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Review article

Remote Medical Alert Monitoring System – Providing Telehealth By Integrating Ayurveda With Sensors And Mobile Computing

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ABSTRACT

Generating medical alerts and providing timely first aid in emergency or adverse situations play a major role in reducing mortality and saving lives. However, this requires effective remote monitoring and timely reach of relevant information to the concerned stakeholders. Wearable sensors linked to smart phones (mHealth applications) are being increasingly developed for monitoring the health status of individuals. But for remotely monitoring medical alerts especially during emergency situations, a framework that supports both development and real time monitoring, and at the same time is cost effective, easily accessible and adoptable by many is the need of hour. It should also be scalable, replicable, evidence based and a viable solution. The purpose of this paper is to propose a conceptual framework for remote monitoring of medical alerts integrating Ayurveda, wearable sensors, mobile based decision support and cloud services. Extensive literature review and consultation with clinical experts, Ayurveda practitioners and technology specialist working with sensors were carried out to develop the framework. The framework enables assimilation of vital parameters of registered individuals 24x7 through wearable sensors and detecting anomaly by combining them with Nadi Prakisha to provide timely notification in case of medical emergencies even in remote areas. This will improve timely communication between relevant stakeholders and help in reducing mortality occurring due to lack of timely help.

KEYWORDS: Wearable sensors, Nadi Pariksha, remote monitoring, decision support system, real time monitoring, mobile computing, and medical alert

INTRODUCTION

Every individual has the fundamental right to have a healthy life [1]. In addition to the deaths caused by chronic diseases, the fourth leading cause of global deaths is due to injuries. WHO estimates that by 2030 there will be another 40% increase in trauma fatalities and more than 90% of injury deaths will occur in low- and middle-income countries [2]. Many of these deaths and resulting disabilities could be prevented if individuals receive timely treatments. Trauma may occur from sudden disease fatalities like heart attack, stroke etc., to severe bleeding, loss of consciousness, impaired breathing due to road accidents, violence and natural or man-made disaster situations like flood, earthquakes or terrorist attacks.

In the event of such an emergency or adverse situation, there is an urgent need to relay information regarding the individual's health condition to relevant response teams as quickly as possible so that necessary actions can be taken to -avert adversity. Such remedial actions are lacking in developing countries like India and Kenya, where there is a lack of infrastructure (beds, drugs, ambulance services etc.), and shortage of healthcare professionals, in addition to large chunks of geographically inaccessible rural areas. The major gap when medical emergency occurs in these situations is contacting people 'on the go', effectively getting out messages timely to concerned persons and quickly transferring the affected individual to nearby emergency facility for providing first aid.

These challenges raise some fundamental questions.

- How do we provide alerts to handle unforeseen health emergencies to save lives as a forewarning?
- How do we provide timely help during accidents and disaster events to reduce disability and mortality due to lack of or delayed provision of first aid?

- Is it possible to provide real time accessibility to emergency services through guided coordination among various stakeholders?
- How do we provide quick and accurate medical alerts to those in areas with reduced access to providers and ambulance services?

The answers to these questions lie on how information and communication technologies (ICT) in general, and 'health-enabling technologies' in particular are being adopted [3, 4]. The technologies that were once used for simple recreation are being increasingly brought together through Internet of "Health" things in a manner that allows for on-demand delivery of healthcare in a way that was once never imaginable. Mobile computing which makes use of handheld devices, mobile phones and embedded systems are increasingly being used for providing health care services to anyone at anytime by overcoming the barriers of place, time and character. It is based on the concept of pervasive computing that makes the interaction between the human and computational devices extremely natural in both day to day living and working environment, in addition to getting multiple types of data in a totally transparent manner [5,6].

They are based on wearable technologies that integrate physiological and biochemical sensors to monitor vital signs (body temperature, pressure, and heart beat), environmental sensors to measure environmental factors and motion sensors to monitor mobility into a wearable wireless body area network for diagnostic as well as monitoring applications as "smart wearables" to monitor sleep patterns, asthma symptoms, breast cancer risk, back pain, blood glucose, body temperature—almost every metric imaginable[7-9]. They are being used in conjunction with mobile applications. A recent approach to utilization of mobile applications or mobile apps is mobile cloud computing or mCloud [10, 11] which is the combination of cloud computing, mobile computing and use of wireless networks. This enhances the availability of rich computational resources to mobile users, network operators, as well as cloud computing providers.

Ayurveda is one of the traditional systems in Indian medicine that involves holistic approach to health by laying emphasis on health promotion, disease prevention, early diagnosis and personalized treatment for individuals [12-15]. An Ayurvedic practitioner not only sees symptoms but also performs "Nadi Pariksha" [12]. Nadi Pariksha reads the vibratory frequency of the pulse at various levels of the radial artery. It is done by placing the index, middle, and ring fingers at the root of the thumb of the subjects over the radial artery as shown in Figure 1. Each pulse has different physical & mental features (Table 1) that can be examined. This is understood in the form of symptoms along with their prognosis, which aids in understanding the cause. Thus, any person's ailment can be addressed on the basis of Nadi Pariksha.

According to Ayurveda, our body is a combination of 5 elements: Ether, Air, Earth, Water and Fire and they influence the three types of "doshas" or humor - Vaat or Vata, Pitta, Kapha or Kaph. Any imbalance in these brings out the ailment which leads to diseases.

Ether + Air = Vaat (Mobility)

Earth + Water = Kapha (Viscosity)

Water + Fire = Pitta (Heat)

Analysis of hollow organs and semi-solid organs is done by feeling the nature of pulse at the deep and superficial layers of the wrist radial artery by applying proper external pressure. The location of organ pulses on both the hands is shown in Figure 1.

Figure 1: Pictorial Representation of Nadi Location

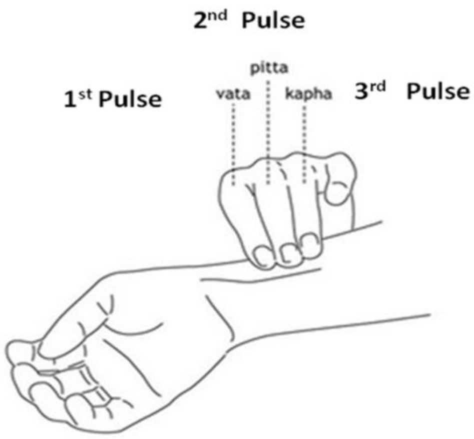


Table 1: Features of the Nadi Pulses

	1st Pulse (Vata)	2nd Pulse (Pitta)	3rd Pulse (Kapha)
Location	Index	Middle	Ring
Frequency	80-95	70-80	50-60
Regularity	Irregularity	Regular	Regular
Amplitude	Low+	High+++	Moderate ++
Tension and Volume	Low	High	Moderate
Temperature	Cold	Hot	Warm to cool
Vessel Wall	Rough Hard	Elastic Flexible	Soft Thickening

If any change in the vital parameters occurs in human body, the speed of these Nadis changes [13]. By analyzing the pulses at various frequency and time domains many diseases can be identified [14, 15]. Ayurveda is known to be effective in diagnosing and treating both chronic ailments like diabetes, heart problem, renal failures, cancer and degenerative diseases like Arthritis, Parkinson's and Alzheimer's [16 -18]. In the last decade, there has been an increase in designing and testing of sensor based Nadi Pariksha especially for diseases like diabetes, heart disease, stroke, arthritis etc [17-20]. Advanced mathematical simulations of pulse waveforms using Fischer Ratio, Artificial Neural Networks, and Bayesian Networks etc have been tried out in pilot mode.

In the milieu of ubiquitous prevalence of smart phone based mobile health applications in the global market, rising relevance of wearable sensor technologies for remote health monitoring and re-emergence of traditional medicines like Ayurveda, the aim of this paper is to propose an integrated approach for developing a healthcare monitoring system for providing alerts during medical emergencies by incorporating the world of wearable biosensors, mobile computing, cloud services and Ayurveda approach. The remainder of this paper is organized as follows: in the next section a brief insight of wearable sensor technologies, their use in healthcare applications and Nadi diagnosis are highlighted. This is followed by the proposed architecture, and future scope.

WEARABLE SENSORS AND M-HEALTH APPLICATIONS

Any healthcare application that is deployed for remote monitoring, needs components that continuously monitor and measure health parameters of the individual, analyze and identify the critical valid data, alert the individual or caregiver on real time basis of the monitored person's situation for an early diagnosis or possible health hazard [21]. A simple human activity monitoring system may include sensors that monitor the physiological signs, a microcontroller for processing the data, transceiver for transmitting data and a display unit. The sensors will depend upon the clinical application like those that monitor vital signs like heart rate, body temperature, pulse, movement or activity etc. The rapid development in microelectronics, integrated optics and other related areas has given rise to a plethora of such sensors. For example body temperature measuring sensors have been used for not only measuring physiological condition [22] also for activity classification [23], harvesting energy from body heat [24] etc.

There are newer sensors based on photoplethyl somography [25], sound and face skin brightness recognition [26] to measure heart rates other than pulse and piezoelectric sensors [27,28]. Mobility or human activity monitored by accelerometers [29,30], ECG sensors [31,32], textile capacitance sensor [33], amperometric sensor [34], micro-machined sensor for biomechanical analysis [35] are some of the recent trends in human activity monitoring. They were mainly adopted in wearable format for home and wellness monitoring, safety monitoring like geriatric patients fall monitoring, home rehabilitation, assessment of treatment efficiency and early detection of disorders like diabetes, cardiovascular diseases, stroke, shock, Parkinson diseases [36 - 41]. This has been possible only as a result of the generation wise evolution of the sensors and their adaption for healthcare. While designing a wearable sensor for remote monitoring, other aspects like type of wireless protocols to be used, monitoring activities to be considered, algorithm to extract important features from the data collected, the design of the wearable sensors, their integration with mobile devices also need to be taken into consideration. Few review articles regarding the wearable sensors, their use in rehabilitation and healthcare monitoring are available that give a brief idea of the same [42-44].

The use of mobile and wireless technologies to support the achievement of health objectives (mHealth) has been potentially transforming the face of health service delivery across the globe. Rapid advances in mobile technologies and applications, a rise the integration of mobile health into existing eHealth services in the domain of Telehealth, continued growth in coverage of mobile cellular networks, other technological advances like cloud computing, integration of sensors, the emerging interest in interlinking diverse technologies and devices through internet (Internet of Things) and availability of low cost mobile phones are driving the change. WHO in its series report on eHealth had surveyed all its member states and identified fourteen categories of mHealth applications that are generally being implemented [45].

Between their ability to connect with chronically ill patients and high risk populations who need to take special attention to their health, to the way they enable providers to reconnect with patients as follow-ups they have been changing the healthcare ecosystem [46- 49]. They have been increasingly adopted as one of the modalities of Telehealth services to provide increased access to and quality of healthcare in rural communities via remote monitoring [49].

PROPOSED CONCEPTUAL FRAMEWORK OF THE INTEGRATED SYSTEM

This section describes the proposed architecture of the integrated system that monitors the medical alerts remotely. The entire system is divided into the following tiers.

The **core part** (first tier) of this system is the wearable body sensor arm band (WBSAB) that collects the patient's vital signs at real time. It consists of combination of optical or piezoelectric pulse sensor to measure the arterial pulses and temperature sensor to measure the skin temperature. The pulses are mainly related to blood flow and heart rate of the human body. Any change in them is reflected as a change in pulse appearance. The pulse repetition rate, frequency, amplitude and shape of the pulse wave forms are the features extracted in addition to body temperature, blood pressure and heart rates. These signals will be preprocessed further by having filters that remove the noise, microcontroller for local data processing and memory to store the sensed data temporarily. Figure 2 illustrates the logical flow of the processes in WBSAB.

Figure 2: WSBAB Processing of Signals

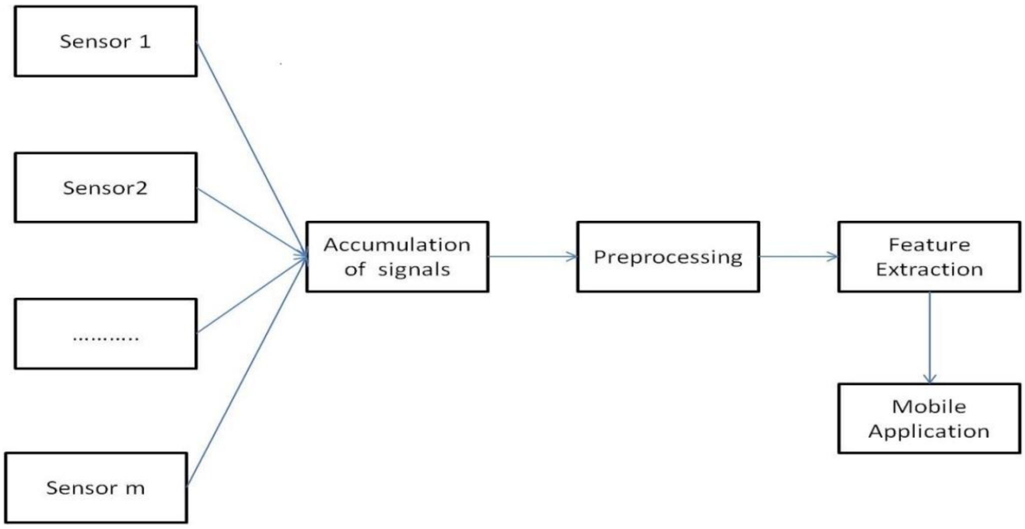
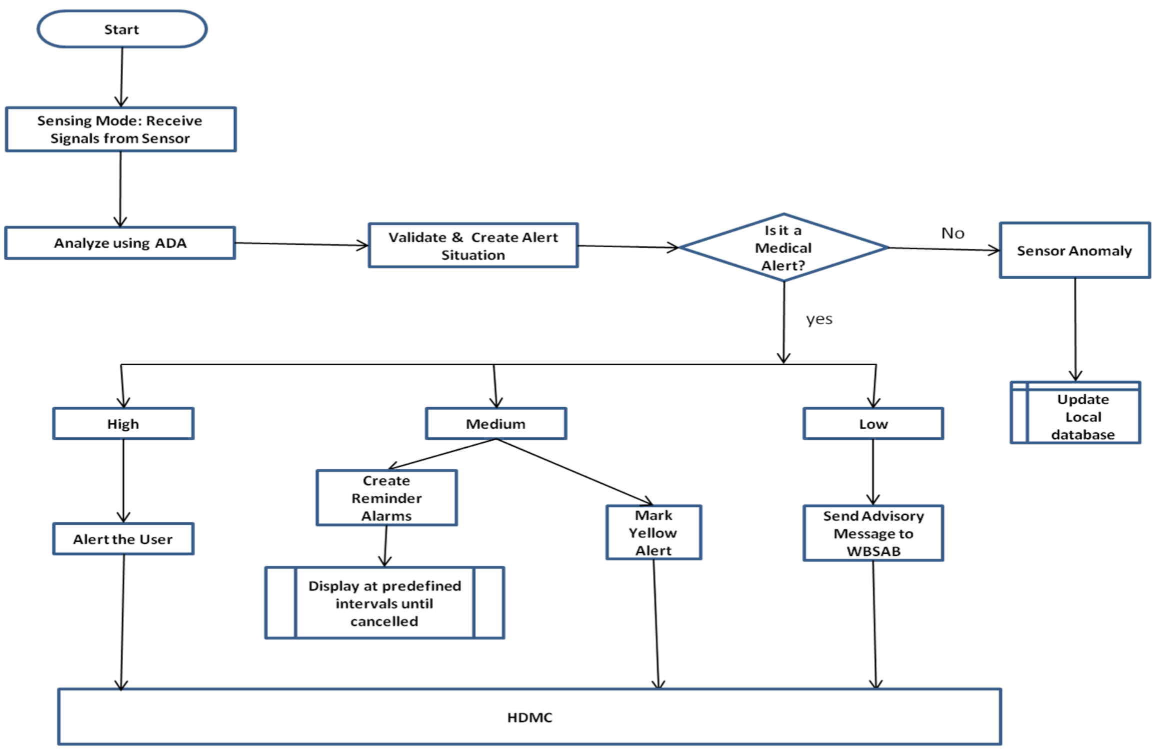


Figure 3: Processing of the Anomaly Signals in Mobile Application



The wearable arm band should be positioned or attached on radial artery where readings can be collected in real time. For female subjects, it should be worn on the left arm, and in the case of male subjects, it should be attached to the right arm. A typical arm band can look like the one shown below with integrated sensors.

In addition, the arm band will contain a blue tooth transceiver for communicating the data to mobile application. Bluetooth technology is a cutting-edge open specification that enables short-range wireless connections between various computer devices and peripherals like desktop and notebook computers, handhelds, personal digital assistants, mobile phones, camera phones, printers, digital cameras, headsets, keyboards and even a computer mouse. Bluetooth wireless technology uses a globally available frequency band (2.4GHz) for worldwide compatibility and provides connection within a 30-foot range.

The **second tier** or component is the platform independent mobile application running in the individual's GPS enabled mobile. When the application is installed in the individual's mobile for the first time, their Nadis will be detected at predetermined intervals using the sensors and a mean value is calculated and stored in the application database as the standardized default threshold value. Simultaneously all the pulse parameters like frequency, amplitude, shape will also be collected in addition to blood pressure, heart rate and body temperature. In addition to this, the application collects the location data in real time based on GPS locating tool integrated with the application. Once initialized, the application will start receiving the signals from the sensor nodes 24x7 and check for anomaly against the default values based on a pre-tested and validated anomaly detection algorithm (ADA) whenever there is a sudden change in the vital signs. These will be further validated based on standardized database of allowed values for each feature detected to check if it is a high alert. The database will be hard coded in the mobile application.

Based on the symptoms if the condition is considered to be a medical alert situation (high priority), it will be forwarded together with the individual's authentication details, mobile number and location to the Cloud Server of the Health Data Monitoring Centre (HDMC). This will be done using 3G, 4G or other long range communications like GPRS. It will be configured for more than one such communication protocol so that alert message forwarding doesn't get hindered due to unavailability of any one type of service. The data sent to the cloud server will be compressed before transmission. These features reduce the traffic congestion and transmission delay thereby increasing the utilization of available bandwidth to a maximum and timely access of individual's health data by the medical staff for providing medical help at a shorter period.

In case of low alert the application will warn the user to take precautionary actions (pre-coded messages) and forward the details to the HDMC for future use. In case of medium alert which requires the user to take medical in the near future, the application will alert the user and forward the information to the HDMC as yellow alert. In addition to this, the medium alert message will be stored in the mobile application and a reminder will be provided to the user in predefined intervals until the user cancels the reminder. Also if the anomaly detected is false which may rise due to sensor anomaly it will be updated in the local database and no alerts will be generated.

While installing the application the individual's personal details like their unique identifier (can be social security number, citizen number or any country- wide unique number etc) that can be used to trace them individually, address, contact numbers of next of kin or caretaker to be informed during emergency and that of personal physician; insurance provider contact details and policy number; blood group, allergies (if any both to drugs and non drug related), pre-existing medical conditions (epilepsy, heart problems, asthma etc) and current medication will be collected and stored in the application local database in a secure manner. Instead of mobile, a Personal Digital Assistant (PDA) can also be utilized. Both the mobile application and the PDA will be configured with the HDMS IP address in order to transmit the data.

The **third tier** is the Health Data Monitoring Centre (HDMC) which is a 24 x 7 health help line manned by paramedical and registered nurse personnel who are capable of recognizing medical alert situations. The alert signal and the individual's data will be received through the data server maintained in the cloud. The receiver of the alert signal (health advisor) will verify the authenticity of the situation by calling back the affected individual. If the contact could be made, the health advisor will ask series of questions to understand and immediately raise the alert if warranted to the respective stakeholders through phone calls and messages as per the standardized protocol. If it is not ascertained to be an emergency situation and/ or if a medium alert signal was received, the individual will be connected to a medical advisor who will further advise the individual. He or she will be provided the necessary information regarding nearby hospital or ambulance service (via help line through mobile) if required and his/ her nearby relative will be informed via HDMC and counseling provided as a precaution. If the alert signal initially received is of low or no risk the information no call will be made. Every alert signal with further action taken by HDMC will be updated and maintained in the HDMC database in the cloud. History of such occurrences of the patient can be traced back if required through patient's contact details.

As a part of the protocol, HDMC will automatically locate and dispatch the ambulance service near to the individual together and forward the details of the individual's medical condition and the address of the emergency hospital nearby. Alert regarding the medical emergency situation will also be simultaneously communicated to the local traffic police station. While the person is being transferred the contact person mentioned in the individual's detail, personal physician (if applicable) and insurance provider will also be intimated. This data centre being the back bone of the architecture can be situated either separately or in medical centers where emergency services are provided.

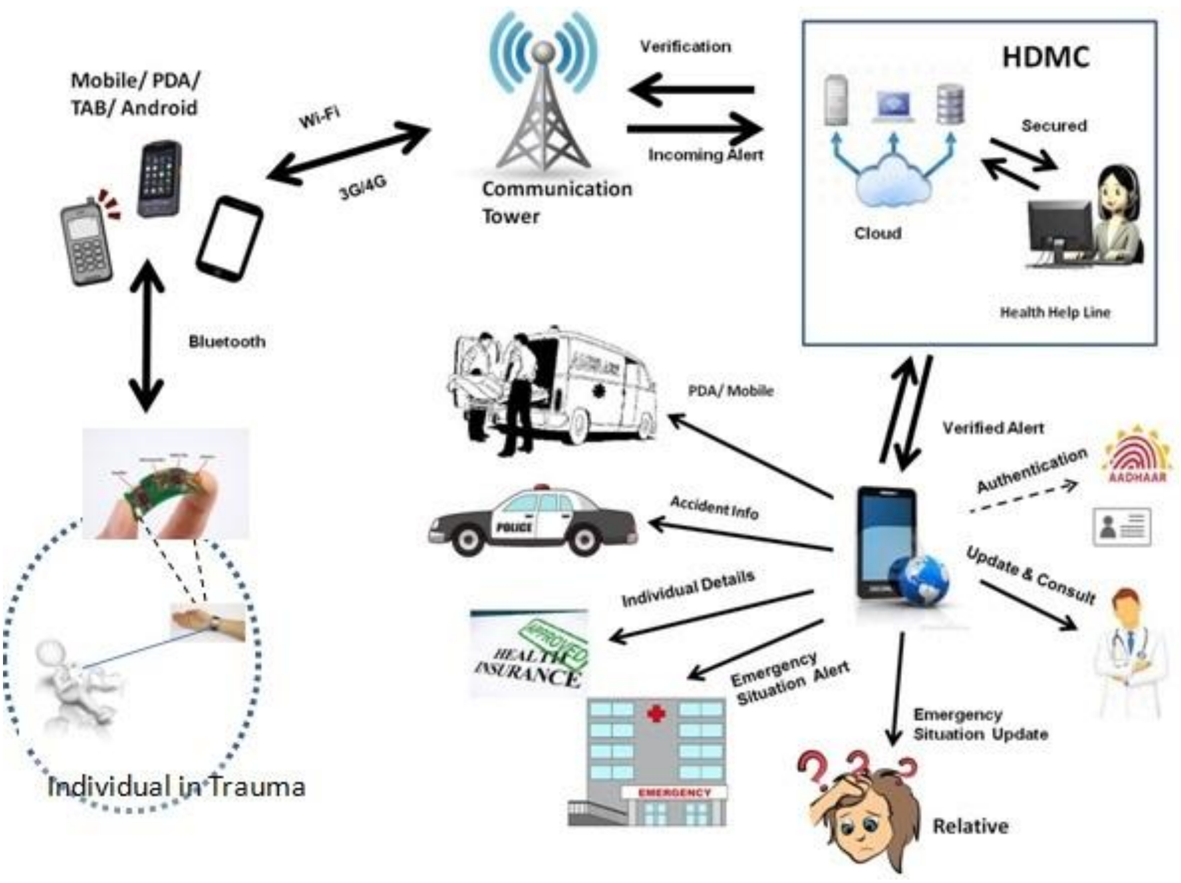
The fourth tier is the contact tier. This is made up of the various stakeholders – the insurance provider, hospital, person's relative, ambulance service and personal physician. The insurance provider may be a state or central government [50,51] or any private providers [52,53] to whom the individual is linked. Inclusion of insurance providers as a stakeholder enables early communication of the medical alert of the individual to the concerned provider.

This not only reduces the waiting time for getting approval from claims it also helps in quick release of insurance approvals. To ensure this two things are mandatory: 1) involvement of the insurance providers in the form of acceptance and collaboration with data centre to be part of the loop and to provide necessary details to the concerned hospital where the individual will be transferred; and 2) availability of the insurance detail of the individual in the app running in the individual's mobile. Similarly communicating to the hospitals will ensure that the hospitals are prepared to receive the individuals and provide quick treatments without delays.

The personal physician will be contacted only if their contact details have been already stored in the app would aid in understanding additional pre-medical details of the individual that has not been entered by the individual during installation prior to providing first aid or treatment. The patient's physician can access the information sent from his / her mobile or work station via the internet, recognize serious anomalies in the individual's health condition and interact with the emergency unit advice them regarding the specific precaution to be taken while treating the individual. Also in case the relative is unable to be contacted by HDMC they can be linked via the physician and vice versa.

The entire architecture is built upon the fifth tier. It is the non functional framework proposed to provide a mechanism for secure, reliable and timely communication among the various group of devices and the stakeholders. Each device follows different standards depending on the manufacturer. Ensuring the security of the patient's data while transmitting over wireless channels is the basic requirement in addition to maintaining the privacy of the user data. Each and every device need to be standardized with proper health data standards and communication protocols in place.

Figure 4: Proposed Overall Architecture of Integrated Medical Alert Monitoring System



DISCUSSION

Even with recent advances and development in bio sensors and wearable devices, their cost is still high to be used as a normal everyday household item. But harnessing the versatility and capacities of digital wearable technology with traditional medicine like Ayurveda on the ubiquitous mobile or hand held device platforms will provide a holistic, personalized and cost- effective approach of implementing a medical alert communication and monitoring system. The growing impetus in developing countries like India, China, Kenya and Nigeria to mainstream the traditional medicines and include them as a part of clinical practice is raising hope of their acceptance as remote monitoring paradigm of future healthcare [54-56].

Such successful combination of two diverse worlds, traditional medicine and modern technology to yield an integrated health system depends on sustained and growing interest of consumers.

For the above to happen, first Ayurveda needs to move more towards an acceptable evidence based system. It is very imperative that suitable care is taken to see that the basic constructs of Ayurveda are not distorted to prove its scientific backing, but systematic documentation, appropriate methodology, rigorous experimentation coupled with epistemologically based good practices, blending with contemporary modern medicines are adopted [57,58].

The second factor that will promote the use of this integrated alert system will be if there is an understanding among all stakeholders that this is not just for providing alert alone, it can also be used simultaneously for day to day healthcare monitoring and for predicting future health problems. This can be realized only if the data collected from the integrated system is put to proper use through analysis and prediction. There is a considerable movement in this direction in the healthcare industry in developing and testing such algorithms based on data mining to predictive analysis to achieve the expected result [59-61].

Gartner has estimated that some 6.4 billion connected things will be in use by the end of 2016, with more than 5.5 million new things on an average getting connected every day [62]. The third factor that will promote the successful use of integrated medical alert system will be influenced by wearable device size (like a small watch or a pendant or a button etc), its non-invasiveness, and ability to measure multiple parameters and provide automated feedback that increases their usage [63]. To achieve this, software and the database need to be updated regularly, support for different connectivity profiles should be available and there should be reduced power consumption. Also the security issue needs to be continuously updated to make the monitoring, updating and sharing system acceptable to a wider community taking into consideration privacy and confidentiality issues.

Another factor that needs to be taken into consideration is the type of the handheld devices that will be used by the individual. ITU statistics suggest that almost 6 billion people have mobile phone subscriptions [64]. The 21st century reality is that the majority of the world's population, nearly 90% of the world, is plugged in via cellular telephony. There are variety of devices from smart phones to androids, tablets etc each operating with different operating system. The mobile application that received the data from WSAB and further transmits to HDMC should be capable of working in all the commonly available operating systems. Not only should the device interface be standardized [65] also the data and information representation should be standardized to an interoperable format that maintains its integrity and security during storage, retrieval and communication [66].

The medical alert situations may vary. Hence the decision logic that is utilized to identify the alerts should be tested and standardized for most common situations [67] and should also be capable of self learning. This is very vital because integration and analysis of heterogeneous data involves complex fusion, reduction and analysis techniques for extracting the relevant information [68]. Since timely access to patient's information is the key of the architecture proposed, reduction of transmission delay and traffic congestions is of critical importance. While transmitting the data from the individual's handheld or mobile device to the HDMC appropriate standardized data compression techniques should be adopted and the data should be prioritized such that important vital details are transmitted first followed by other details in sequential order based on priority.

Linking the integrated health monitoring system with unique identification number (uniqueID) like social security number, Aadhar number (in India) [69], citizen ID [70] etc would help in reducing the amount of information being passed from the user's mobile to HDMC. Also unique ID in most cases are linked to the individual's contact address and in many cases to their insurance details, hence these information need not be transferred. Using the number HDMC can retrieve the relevant information from the concerned authorities after proper verification.

Not but not the least, in the integrated remote medical alert monitoring architecture proposed by us, integral to the system is the involvement of external stakeholders like the physician, ambulance service, hospitals providing emergency care and insurance agencies for providing immediate medical treatment and support. For this to happen, there should be a collaborative, cooperative and integrated networking between them that offers an win-win situation to all. All the hospitals and ambulance services in a given locality should be mapped and those willing to participate in the network should be identified and tracked by the HDMC. It is vital that hospitals linked to the system are capable of providing emergency services.

Another implementation option that can be profitable and viable is, that the HDMC can be hosted by insurance agencies. Agencies can utilize their existing help desk facilities, tie ups with hospitals and care providers for providing medical alerts to their existing customers as a value added service. This may further increase their business opportunities also.

The uniqueness of the architecture proposed here is that it can also be customized to provide alerts specifically for patients of chronic disease and later adopted for general monitoring also.

CONCLUSIONS

Over the last decade, technological advances have supported the evolution of a pervasive health paradigm leading to development of sequence of technological steps necessary to provide integrated care. However they are typically fragmented into many processes that do not talk to each other. One of the reason may be the difficulties prevent in implementation of the requisite infrastructure due to financial constraints, particularly in developing countries like India. In the current paper, we have put forth a framework for designing an integrated remote medical alert monitoring system that combines wearable technologies, decision support system and mobile application to the traditional Ayurveda method of health diagnosis that promises to hold a potential role in remote monitoring of medical alerts.

CONFLICT OF INTEREST

The authors have no conflict of interest for this publication.

CONTRIBUTORS

There are no collaborators beyond the co-author of the paper.

CONTRIBUTORSHIP

ST initiated the process for this paper. AR and ST together designed the study and prepared the manuscript. AR edited the manuscript and conceived the final form. Both AR and ST take equal responsibility for the information provided in the paper.

COMPETING INTEREST

The authors have no competing interests for this publication.

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