The Internet of Things for Medical Devices - Prospects, Challenges and the Way Forward
About the Authors

Ashok Khanna
Business Head UK, EU and Major Accounts, Life Sciences (EIS)
Global Head, Presales and Solutions for Life Sciences (EIS)

Ashok Khanna has over 19 years of industry experience in the field of healthcare, hi-tech and telecom. As a business leader, his expertise spans multiple medical and pharmaceutical domain areas including new product development, product lifecycle management, manufacturing operations management, R&D and quality, regulatory and product sustenance.

Prateep Misra
Research Area Manager, TCS Innovation Labs

With over 21 years of experience in the IT industry in areas such as software development, research, technology consulting and software quality assurance, Prateep Misra leads the development of platforms for Internet-of-Things applications. Misra's current focus areas include IT infrastructure architecture and design, IT transformation, storage systems, large scale and real time analytics platforms, and cloud computing.
With the increasing use of sensors by medical devices, remote and continuous monitoring of a patient’s health is becoming possible. This network of sensors, actuators and other mobile-communication devices, referred to as the Internet of Things for Medical Devices (IoT-MD), is poised to revolutionize the functioning of the healthcare industry.

Connected health technologies have gained prominence as a result of the widespread occurrence of chronic diseases and the stringent need to control healthcare costs of an aging population. A connected healthcare environment promotes the quick flow of information and enables easy access to it. Improved home care facilities and regular health updates to clinicians reduce the chances of redundant or inappropriate care, improve patient care and safety, and reduce overall costs of care. Connected health solutions can also be used to track lifestyle diseases such as hypertension, diabetics and asthma which need continuous monitoring.

The IoT-MD provides an environment where a patient’s vital parameters get transmitted by medical devices via a gateway onto secure cloud based platforms where it is stored, aggregated and analyzed. It helps store data for millions of patients and perform analysis in real time, ultimately promoting an evidence-based medicine system.
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1. Introduction

The Internet of Things (IoT) is increasingly being recognized by researchers and analysts as one of the most sophisticated technologies that has the potential to not only affect the health, safety and productivity of billions of people but also has a major economic impact. It primarily consists of physical objects that are embedded with sensors, actuators, computing devices and data communication capabilities. These are linked to networks for data transportation.

Imagine a scenario where a patient’s medical profile, vital parameters, and dialysis machine inputs are captured with the help of medical devices attached to his body. The patient does not even have to move from facility to facility to receive treatment. Rather, he can get his dialysis done with the help of a portable/home machine designed for the purpose. Data gathered from this device is analyzed and stored, and the aggregation from multiple sensors and medical devices helps make informed decisions in a timely manner. Caregivers can monitor the patient from any location and respond appropriately, based on the alert received. Advanced treatment of this nature can drastically improve a patient’s quality of life.

Figure 1. Remote Monitoring of a Renal Patient
Health and wellness is one of the most promising application areas of IoT technology. Remote health management, managing lifestyle-related diseases and conditions, fitness programs, care at home, chronic diseases and care for the elderly are some of the important use cases. Other use cases include improving a patient’s compliance to treatment and medication in hospitals, clinics and other care facilities. Medical devices such as personal home-use diagnostic devices or low-end diagnostic and imaging devices that are used by mobile health workers are one of the key technology components.

Backend systems exist for data aggregation, storage, analytics, visualization and host user-centric services. In the IoT, physical objects monitor their surroundings and participate in daily activities, helping create new products, services and business models, to improve efficiency and optimize business operations.

Additionally, mobile phones can be used for many physiological monitoring and examination tasks. The potential economic impact of IoT in healthcare alone could run into trillions of dollars of annual savings.

In this paper, we identify potential application use cases as well as the challenges caused by the IoT on medical devices. Further, we analyze how a service oriented platform based approach can address these challenges.

2. Diverse Applications of IoT-MD

Connected healthcare programs utilize scarce resources to provide an improved quality of care, leading to better clinical outcomes. Measureable benefits of connected medical devices include reduction in mortality rates, reduced clinic visits, emergency admissions, and hospital admissions, including reduction in bed days of care and length of stay in hospitals. The major use cases in this domain include:

- **Care for the pediatric and the aged:** Connected health programs are designed to improve existing healthcare systems for pediatric and aging populations. The key idea is to allow the care to be administered in the patient’s home. Pediatric patients need attention and specialized care. Most aged patients, on the other hand, have multiple chronic diseases. Their physiological parameters, activities and home environment need constant supervision. Another class of devices detects mood and emotion which is used to monitor the psychological state of the patient.

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**Devices**

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*Figure 2. Versatile Offerings of Connected Medical Devices*
Chronic disease management: Chronic ailments such as cardiovascular disease, diabetes, high cholesterol, hypertension, obesity, pulmonary problems and other diseases affect billions of people worldwide. Chronic disease management involves managing the lifestyle of the patient via continuous engagement, to help the patient adhere to a personalized care plan involving specific treatment, medication and diet regimes.

Personal health and fitness management: This class of applications is intended for people who are self-motivated and take steps to stay healthy and fit. These users monitor their daily exercise and fitness regimes and use an app or web based application to store the data and keep track of their progress. These apps are also used to track adherence to schedules created by trainers. Sensors and devices used in this case include weight sensors, activity monitors, heart rate and blood pressure monitors, connected treadmills and other fitness equipment.

3. Unlocking the Potential of IoT-MD

Connected medical devices and associated IoT technologies will primarily be used to achieve the following capabilities:

- Access real time visibility of the patient’s condition, his/her activities, context and physiological parameters
- Monitor compliance to prescribed treatment, diet and exercise regimes
- Provide feedback and cues to patients, family members, doctors and caregivers in order to implement corrective action
- Leverage high performance computing for real time feedback and use evidence-based medicine for better patient outcome

Remote monitoring of patients leads to more effective and timely treatment, leading to better management of health. In addition, patients (and their relatives) are empowered by getting greater visibility into their actual health conditions, enabling them to play an active role in controlling and influencing their treatment.

4. Addressing Emerging Challenges in IoT-MD

The integration and management of IoT-MD is not without significant bottlenecks and challenges.

Managing device diversity and interoperability: In the connected health domain, a variety of devices, instruments and equipment from device vendors and OEMs, located in homes and clinics, will connect to backend databases via aggregation devices located at the site. Aggregation devices are dedicated device gateways, home routers, smartphones and PCs, and their network is often referred to as the Peripheral Area Network (PAN). Commonly accepted standards of network interface are required between the devices and the aggregation device. Similarly, the interface between the aggregation device and backend medical records will be governed by regulations that mandate the use of certain approved standards and certification. Examples of standards in use in PANs include Continua Alliance Bluetooth Profiles and the ISO/IEEE 11703-20601 Optimized Exchange protocol¹. An emerging problem today is that there are still many vendors who do not support these standards in their products, thus leading to significant interoperability issues and increased system integration costs.

Data integration: In order to build intelligent, context-aware health and wellness applications that generate relevant patient-specific cues and alerts, there is a need to integrate data from multiple sources. These sources include different types of medical devices such as blood pressure monitors, weighing scales, thermometers, pulse-oximeters, glucose meters, ECG monitors, imaging systems as well as equipment such as fitness and strength machines. Apart from devices and equipment, there is a need to integrate with other sources of patient-specific contextual data including mobile devices, social network feeds and other web resources.

Device interfacing and data collection will not yield results unless the structure and syntax of data and its meaning is properly understood. It is only when the semantics is understood that intelligent applications or mashups can be built, using techniques such as correlation, complex event processing and automated reasoning with semantics technology. The semantics of the data must be part of the data itself and not be locked up within the application logic in different application silos.

Scale, data volume and performance: As the quality and accuracy of medical devices improve, more applications will be developed for an expanding user base. The amount of data that needs to be ingested, stored and analyzed will also increase exponentially. Some medical devices will need to store high resolution data, and some will generate multimedia output such as high resolution images and videos. This will lead to a typical 'Big Data' problem where the sheer volume and velocity of data ingested will make standard architectures and platforms inadequate. In other cases, some applications may demand more stringent real-time performance than what is ordinarily possible using standard internet technologies. Applications and the database backend must be seamlessly scaled up as operations become more complex.

Flexibility and evolution of applications: As newer analytics, techniques, algorithms, use cases and business models evolve, advanced medical devices with improved capabilities will be created. Newer applications and software components need constant upgrades by specialists with specific technology and medical domain skills.

Many of the applications will be in the form of dedicated purpose-built ‘apps’ that are developed using a crowd-sourced model and downloaded by end users from an app marketplace. The ability to quickly develop and deliver apps with minimal effort is a key requirement. There is a need to create ecosystems and platforms that sustain such a crowd-sourced application development and consumption model.

Data privacy: Data collected from medical devices is sensitive and must be protected from unauthorized access. It should be used only for the specific purpose for which the patient/user allowed that data to be collected. Policies to share medical data with authorized persons and applications must be strictly followed, and data securitization be given utmost importance.

Need for medical expertise: The diagnosis and transmission of medical data to healthcare providers is governed by regulations. The inability to interpret data captured by medical devices, with patients trying to diagnosis themselves based on an incorrect understanding, can lead to major risks. Every diagnosis and prognosis bases itself not only on current observations made by devices, but on the history and the health profile of the individual patient. Diagnosis and detection of alert conditions is aided by automated decision support systems where rules/decision trees are provided by trained physicians, customized for each condition and patient.

5. Maximizing Results with a Platform-Based Approach

To meet the challenges of the IoT-MD, we recommend using a service-oriented platform. The platform, following a service-oriented architectural (SOA) approach, should be modular and made available as services that are callable from external applications by means of Application Programming Interfaces (APIs). The APIs should be open, well-documented and be made part of a developer portal, together with an example code and a testing environment.

Device and data management

A critical aspect that the platform needs to address is the set of challenges posed by device diversity. Simplifying the interfacing with multiple devices, seamless data collection and device management will go a long way in enabling IoT. A set of backend cloud connector libraries will be provided for both standards compliance and proprietary devices. Moreover, it will be easy to add support in the form of plug-ins for new kinds of devices as they become available.

The platform should support integration of data from multiple sources—namely, many different types of medical sensors as well as non-sensor sources such as data from diagnostic equipment, pathology lab instruments, data from hospital management systems and web sources among others. The data layer should ideally be supported by a single common information model that will be able to describe any sensor or sensor observation and provide common schemas for capture and query transactions. The information model and schemas can be made open so that any software application running on the platform can easily understand and query the data captured from any source. Separation of the data layer from any application specific processing creates a platform that is flexible and one that allows newer applications to be created at different points in time by different sets of developers.

Real-time and batch analytics

Connected health applications need to support both real time analytics on streaming data as well as analytics on stored historical data. Examples of real time data management include complex event processing to detect events of interest/significance, mining sensor event streams for interesting patterns and rule-based processing of incoming data in sensor streams. On stored historical data, analytics should run using batch jobs and it should include tasks such as data mining, training of machine learning algorithms for predication and filtering and statistical processing. Integration of data from multiple sources also requires the ability to understand the semantics of the data and perform automated reasoning based on the data. The support to describe devices and observation data with rich metadata should be available on the platform.

Data privacy

Privacy of patient and user data is a critical requirement. The platform should define policy-based access controls to medical device data. The patient should be in control of what is being accessed by whom and the platform will allow him to view and set the access control policies, maintaining anonymity and masking of data wherever possible.
High scalability

From an architecture viewpoint, the platform should be highly scalable. Horizontal scalability allows resources to be added to the common resource pool as and when the number of devices and users increase. Services will be made available in the form of easy-to-use and well-documented APIs. A multi-tenanted approach allows different applications and users to be supported on the same platform, while providing separation of data and resources between the tenants. Ideally, the platform should be able to run on both public and private clouds.

Support for application development and deployment

The platform must support development and deployment of applications by users/tenants. Web applications as well as backend services, batch programs and sensor stream processing programs should be supported. It is desirable that many different types of programming languages and application runtimes be supported.

Finally, a desired capability of the platform is that it will allow a model-driven approach to connected health application development. In this approach, the application developer simply defines the model of the application, the rules of data processing, and instantiates the devices and the data processing rules using a GUI based tool. The platform then generates the necessary code and scripts needed to run the application backend and the data visualization interfaces.

6. Benefits of IoT-MD

The key benefits of IoT-MD applications in healthcare are as follows:

**Lowered cost of care**: By leveraging IoT-MD systems, the health of patients can be monitored on a real time basis, avoiding unnecessary doctor visits. Home care is possible, further reducing hospital stay. Caregivers can address common use cases and reach out to doctors only when needed.

**Improved patient outcomes**: By referring to a comprehensive knowledge base compiled from previous disease outbreaks and proven research, caregivers and doctors can use evidence-based medicine for improved patient outcomes. The real-time information can help provide timely care and address issues at an early stage.

**Real time disease management**: In a connected healthcare environment with continuous remote monitoring, patients can get treated proactively before their condition worsens. This not only helps patients' health, but also reduces the cost of care. The focus is shifted from 'treatment' to 'wellness'.

**Improved quality of life**: For the critically ill, pediatric and aged populations, IoT-MD offers an easier life. The elderly can live independently at any location of their choice while getting their medical condition monitored.

**Improved user experience**: For patients as well as caregivers, IoT-MD makes it possible to have a richer and more intimate engagement with each other. Automation of data collection makes it possible to collect data accurately, on time and with minimal human intervention. All stakeholders receive better visibility with respect to the patient’s condition, progress and outcomes of treatment. Automation of engagement also allows better compliance to prescribed treatment regimes.

A platform based approach makes it easy to develop connected health applications, enables creation of smart/intelligent applications, allows newer applications to evolve over a period of time and supports new devices as they become available.
7. Conclusion

IoT-MD will drastically change the face of healthcare monitoring and treatment outcomes. By providing personalized and optimized services, it will promote a better standard of living. Nations across the world are struggling to improve patient care and IoT-MD provides a timely and cost-effective response to this critical imperative. Moreover, recent developments in sensor, internet, cloud, mobility and big data technologies have led to affordable medical devices and connected health programs, vastly increasing the potential of IoT-MD to influence further changes.
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Contact
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