IoT, Fog and Cloud Computing Based Virtual Patient Monitoring and Telemedicine

Satadru Banerjee
A.K.C. School of Information Technology,
University of Calcutta,
Kolkata, India
satadru.banerjee20@gmail.com

Shreemoyee Goswami
A.K.C. School of Information Technology,
University of Calcutta,
Kolkata, India
shreemgoswami@gmail.com

***Abstract* - The paper focuses on a combination of emergency response and health system capacity-building efforts consistent with the COVID-19 containment plan that was recently developed by the Ministry of Health and Family Welfare (MOHFW), Government of India with support from the World Health Organization (WHO) and partners. It utilizes existing healthcare devices as nodes in an IoT network for large-scale patient monitoring as well as remote healthcare (Telemedicine). The system combines network-enabled devices with a mobile application acting as the fog node. The final data is stored in the cloud where long-term analytics and symptom-based diagnostics take place. These data and relevant analytics are made available to the medical personnel who can make the final diagnosis. The system finds relevance in both maintaining a medical presence in ill-equipped and remote locations as well as round-the-clock monitoring of elderly patients at home or in assisted living centers. So, we propose a continuous checking and control instrument to screen the patient's condition and store his/her information in a server utilizing Wi-Fi-based wireless communication.[2]**

Keywords – Internet of Things, Fog computing, Cloud Computing, 5G networks, Health Monitoring

I. Introduction

According to statistics from the Medical Council of India, our nation has a doctor to patient ratio of 1:1445, considering an average availability of 80% of the total doctor populace. With an approximate 9.27 lakh active allopathic doctors serving a population of 1.3 billion with a growth rate of 1%, there is a dire need for manpower in the Indian healthcare sector. Internet of Things (IoT) is a new revolution of the internet and is an adaptive growing research area in multiple domains, including healthcare. With the increasing accuracy and affordability of wearable sensors and smartphones, remote health care monitoring has evolved at a rapid pace.[4] IoT health monitoring also helps to monitor and control the spread of any contagious disease as well as to get a proper diagnosis of the patient, even if the medical personnel are at a different geographical location. This situation, therefore, provides a perfect opportunity for the introduction of virtual patient monitoring solutions (VPMS). The injection of technology will greatly benefit this sector, allowing more efficient use of human resources and ready availability. The situation is further benefitted by the growing internet penetration in rural areas. With the increased implementation of IT and management, data is now playing a vital role in disease diagnostics, drug administration, and healthcare management [16]. The developments in wireless sensor networks (WSN), body area networks (BAN), cloud computing, and big data technologies further simplify the implementation of the Internet of Things (IoT) in the healthcare industry. [17]

This paper aims to demonstrate an IoT-enabled system on high-speed 5G networks that allow doctors to check a patient's health parameters and monitor their progress remotely. It builds on the techniques first demonstrated by Shaw [6] as well as the INTEGRIS TeleRehab program [8]. It also incorporates a few under-development wearable technologies being developed by the IoT research cell of the University of Calcutta. Communication can be established through secure video conferencing channels while a network of internet-enabled devices and sensors continuously monitor the patient's vitals. For individuals requiring round-the-clock monitoring, these sensor networks can be autonomously run under the commands of a local centralized system acting as the fog device that continually backs up sensor data to the cloud. The system can ensure that the patient's vitals remain within predetermined levels, and generate alerts if any anomalies are detected. This concept can also find implementation in other applications such as elderly care in urban and peri-urban backgrounds, where we have the added benefit of relatively less interrupted cellular data services (4G+ speeds).

II. Literature Review

Virtual or remote patient monitoring has already been implemented in several developed nations across the globe. [1]. The concept of Telehealth has existed ideologically since the early twentieth century with radio and later television being a source of communication. Telehealth capacities were built into the spacesuits of the Apollo astronauts to monitor their health parameters and address any issues.[7] Modern telehealth combines the domain of IoT along with existing communication systems for comprehensive monitoring, early detection, and long-distance care system.[3] A modern evolution of this domain is the virtual patient monitoring systems (VPMS). In developing nations like India, VPMS provides a suitable solution for medical support in remote areas as well as providing round-the-clock care to patients institutionalized for prolonged durations.[12]

In his publication [6], Shaw elaborates on the development of Telehealth in the modern era and how in over 30,000 Trans-telephonic exercise monitoring sessions of patients with cardiopulmonary diseases, no circulatory arrests were documented despite the inclusion of high-risk cardiac conditions. Wakefield's evaluation of video and telephonic communication for monitoring patients with high-risk heart conditions showed a noticed delay in time to readmission as well as a massive increase in general data about symptoms pertaining to cardiovascular conditions.

In their publication [8], the team has highlighted the feasibility of using a real-time pulse oximeter and ECG data from the patient exercising on a motorized treadmill at a remote site. The researchers concluded that advanced aged patients with the aforementioned conditions can safely be monitored via telerehabilitation systems. The INTEGRIS TeleRehab program, based out of Oklahoma since the late 1990s has shown significant success in telehealth systems through a high-speed T-1 communication line and a Polycom system. Their success led to expansion into the domains of occupational and speech therapy.

The significant success of telehealth over the years combined with the beleaguered national health system of India facing an acute shortage of medical personnel causing over-extension of these valuable resources presents an ideal situation for implementing such a system.[10][11] Also, the recent SARS Cov2 outbreak [15] that has affected numerous countries around the globe and caused significant economic damage is a classic example of how the modernization of our health care systems has been ignored for too long. Remote Patient Monitoring arrangement allows observation of patients outside of customary clinical settings (e.g., at home or isolation centers), which expands access to quality health services and significantly reduces expenses. With benefits to both rural and urban sectors, this is the logical step forward for more efficient utilization of our nation's limited health resources.[13] With a primary focus of monitoring patients with cardio-pulmonary conditions, the system may be further extended and established to support a wider array of medical conditions as well as general vigilance of individuals who require constant monitoring such as the elderly and the differently-abled.[5]

III. PROPOSED METHODOLOGY

The data collection process will revolve around 4 primary parameters to be monitored along with the patient's inputs on a daily questionnaire. Here, the intention is to build an independent sensor hub for monitoring user vitals and alerting if necessary. The final communication with a medical professional takes place through a live teleconferencing solution, choosing one of the many readily available solutions. The sensor hubs (FOG devices) are individually connected to the cloud where the bulk of data processing and analysis takes place. The analyzed data is readily available to medical professionals for their opinion through a simple and vivid online dashboard. Fig. 2 demonstrates our data acquisition (DAQ) module.

At the simplest level, the system accepts e-prescriptions from authorized medical personnel. It then updates the patient's current daily medical roster (if any) and appropriately generates alerts at the designated time. This aims to prevent missing doses, which is especially prevalent in the case of elderly patients

Fig. 1. E-Prescription concept.

The parameters being considered for this study include blood pressure, body temperature, oxygen saturation in the blood (SpO2), real-time heart rate readings as well as blood glucose levels. The blood pressure readings are to be taken at regular intervals through a connected Sphygmomanometer that transfers its readings to the local fog device after measurement. The data is then stored in the cloud and analyzed based on previous data for the patient. Any risk markers such as recurring high blood pressure or hypertension can be flagged and reported accordingly to the doctor's patient dashboard.

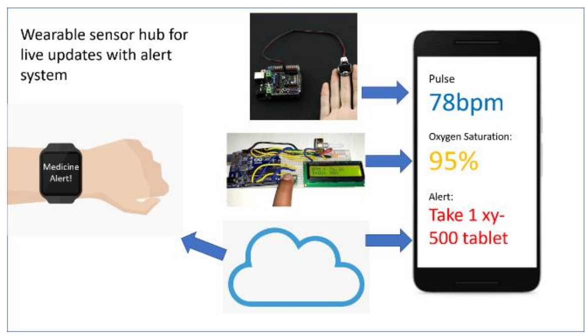

Fig. 2. Data Acquisition Module

The temperature sensor is connected to the digital pin of the microcontroller board. Based on the data in Table 1, we determine if the temperature lies within the normal range. Using the data, the controller converts it into its corresponding value in degree Celsius (°C) using the equation:

temperature (°C) = [raw value*5/4095- (400/1000)] *(19.5/1000)

Oxygen saturation is monitored through a similarly connected pulse oximeter (Fig.3). The device detects the patient's blood oxygen level and communicates it to the fog. These readings are especially necessary for patients facing chronic obstructive pulmonary diseases and other respiratory hindrances. Sudden drops in oxygen levels will generate high-level alerts and the nearest caregiver can be instructed to administer respiratory aid. Table 2 highlights the optimum oxygen saturation levels.

Fig. 3. Oxygen Saturation level monitoring

The patient’s pulse is calculated in two primary ways as shown in Fig 3 and Fig 4. Wearable technology with embedded passive heart rate sensors is used for real-time pulse readings. Additionally, secondary and tertiary readings are collected through the blood pressure and oxygen saturation sensors, since both operate in close contact with the patient. A combination of these readings will minimize any possibly erroneous data that crops up, reducing the chance of false alerts. Table 3 highlights just this.

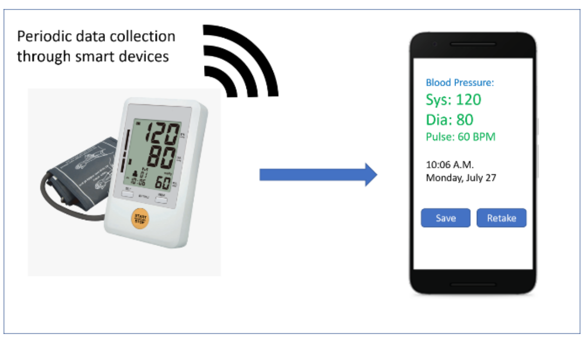

Fig. 4. Blood Pressure Monitoring

Finally, we also aim to monitor a patient's blood glucose through a similar, internet-enabled glucometer (Fig. 5) that can transmit data to the fog node. While much research is being conducted in the field of non-invasive glucometers, the lack of affordable and proven technologies will require us to currently rely on the readings of the standard blood-based invasive glucometers. This will be substituted for a non-invasive system as soon as a compatible, accurate, and economical product is available[14]. The values of Table 4 are some basic benchmarks we consider.

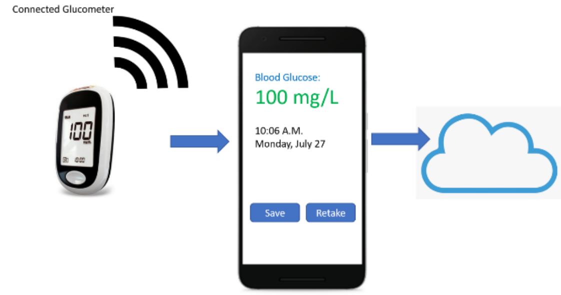

Fig. 5. Glucometer data collection

With these sensors appropriately deployed, the next point of action is the fog node. It can be a compact, low-power server based on Raspberry Pi or a more powerful server for large patient hubs as well as a controller application running on a sufficiently powerful smartphone. The benefits of sensor fusion are visible in Table 5 where we combine oxygen saturation and body temperature for some common diagnostics. Besides doubling as a local server, the smartphone will also provide a means for showing health alerts and limited analytics data to the patient or their local caregiver. The full dataset and its analysis will be visible to the designated doctor, allowing virtual patient monitoring. The smartphone application will also provide the patient with daily questionnaires (Fig. 6) aimed at identifying any new symptoms or conditions that might require medical intervention. These questionnaires will need to be filled up daily and stored in the cloud for the patient’s symptom analysis and the doctor’s reference.

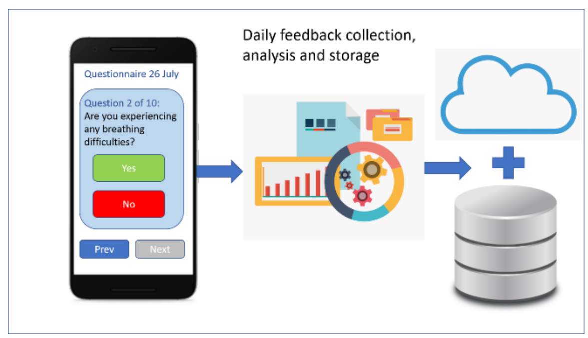

Fig. 6. Proposed questionnaire system

The final system has a structure like Fig. 7

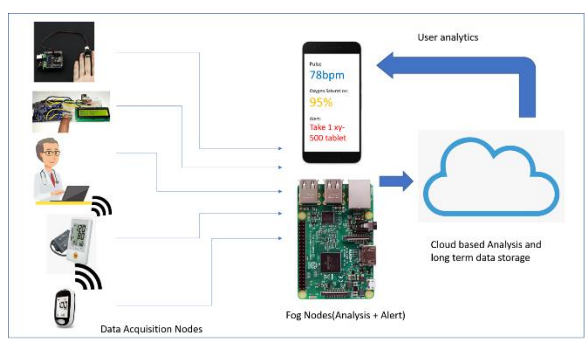

Fig. 7. Composite system

A. Alert Generation Criteria:

TABLE I. BODY TEMPERATURES

Body Temperature (°C)	State
36.0 – 37.5	Normal
>37.5	High
<36.0	Low

TABLE II. BLOOD OXYGEN SATURATION CLASSIFICATION

Reading(%SpO_2)	State
95% - 100%	Normal
90% - 95%	Low
<90%	Very Low

TABLE III. PULSE RATE CLASSIFICATION

Pulse Rate (BPM)	State
60 BPM – 100	Normal
>100	High
<60	Low

TABLE IV. BLOOD GLUCOSE METRICS

Fasting Blood Sugar Levels	Post Meal Blood Sugar Levels	State
70-100 mg/dl	70-140 mg/dl	Normal
101-125 mg/dl	141-200 mg/dl	Prediabetes (Low)
>=125 mg/dl	>=200 mg/dl	Diabetes (High)

TABLE V. POSSIBLE DIAGNOSIS

Pulse Rate with SpO_2 (from Oximeter)	Body Temperature		
	Low	*Normal*	*High*
Very Low	Emergency Checkup	Respiratory Distress	Emergency Checkup
Low	Hypothermia	Mild breathing trouble	Fever
Normal	Health Checkup	Healthy	Fever

[a] **Red** indicates high-risk alert

Orange indicates moderate risk warning

B. Risk and Mitigation Plan

- There has to be a proper and continuous internet connection, otherwise, the data would not be updated timely. So, stable connectivity is essential.
- As common with any solution that requires data transmission between devices and servers, there is a risk of unauthorized access to the secure networks. This may be mitigated by implementing encryption algorithms to convert our data into appropriate ciphertext.

IV. Possible Use Cases

As mentioned before, the domain of Telehealth and Telemedicine has been in use since the 1960s. In the ongoing SARS Cov2 (Covid-19) Pandemic, its relevance and usefulness have once again come to the forefront of the medical community. Many government health organizations, including the Indian Health Ministry, are openly advocating telemedicine as a quick and efficient method of treating the massive population. It also reduces risks of contamination in case of pathogens as highly contagious as the SARS Cov2. Therefore, it is only fair to assume that this medium of virtual healthcare will remain relevant in a post-pandemic world.

Apart from healthcare and monitoring patients with highly infectious diseases, the system can make modern and high-quality healthcare accessible in remote locations of India. Doctor consultations can be carried out virtually through teleconferencing while the aforementioned sensor networks can effectively monitor the patient's vitals and flag any inconsistencies. Machine learning-based models can also be used to assist the diagnosis by efficiently relating the patient's symptoms and current health parameters with relevant online repositories and make suggestions to the medical personnel. This can allow currently overstretched medical resources to be utilized more effectively and efficiently.

Another possible use case could be the domain of geriatric care, where the system could be adapted for round-the-clock monitoring of elderly patients with minor editing. In this case, a new functionality of a local caregiver can be added which will alert the patient's local attendant in case of any anomaly. The wearable alert and monitoring device can also be adapted with multi-axis gyro-sensors to detect and predict falls, alerting the local caregiver if any of the parameters cross predefined thresholds. Significant research has already been carried out in the domain of fall prediction [9].

V. Conclusion:

The Internet of Things (IoT) increases interoperability, machine-machine communication, and data sharing that makes healthcare service delivery more efficient and effective. It facilitates that the individual's health parameter data is secure within the cloud, hospital stays reduced for traditional examinations, and most importantly, health parameters can be monitored and disease diagnosed by specialists remotely. This project is an ideal example of implementing technological assistance in the Indian healthcare domain with potential for expansion in other developing nations. It will also highlight and remedy previously unanticipated challenges and issues that may arise in moving a real-time connected system into locations with limited connectivity.

VI. Future Scope:

The future scope for this project includes more dense networks of sensors, simultaneous monitoring of patients through interconnected hubs as well as comparative studies with patients in different geographic locations. Also, the potential for the development of new, minimally invasive medical devices as a corollary (Non-invasive glucometers, Non-contact sphygmomanometer) is not to be ignored. Finally, the system aims to mitigate the challenges brought forward in highly contagious outbreaks similar to the ongoing SARS Cov2 pandemic.

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