provide real time updates, alerts and perform computations. Fig. 1 illustrates the layers of the ReTiHA architecture, the functions of which are subsequently discussed below.

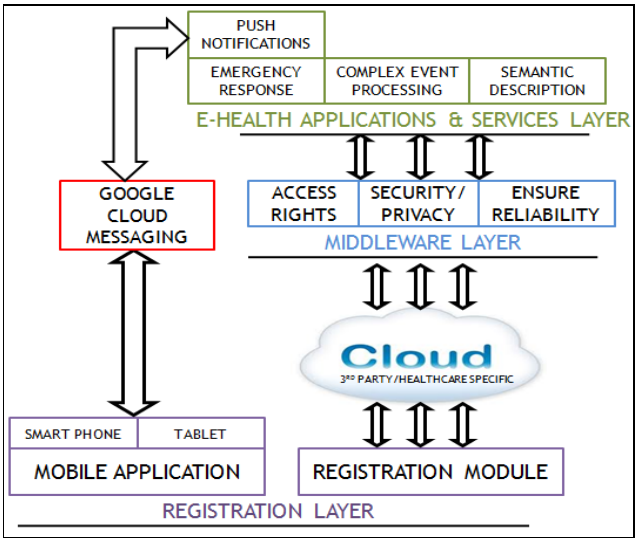

Fig. 1. Illustration of the ReTiHA Architecture

A. Registration Layer

In this layer, the patient registers for monitoring with personal data. The patient enters his/her electronic health record with previous medical history, previous checkups, complications and emergencies. The patient also registers the names and contacts of the emergency contacts who are alerted in times of emergency. The patient also registers for the services he would like to opt for pertaining to his health and can also opt for push notifications for medicinal updates, emergency alerts and inventory updates.

The mobile application plays a major role in the registration layer and the whole system of ReTiHA itself. The mobile application can be used to register the patient and receive updates directly from the cloud server through the Google Cloud Messaging. The device is also instrumental in receiving the sensor values and local computations for simple situations.

B. Middleware Layer

The data of each patient is stored to the cloud including personal data, electronic health records and data collected from the sensors. The function of the middleware layer is to provide security to the data for each patient. This layer ensures security privacy, i.e. the data is confined to the cloud and is not shared in any unauthorized manner. The data is only available to the hospital doctors and caregivers.

The Middleware Layer is also responsible for managing access rights to the data. When there is an attempt to login to access the data, the cloud redirects the request to this layer, which compares the user name and password to the registered users and returns an acknowledgement for access if a match is found. The module for reliability ensures integrity of the data, i.e. the data is sent accurately between the cloud and the services layer. It also offers authenticity of data, which ensures that the identity of the patient and the doctor is verified every time health advice is offered.

C. E-health Application and Services Layer

The top most layer offers the services to which the patient is registered for in the registration layer. The primary functions performed in this layer are emergency response, semantic description, sending push notifications and complex event processing.

The data from the sensors are received in the form of Sensor Markup Language (SenML). Semantic description uses this data to comprehend the reading for the data, i.e. the value, the unit of the data, the timestamp at which the data was recorded and the identification of the patient. This classified data is then used for complex event processing. Complex event processing takes multiple sensor values into consideration and computes a pattern from the same using pre-defined heuristics. This module is used to predict possible major health mishaps from the symptoms in real time parametrical values. It considers the patient electronic health record to compare any current emergency to that of a similar one in the past to offer a conclusive decision.

Depending on the level of emergency realized from the computations, the emergency response module alerts the doctors and caregivers of the impending emergency through a message. For the highest level of emergency doctors, as well as caregivers are alerted. For lower levels of emergency only the caregivers attend to the situation. If the patient is registered for push notifications, they are generated in this layer and are disseminated to the emergency contact as well as the patient through the mobile application or to the contact numbers registered.

III. Application Design

The applications and services of ReTiHA are designed keeping five major aspects in mind viz. storage, security, selection of services, push notifications and alerts and updates provided. The storage and organization of data is instrumental in reduction in time for fetching data, quicker processing of data and in turn producing outcomes swiftly from computations. The data is kept secure from possible attacks and is designed to be accessed by only authorized people including the patient, immediate family, caregivers and doctors. ReTiHA offers a wide range of services from simple localization of the patient to monitoring for multiple emergencies. The patient chooses a set of services for which he is only charged and is eligible for. Updates and alerts are provided to both the patient and the family of the patient according to the level of emergency. The doctors and caregivers receive periodical updates along with alerts during emergency. If the patient opts to receive push notifications, the patient along with the immediate family receives the notifications with data on health status and vital parameters.

A. Storage of Data

The data stored for the patient is classified into the following categories: personal information, login data, electronic health records, current sensor data and archived sensor data. The data stored for each patient is uniquely represented by the identification number of the patient on the cloud server.

1) Personal Information:

Personal Information regarding the patient includes the name, date of birth, gender, nationality and religion of the patient along with the contacts of the patient and immediate family. This data is collected when the user registers with the hospital for e-health monitoring services. Once registered these values are stored and are not further requested from the client. The patient is assigned an identification number post registration in accordance to which the data is stored.

2) Login Data:

Once the patient is registered, the patient can choose a user name or the email ID which is registered to receive updates regarding the patient. The password is chosen by the patient and is stored in the database for verification, every time someone tries to access the patient's database.

3) Electronic Health Records:

The Electronic Health Records (EHR) of the patient is a time based system which stores multiple entities for the patient including medical history, prescribed medicines, allergic medicines and heuristics regarding the patient's previous and possible emergencies. The medical history stores previous X-Ray reports, blood reports and all other related reports which can prove useful in future for medical evaluation of the patient. The prescribed medicines and allergic medicines are stored along with the name of the doctors and date prescribed. These prescriptions are stored in XML format rather than text for quicker processing. JASON is used to program the behavior of various entities in the system. The heuristics for the patient stores the previous patterns of the vital parameters which led to the emergencies along with threshold values for which the system issues an alert for anomalous parameter values.

4) Current and Archived Sensor Data:

The data received from the sensors are represented in Sensor Markup Language (SenML) which ensures storage of the timestamp, value and unit of the sensor data in an organized representation [4]. The parametrical values from various sensors are periodically archived and stored for each patient such that they can be used as a reference in future. The current parametrical values include the data received by the cloud for processing and computation in real time. This data is processed in real time and the results of the computation are returned to either the reporting entity (smart device) or to the base station from which the request for computation was received.

B. Security of stored data

The data stored for each patient is prone to attacks from multiple sources that would benefit from the patient data. Hence measures are taken to prevent the same. The user name and password assigned to each patient is unique and offers basic level of security preventing login to the server from unauthorized people. Along with this measure for unauthorized login, the patient data is also protected using measures of confidentiality, integrity, authenticity and non-repudiation.

The most important aspect of ReTiHA is that it provides remote health advice when there is a situation of emergency and a doctor is unavailable to treat the patient. However this remote health advice is always to be approved by the doctor remotely upon judging the medical parameters of the patient in real time. Hence non-repudiation is pivotal to this system as an advice once approved by the doctor cannot be denied later under any circumstances.

C. Selected Services

Our system for ReTiHA is designed to handle multiple types of emergencies based on different parametrical emergencies and for multiple types of health disorders. The patient can choose from the parametrical services or choose all of the parameters as well. For example, someone suffering from high blood pressure may choose to opt only for the blood pressure updates and emergency services or for all parameters on the whole. The patient can also opt for modules pertaining to each health disorder which would offer its own set of services. For example, a patient who has been operated on for a heart ailment will receive the services for post-surgery recovery and monitoring. The services opted for by the patient are stored in the database along with the profile of the patient.

D. Alerts and Updates

The updates sent to the patients and immediate family can be classified into two types viz. parametrical updates and medicinal updates.

1) Parametrical Updates

The patient can opt for parametrical updates, where the values from the sensors are periodically reported to the immediate family of the patient. The patient can also be registered for alerts wherein their family receives alerts when a particular parameter breaches the threshold value. These updates and alerts are simultaneously sent to the caregivers and doctors for real time monitoring of the patient as well.

2) Medicinal Updates:

These updates include reminders for periodic consumption or injection of medicine for the patient. These updates are particularly useful in the stage of recovery post-surgery or trauma. If the patient fails to acknowledge the alert for consuming medicine the alert is forwarded to a family member to ensure the patient receives the medication. These updates can be sent as push notifications in the patient smart device through an application or can be sent as an SMS to a mobile device as well. Medicinal updates can be used to alert the immediate family of requirements for blood, oxygen or other necessities beforehand if found required by computation of parametrical values.

E. Push Notifications:

Push notifications are used to notify the patient and the immediate family through an application on the smart device. The application receives data regarding the patient from the hospital servers which is then relayed back to the family of the patient through the Google Cloud Messaging (GCM) service. The steps by which the notifications are received are explained below and are portrayed in Fig. 2.

- Step 1: The patient registers for the service to receive push notifications from the smart devices. The device upon receiving this request from the patient sends a packet to the GCM service to register a new patient.
- Step 2: The GCM service responds with a unique ID which will be used as a reference in future to associate the patient with his own medical data and subsequent notifications.
- Step 3: The smart device application sends this unique ID to the hospital cloud server, which maps the patient's unique ID with its own ID of the patient.
- Step 4a: The first step to receiving the push notifications from the hospital server is to send the metadata for the patient along with the health status from the hospital server to the GCM service.
- Step 4b: Upon receiving the data from the hospital cloud server for the particular patient, the GCM service sends the vital parameters and health status to the family of the patient through the smart device application.

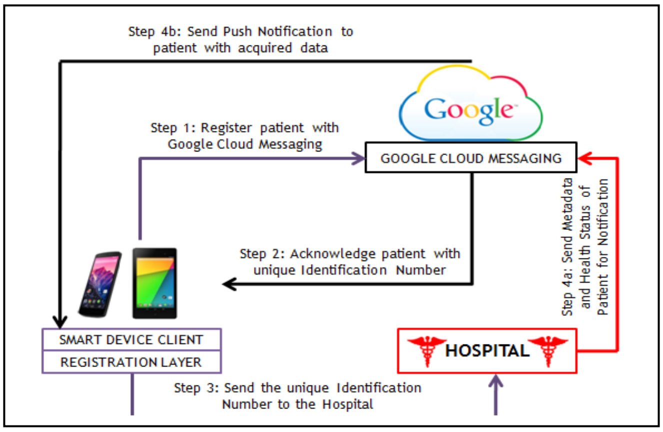

Fig. 2. Steps involved for receiving Push Notifications

IV. Operational Flow for ReTiHA

The operational flow of ReTiHA consists of the following steps, which include patient registration, patient data storage and computation from patient data. These operations take place through intercommunications of three entities, viz. the patient, the hospital (cloud storage, caregivers and doctors) and the immediate family of the patient.

A. Patient Registration:

The patient initializes the registration process for ReTiHA by requesting the hospital servers to create an empty profile for the patient. This message REG_REQ is countered by the servers by replying with REG_ACK, which creates an empty profile for the patient and returns the identification number. The patient fills up the necessary parameters of the form including login credentials, name, age, blood group and gender along with medical allergies, previous doctors, records and other medical history. This message UI_REG sends the user information to the server which acknowledges the patient of completion of registration with UI_ACK.

Once registered the patient or the immediate family of the patient can login to the system with a request for login entering the username and password through the message LOGIN_REQ. The server replies with LOGIN_ACK acknowledging the fact that the user is logged in. The user can then request for real time updates on the patients or check on medications through a request to view the user profile data in the form of UPD_REQ. The server replies with the requested information through UPD_RPL. Fig. 3 illustrates the operational flow for the patient registration process.

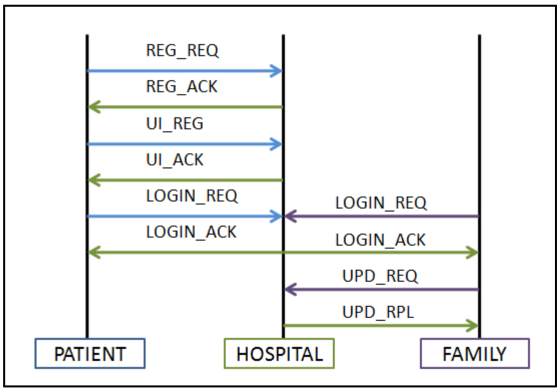

Fig. 3. Operational Flow for the patient registration process

B. Patient Data Storage and Computation:

In the operational flow for patient data storage, the data is received in real time from the patient's wearable sensors and embedded environmental sensors through SEN_DATA. The storage server periodically acknowledges the receipt of data through the message SEN_ACK to the base station for the sensors or the smart device handling the same. The data received from the sensors are periodically archived for future reference or are stored when a case of emergency rises.

The data received from the sensors are then computed for emergencies by checking the values with the emergency parameters using the message CHK_ES. The emergency handler module returns the state of the emergency to storage using RET_ES which states the level of emergency. Depending on the level of emergency, the Emergency Handler sends an update alert to the caregivers and doctors along with the immediate family of the patient through ALT_MSG. This message is accompanied by EM_DATA from the storage system containing the vital parameters causing the emergency, when reporting the alert to a caregiver/doctor. Fig. 4 portrays the operational flow for patient data storage and computation.

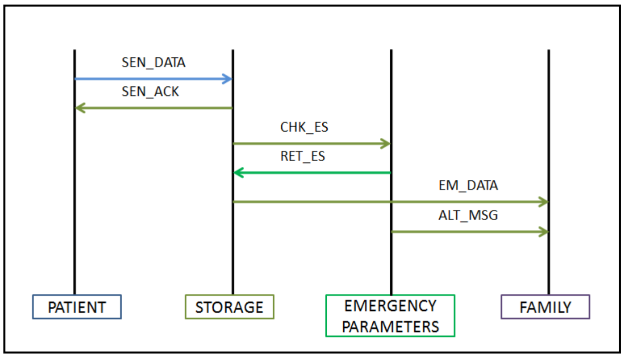

Fig. 4. Operational Flow for Patient Data Storage and Computation

V. USE CASE:

In this section we have discussed a case study wherein a patient suffers from high blood pressure and diabetes and is under monitoring in real time post an open heart surgery to equip a pacemaker. The patient registers for real time monitoring of these parameters along with other basic health parameters like body temperature and blood oxygen levels which is associated with the aforementioned health issues.

The patient enters personal details into the system along with health history and enters the contacts of his wife and son as his emergency contacts. The patient gets monitored in real time with data collected from the sensors and stored in the cloud server. The simpler parameters like the blood temperature are being computed locally on either the smart device or the base station unit receiving the parametrical values from the sensors. The other parameters being computed through complex algorithms are being processed on the cloud server.

The patient is registered for an alert when the blood pressure suddenly spikes due to some reason or the blood sugar level drops. There is also a provision for sending out an alert if the pacemaker provides anomalous readings over a period of time predicting a possible mishap.

While monitoring the parameters if there is a monotonic increase in blood pressure, the caregivers are alerted through a message and they bring the situation under control through medication. If there is a sudden increase in the value of blood pressure or a sudden drop in blood sugar, the doctors as well as the caregivers are alerted and treatment is provided to the patient. The emergency contacts receive real time updates regarding the heath of the patient during this time of emergency.

If such a case arises where the patient is in a critical state and a doctor is unavailable for advice, the server checks for heuristics pertaining to the particular patient and the pattern of values which has caused an emergency. If it finds a similar situation in the electronic health records, it recalls the medicine and dosage which took care of the emergency and sends a medical health advice to the caregiver to treat the patient immediately. Once the emergency is dissolved, the server archives the values and the treatment provided for the same for future reference.

VI. RELATED WORK

The initial research in remote health monitoring involved use of simple unobtrusive sensors [5] to measure a particular parameter of the patient and monitor the health of the patient. However these systems had limited computing and processing power and most decisions were taken manually after observing the patient data. Gradually, mobile devices with computational capabilities came into being for simple computations and autonomous monitoring of the patient, wherein the anomalies in the pattern of readings of the sensors were detected by the system itself. This led us to a new direction in research towards service oriented approach for remote healthcare systems. Service oriented systems were designed keeping in mind specific requirements for each patient as well as exploiting the resources to optimize the utility of the system.

The authors of [6] make use of biosensors to track the vital parameters of the patient. The data is stored and relayed from the cloud and the system is based on Service Oriented Architecture (SOA). The system is aimed at monitoring patients with chronic diseases. C.J.Su et al [7] has proposed the use of mobile agents to monitor the health of patients on a larger scale for wide area networks by working on a mobile multi-agent based information platform (MADIP). The presence of mobile agents reduces delays in communication, improves throughput and makes the system customizable and compatible with multiple platforms. The authors of [8] present another multi agent based approach to healthcare systems to expand the limitations of the environment of the patient while wearing sensors. This system uses multiple intelligent agents to collect data from patients, compute the data and offer solutions to the patients under the supervision of doctors.

In our previous work [9], we had proposed the architecture for ReTiHA with the functions and design of each layer in a top down approach. We had also mentioned the use cases for the algorithm for ReTiHA along with security and privacy measures to be taken. This paper extends our work on ReTiHA with the operational approach of the system along with the working mechanism and architecture of the system with respect to the entities concerned, i.e. the patients, caregivers, doctors and immediate family of the patient.

VII. DISCUSSION AND FUTURE PROSPECTS

Recent research work in e-health monitoring systems is widening the scope for remote health monitoring with improved diagnosis, quicker response time and facilitated storage of electronic health records. However most of the research work is aimed at health care centers and in the urban scenario where resources are abundantly available. Our research is focused on reaching out to rural areas where resources are scarce and doctor advice is not always available immediately. Hence our system is designed to handle emergencies remotely and offer health advice based on pre-defined heuristics. This enables patients to be treated in the absence of a doctor. The advantage of our system is that the doctor can remotely monitor the vital parameters for the patient and approve the remote health advice generated by the system to be carried out.

The mentioned system provides updates, alerts and several other services through the smart devices. The energy consumption in such devices is still a major constraint. Also we foresee that the proposed mobile application will be running for a significant amount of time in these devices which might drive up the power consumption. Power consumption in smart devices has been investigated in [10], [11], [12]. We will further optimize the application and overall architecture using the framework forwarded in [13].

With the advent of Internet of Things (IoT) many new components can be added to the current system. The architecture can be modified as proposed in [14] to include provide more novel services. Inventory handling can be introduced which can alert the authorities beforehand of low supplies in a particular blood group, oxygen or low stock for a medicine. These alerts can then be used to generate a request for the particular entity low in stock to nearby healthcare centers for handling emergency requirements. With the use of IoT, data from environmental and medical sensors can be used for a feedback mechanism to control entities like room temperature, saline and blood influx. With investment of resources in the system it can be further improved to accommodate various other novel services and facilitate health monitoring further.

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