Transforming healthcare through Internet of Things

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Abstract

The objective of this technical paper is to demonstrate how internet of things (IoT) is transforming healthcare and the role of IT in healthcare. The applications of IoT are nowhere essential in transforming lives of people than in healthcare. IoT refers to physical devices, such as a weight scale, thermometer and patients’ vital monitoring devices (glucose, blood pressure, heart rate & activity monitoring, etc) connect to the internet and transforms information from the physical world in to the digital world. According to Gartner, there will be nearly 26 billion devices on the Internet of Things by 2020[2]. These devices seamlessly gather and share information directly with each other and the cloud, making it possible to collect record and analyze data. This information provides insight in to the health and supplements actions to improve the health, without the hindrance of the daily routine. In this paper, we'll explore in greater depth the role of the IoT devices in healthcare and the role of IT in managing the huge volume of high security patient’s medical data. Expected key take away from this paper is current trends, challenges, case study and a real world project management experience. This paper proposes few applications of IoT in rural healthcare and ways to improve primary health needs of the developing nations.

Keywords: healthcare, cloud, Internet of Things, data analytics
1. Introduction

In the current technology enabled world, changes are rapid and the status-quo is constantly disrupted. Internet of Things (IoT) is one such disruption happening right now, which has the potential to change the way healthcare is delivered. There are no standard definitions for the Internet of things, As per the definition of Gartner [1], “Internet of Things (IoT) is the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment”. The IERC definition [4] states that IoT is "A dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual “things” have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network.” The IoT allows people and things to be connected Anytime, Anyplace, with Anything and Anyone, ideally using Any path/network and Any service [3]. The main contributor for the IoT can be attributed to the growth of smart phones and tablets. These mobile devices act as a window to the IoT world. They have the capabilities to perform the wide variety of tasks for the patient & doctors, in addition to providing mobility and connectivity. The mobile revolution is pushing the connectivity of other physical objects seamlessly using the cloud storage. As more and more devices are connecting and communicating with each other, huge volume of data is exchanged. This explosion of data needs to be stored, analyzed with complex data analytic techniques to provide the necessary information for both the patient and doctor. However, in the current trend, only the medical devices within the hospital infrastructure are connected within themselves and this network provides access through medical apps available to the clinicians.
This paper is organized as follows: Section 2 describes about vision and architecture of internet of things, section 3 discusses about the applications of IoT in healthcare and the current trends, section 4 discusses about the case study about real-time remote diagnostics, section 5 describes a real world project experience on developing products for rural healthcare, section 6 discusses about challenges for the penetration of IoT in the healthcare, section 7 discusses the roadmap for IoT and the future of the healthcare delivery model, section 8 concludes the paper by summarizing the discussion points from this paper and section 8 provides research references.
2. Vision and Architecture

IoT is a vision which is still at very early stages, where everyone interprets the vision with their own perspectives. There are three main visions of IoT based on the things, digital and semantic perspectives [6]. All these three perspectives of IoT should integrate with each other seamlessly as shown in Fig 1, for extracting the full benefits of IoT architecture.

1. Things oriented vision
2. Internet oriented vision
3. Semantic oriented vision

Fig 1: Vision of Internet of things

- **Things oriented vision**: This vision provides the perspective that all the real physical objects can have the sensors attached to get the real time information from them. This can be accomplished by the sensors based network of
embedded devices using RFID, NFC and other wireless technologies. This vision provides the base for integration of all “things” using different sensor based networks to collaborate and co-exist together.

- **Internet oriented vision**: This vision provides the perspective that all the devices can be connected through internet and can be described as smart objects. This can be accomplished by using unique IP for each connected object. This vision provides the base for the data integration of all the smart objects, which can be continuously monitored.

- **Semantic oriented vision**: This vision provides the perspective that all the data collected from various sensors need to be analyzed for meaningful interpretation. This can be accomplished with semantic techniques, which separates raw data from the meaningful data and their interpretation. This vision provides the base for the semantic integration through the use of semantic middleware.
The sensors help to transform the physical world data (e.g. temperature, pressure, humidity, etc) including human health data (heart rate, oxygen saturation, blood pressure, blood glucose, etc) to the digital world and the actuators transforms the digital data to physical actions (e.g. Infusion pumps, dialysis system, etc). The IoT devices have sensors for receiving signals from the environment for analysis, or actuators for controlling the environment based on the inputs, or both sensors and actuators [5]. These devices connect with each other through internet transfer and cloud storage for communication with similar devices and people, as shown in Fig 2. There are multiple studies from various research companies for the projected figures of these IoT devices ranging from 26 – 212 billion IoT devices in 2020 [2].
3. Health care trends:

The current trends in the healthcare can be classified in multiple ways based on the perspective of the technology, functionality and the benefits. There is a trend happening with the convergence of consumer devices and medical devices. Most recent smartphones are being launched with health sensors in the accessories like wrist gear. This enables the mHealth, which refers to the use of mobile and wireless technologies in the practice of medicine and the monitoring of public health. This reduces medical errors based on continual monitoring practices. IoT applications in healthcare can be grouped in to following categories based on the functionality [7].

1. Tracking of objects and people
2. Identification and authentication
3. Automatic data collection and sensing.

Health trends can be analyzed with respect to the application areas in medical practice. Some of the applications areas are listed below along with the usage of IoT concept and their benefits.

- **Wireless patient monitoring:** This application is for remote surveillance of patient vital functions through the use of internally and externally located patient devices. As opposed to discrete interactions, the provision of healthcare is moving to a model where information is being transmitted and shared in real time between individuals and caregivers. This is especially relevant for chronic disease management such as hypertension, diabetes, coronary heart disease, asthma. Examples: Wirelessly monitored pacemakers and automatic defibrillators.
• **Mobile system access:** This application is based on the mobile technologies that enable remote/virtual access to current clinical systems (electronic health records [EHRs], picture archiving and communication systems [PACS], etc.). All the medical system can be automated with easy to use mobile app interface. This application of technology in healthcare is referred as e-Health. If the mobile is used as monitoring and delivery of healthcare, the application area is termed as m-Health. Examples: Websites, portals, mobile apps.

• **Medical devices:** This application is used to capture and track key care compliance and disease management data. Mainly these are used as fitness solutions for tracking of patient activities and smart diagnostic devices used for capturing the data from the sensors for further analysis by doctor. Google glass is also under research for possible medical devices as this can used to perform assisted surgeries and recording, etc. Examples: digital glucometers, blood pressure devices, pedometers, wearables – fitbits, google glass, etc.

• **Virtual consultation (telemedicine):** This application is based on the remote connectivity and multimedia solutions that enable virtual care consultation, education, medicine delivery and therapy procedures as shown in Fig 2. In some countries appointments and wait times are getting longer. Through virtualization, the majority of routine care can happen within minutes and even seconds. The remote diagnostic screening has become common in some countries and markets. There shall be the possibility to see the advent of telesurgery for routine procedures using robots and nurse assistants. Examples: Tele-consultations, mobile video solutions.
- **Aging in place**: This application is used to enable clinically monitoring for independent living of aging populations. These devices mostly come up as wearable for monitoring the elderly patients without the need for manual intervention. The vital signs data from the elderly care is acquired from the monitoring devices and transmitted to a standard mobile device which acts as a network node for transmitting the real-time data to the doctor. The information can be used to give medical assistance to the needful person and in case of higher abnormalities, the nearby efficient hospitals can be alerted and thus the hospitalization costs can be reduced through early intervention and treatment. Examples: Personal emergency responses systems (PERS), video consultations, activity monitoring and fall detection.

There has been clinical evidence that the physiological data received from wireless devices has been a valuable contributor for managing or preventing chronic diseases and monitoring patients post hospitalization. As a result, a growing number of medical devices are becoming wearable nowadays, including glucose monitors, ECG monitors, pulse oximeters, and blood pressure monitors and so on.

All these data are stores, monitored in real time to see the trend along with analytical capabilities of the modern systems.

The Internet of Things enables health organizations to lift critical data from multiple sources in real-time, and a better decision-making capability. This trend is transforming healthcare sector, increasing its efficiency, lowering costs and providing avenues for better patient care.
4. Case study

VSee team in real-time telemedicine eye clinic

VSee telemedicine deployment team has setup the temporary eye clinic and the operating room by using the tiny cabin provided to them at the syrian refugee camp in duhok. Team arrived with the telemedicine field kit along with surgical equipment and medicine. This telemedicine kit features all the basic healthcare diagnostic devices (stethoscope, heart rate, blood pressure, pulse oximeter, ultrasounds, otoscopes, dermascopes, etc) connected remotely with the doctor. Based on the need of the doctor, this kit can be customized with the selected list of diagnostic devices. In this case study, the eye doctor needed an ophthalmoscope and it is included in the kit as shown in Fig 3. All the diagnostic devices transmit the data to the doctor in real time along with video conferencing capabilities. This field kit can be easily operated by the field service technician with a little overview and training. A long line of refugee patients were treated by the medical team. Team started operating on patients continuously just by using the power generator. Team is able to setup the remote eye clinic and operating room and perform surgeries locally within few hours.
This has helped to control the number of minor cases crowding the local hospital, freeing up more appointments for urgent and serious cases. In addition to the speed, the quality of healthcare is as equal to the personal visit. This is also more convenient for patients, which helps to avoid frequent and long distant travel for doctor’s visit.
5. Project experience

This is a real world project experience on developing a product for improving the rural health through connected healthcare. This product is called Health operations enabler, since this connected health project addresses primary problems faced by the rural healthcare.

- Rising patient demand and shortage of medical professionals
- Increase in cost for providing high quality healthcare in rural areas.
- Lack of medical accessibility in remote areas.

The idea is to connect the rural patients to the doctor in an urban specialty hospital through semi-trained healthcare professionals. These healthcare workers are trained on the standard diagnostics and defined clinical pathways with Clinical Decision Support System (CDSS). These clinical pathways help in identifying the primary cause for multiple diseases with guided and step-by-step clinical decision making. This decision making process is based on the combination of standard healthcare practice and the experience of clinician. The clinical pathways can be customized and authorized by the respective clinician and deployed with the help trained professional as shown in Fig 4. Here, the purpose is not to replace the doctor, but to enhance the efficiency and healthcare reach to remote areas.
In the project management perspective, cost and schedule are constantly negotiated with the sponsoring team. However, the quality factor is not negotiable, since this is a healthcare project. Risk management is another important aspect of this project considering the safety of the patients with insufficient diagnostics. There are strict regulations that only practicing clinician should perform the diagnostics and prescriptions. Hence the health workers and program manager are playing only the facilitating roles to connect with doctor. Also the intelligence built in to the clinical pathways are agreed and signed-off by each clinician individually. This project deals with three important stakeholders (healthcare workers, program manager and management/doctors). After the data collection program manager feeds the data to the clinician through internet. There is a central data server established for storing the entire patient’s data. This can be used for data analytics to identify the trend of diseases in this particular area; thereby outbreak of epidemic can be predicted and controlled efficiently.
The pilot of this project happened in partnership in Barhara village of West Bengal, in partnership with Dr. Achyutananda Ghosh centre for public health intervention program. This camp is setup with the primary aim to pilot the product in the field and get the feedback to improve further. All the stakeholders arrived at the venue for a briefing on the product. Then the healthcare workers are trained by the system experts on operating methods and data collection procedures. After this short but hands-on training, healthcare workers are confident on the usage of the system. Healthcare workers started the patient’s visit as per the pre-defined clinical pathways. These clinical pathways are verified in parallel with the doctor at the site as shown in Fig 5. All the stakeholders felt that the product is very useful for remote and rural healthcare.
6. Challenges

IoT world has challenges in many directions including technical, regulatory, market-based and socio-ethical considerations. The center of focus is on protecting privacy as this is the primary cause of other challenges including government participation. Integrated effort from government, civil society and private sector players to protect these values, the development of the Internet of Things will be hampered if not prevented. [8]

- **Scalability** – As the billions of IoT devices gets connected to the network, large volume of data needs to be processed. The system which stores, analyses these information from the IoT devices needs to be scalable. In the current state of the IoT evolution people and everyday objects are connected with each other. The raw data from this connected world needs big data analytics and cloud storage for the interpretation of meaningful data.

- **Interoperability** – Technological standards on most areas are still fragmented. These technologies need to be converged. This will help to establish the common framework and the standard for the IoT devices. As the standardization process is still lacking, interoperability of IoT with legacy devices should be considered critical. This lack of interoperability is preventing us to move towards the vision of truly connected everyday interoperable smart objects. [9]

- **Lack of government support** – The government and the regulatory bodies like FDA should come and play an active part in bringing up the regulations by setting up the standards committee for IoT devices for safety and security of the devices & people.
• **Safety of patients** – Most of the times IoT devices are left un-attended, since they are attached to the real world objects. If used on patients as implantable or wearable, due to purpose and nature of IoT devices, any breaches in security are life threatening and considered very critical [13].

• **Security and personal privacy** - Security vulnerabilities and improvements have not been well researched. The IoT in healthcare should ensure Confidentiality, Integrity, and Availability of patients’ personal data.

• **Design challenges**: - As the technology is improving at a faster rate the design challenges can be met in the near future. Nevertheless these are still challenges as on today, while designing an IoT based system [12].

  o Limited energy
  o Limited memory
  o Limited compute power
7. Roadmap

SRI Consulting Business Intelligence [6] sees the development of IoT in waves as per Fig 6. The first wave started with the use of RFID tags to facilitate routing, inventorizing and loss prevention, as supply chain helpers. In the second wave, vertical-market applications e.g. surveillance, security, healthcare, transport, food supply and document management are developed. The third wave, which we are currently experiencing, is about ubiquitous positioning e.g. locating people and everyday objects. The next wave, which is expected to mature in about a decade, will be the creation of a physical-world web e.g. tele-operation and tele-presence, ability to monitor and control distant objects. In this phase of IoT evolution, it is expected that all the physical objects will be seamlessly integrated in all three visions.

Fig 6: Roadmap for IoT
These are some of the future areas in healthcare area listed below, which is primarily driven by the ability to monitor and control distant objects every time.

**Ingestible sensor**

The ingestible sensor is the sensor based technology swallowed as a pill. It’s made entirely of ingredients found in food and activated upon ingestion. This is taken alongside the prescribed medications, capturing the exact time of ingestion for tracking the compliance to medication. The ingestible sensor is powered by the human body fluids. There are no battery and no antenna. After the pill with the ingestible sensor is swallowed, a stomach fluid chemical reaction provides required power source and activates the sensor. This sensor remains in the patient’s stomach and provides real-time information about how the patient responds to medicine. The patients do not have to endure blood tests, x-rays, or biopsies for their doctors to determine whether a drug is working. This can be especially helpful for patients who regularly take medicine for chronic devices [10].

After activation this sensor generated and transmits the unique number. The patch, body-worn and disposable, captures and relays your body’s physiologic responses and behaviors. It also receives the unique information from the ingestible sensor, detects heart rate, activity, and rest, and sends information to your mobile device. Then these inputs are passed on to the central gateway to the secured data server. This input is further distributed to needed healthcare providers as shown in Fig 7.
Digital medicine

This is an evolution of the ingestible sensor, here the medicine itself goes digital, instead of an additional pill for tracking compliance. Digital Medicines are the same pharmaceuticals consumed today, with one small change: each pill will also contain a tiny sensor that can communicate, via the digital health feedback system, vital information about the medication-taking behaviors and the responsiveness of the body. These ingestible sensors within medications are activated only on contact with stomach acid. This helps in providing higher truth and better granularity of tracking the health of patients [11].

This is the next stage of continuous, where sectors will soon be prescribing ingestible sensors, which will wirelessly report back on the body’s vital signs on a 24/7 basis. Digital Medicines are under development and are not yet FDA cleared. Currently clinical trials are conducted in these therapeutic areas:

- Heart Failure
• Central Nervous System
• Transplant & dialysis

Personalized medicine

Currently, the healthcare delivery is based on population statistics. Patients are separated into groups defined in various ways but usually by similar symptoms or by the results of basic lab tests (like cholesterol levels). These groups are then treated with drugs that may help many people, but not all of them, and often only a fraction of them. Healthcare coordinators and electronic medical records will drive a personalized approach to delivery, based on the DNA analysis of the patients personalized medicine will also enable customization of drugs and effective drug combinations based on the person’s genetic makeup [14].

Predictive analytics

The use of predictive analytics in healthcare will benefit from the merging of different data repositories, which has the trends of food & lifestyle habits. The more we know about an individual or population, that is, the bigger the picture, the more precise the predictions will be. These models can be customized based on the data points, to a specific patient or group of patients that ultimately leads to more precise and effective treatments that are bound to improve the overall efficacy of the healthcare system while at the same time reducing costs [15].

In the near future, the health buddy mobile app may be able to warn you days in advance that you are going to have a heart attack by sensing certain genomic signals circulating in your blood stream and sending you to your cardiologist or to the emergency room.
8. Conclusion

As discussed in this paper, all the physical objects will work seamlessly with machine-to-machine and human-to-machine interfaces. This level of interconnection is a boon for the healthcare, where health influencing factors both internal & external to the human body can be analyzed based on the model. These factors along with the genomic inputs shall make it possible to predict the health trends and allergies of the person; thereby the technology can provide customized recommendations on suitable physical activities, diets, etc. This mobile doctor buddy apps are not meant to be the replacement for experience of the doctors. They should work collaboratively with the doctor. In this approach of complementing the doctor with the technology based inputs, the new trends in IoT has the capability to transform the way the primary healthcare is delivered to the patients. However for the developing world, IoT brings new delivery model for healthcare with good quality at affordable level. Proposal of IoT healthcare devices for the developing world are remote consulting, handheld diagnostic devices for detecting epidemic deceases like malaria and cholera. These devices shall have the far wider reach compared to the traditional primary care healthcare. It is evident that IoT will facilitate new business models and new healthcare delivery models in the future for both developing and developed worlds, irrespective of the challenges faced at the current time.
9. References


10. Author(s) Profile

Vijayakannan Sermakani received the Bachelor of Engineering in Electronics and Communications (ECE) from Government College of Technology (GCT, Affiliated to Anna University), Coimbatore in 2002. He is a certified Project Management Professional (PMP) from the Project management Institute (PMI). He has around 12 years of design and development of embedded systems for the healthcare and automotive domains. He has experience in the development of class III safety critical medical device and worked for PMA submission to FDA. Currently he works as the project manager in Robert Bosch Engineering and Business Ltd. He has been active in the product development cross functional teams and ideation workshops in the healthcare domain. His area of interest includes project management and product leadership.