

# Internet of things (IoT): Frontier and Panorama for Biotechnology and Biomedical Applications

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## **Abstract:**

Recent advancement of technologies, easier availability of internet and big data era and their prospects in applied areas such as biotechnology and biomedical are tremendous. Advanced smart sensors, smart phones based instruments/devices and integrated networking provides automation in research and development (R&D) with IoT (The Internet of Things). IoT has huge prospective for technological revolution and innovation thereby advancing biotechnological and biomedical research, innovation and its application in smarter and innovative way. This review focuses comprehensive, fundamentals, technical, advanced and applied chore of IoT, especially focusing the biotechnological and biomedical aspects. Past decade has witnessed dramatic rise in internet-based technology and generation of big data in digital diagnostic, digital imaging, digital biotech, precision farming, lab-on phone and automation of R&D. IoT based digital health uses platforms and technologies for cloud storage, data sharing, big data analytics, embedded sensors, smart wearable devices, sustainable computing, data mining, biomedical imaging, intelligent algorithm and healthcare informatics etc. IoT provides healthcare mobility solution and system for realtime data collection, big data storage, transmission and analysis on cloud platforms. Additionally, IoT impede disease diagnosis, remote patient care, optimizing hospital operations, green smart city, inventory control, livestock control and streamlining data management moving these sectors toward digital revolution era.

**Keywords:** *Internet of Things, Digital Healthcare, Sensors, Biotechnology, Integrated Networking, Digital Biomarkers*

## **I. INTRODUCTION**

Briefly, the Internet of Things (IoT) provides network platform that connect, shares and interact data from machineries, instruments and appliances to portable devices (mobile and small accessories) with internet system [1-4]. IoT has impact on various sector of R&D, healthcare, pharmaceutical and biotechnology industries which use several devices, instruments, network platforms, computational data generation, data storage, capacity to integrate, share the data through efficient central networking system for automation analysis and innovation [5-9]. Current biotechnological advancement, its interdisciplinary dependency on various fields such as on computational biology, data sciences, information technology, nanotechnology, physics and engineering etc necessitate for the amalgamation of IoT in biology for enhancing the automation, reproducibility, efficiency as well as exploring this dimension for smart strategy and innovation in biological sector [10-13]. Artificial intelligence (AI) has also revolutionized the diagnostic, drug development, pharmaceutical and healthcare sectors. In medical field real-time monitoring of patients, sharing of critical data, timely analysis of reports and efficient diagnostic are crucial area where AI has shown enormous impact [14-16]. AI is related to the IoT, has been applied and reported for diverse disease diagnosis and digital biomarkers studies [17-19]. The data analytics in health sector is also supported via AI that derives significant patterns from

unstructured data and provides feedback to the user interface. The user interface subsequently facilitates visualization and interpretation for downstream patients.

IoT is the network of physical objects that utilizes embedded technology to communicate and interact; theoretically the “thing” in IoT could be anything like either mobile or wearable/portable devices. The concept of network of smart devices was discussed at 1982, with Coca-cola vending Machine at Carnegi Mellon University, to report its inventory whether the loaded drinks are cold or not [20]. The term "Internet of Things" was coined by Kevin Ashton Proctor and Gamble in 1999 [21]. They used this term to describe the role of RFID (Radio Frequency Identifier) tag in making supply chains more efficient. IoT is the rapidly growing topic around the world. The concept behind "Internet of Things" is the connection of any devices or machines in order to share the electronic data over internet. Recently IoT been evolved as technology referred to the Internet of Everything. IoT has also evolved as technology in biological and medical sector (IoTB/ IoTM). Usually, devices with embedded sensors, gateway, cloud, analytics, and user interface are common components of IoT. Externally information collected via embedded sensor devices are communicated via wireless network (Wi-Fi, bluetooth or long range). 5G network is superlative choice for IoT due to efficient connectivity, both 5G cellular and IoT technologies are expected to see pervasive consumption in upcoming years [22]. Embedded sensors and gateway are usually involved in receiving information and delivering it to a cloud based tool to collect, analyze, and store big data generated from devices and instruments for real time monitoring and associated analysis. Internet of Health Things (IoHT) is applied to collect data and vital healthcare information from hospitals. This data utilized for decision making process using big data analytics and intelligent algorithms [23]. Interestingly, during 2020, 40% of IoT-related technology is health-related and making this up a \$117 billion market. This convergence of medicine and information technologies (medical informatics) have shown to revolutionize healthcare. Devices that are capable of constant, real-time monitoring as health indicators and auto-administer therapies devices can use high-speed internet and smartphones to manage various health needs when integrated with telemedicine and telehealth via the medical Internet of Things (mIoT) [3,12].

## II. CONCEPT AND COMPONENT OF IOT

Contribution of IoT is mostly shown its application in the development of smart city, smart villages, digital health, precision agriculture, wearable devices, connected car, smart supply chain, industrial internet,

intelligent R&D and smart houses etc. Basically, IoT is the combination of four different components integrated together that are: sensors/devices, connectivity, data processing and user interface [24-30].

- A. **Sensors and Devices:** These are smart and portable appliances which are used to collect the information from environment eg, temperature, humidity, rate of wind etc. Devices like cameras, accelerometer, GPS-trackers etc in our personal gadgets are nothing but the sensors [31-32].
- B. **Connectivity:** The link between the sensor/devices are connected to cloud through varieties of methods like cellular, satellite, wifi, LPWN (Low Powered Windarea Network) are connected with internet or ethernet [33-34].
- C. **Data Processing:** When sensor detects an intruder, it first verifies the intruder whether it is authenticate user or not. If the intruder is authenticated then it stores the information about the user. If not, then it will buzz the alarm and it will ping the message to the respective owner, for example IoT based Electro Cardiogram (ECG) machine starts buzzing when the heart rate of the patient starts sinking [35-36].
- D. **User Interface:** it simply indicates the interaction between the user and the sensor/ devices, for example: temperature fluctuation in company cold storage appliances can be detected and could be send to the operator to maintain the temperature to save the instrument from freezing, moreover similar principle can be applied for the regulation of various appliances and instruments in healthcare, pharma and biotech R&D organization [37-39].

## III. APPLICATION OF IOT

Smart sensor, wireless network, actuators, and devices in R& lab, instrumentation, production equipment, and networked through computer systems generates huge data in Biotech/Pharma/Healthcare sector. Digital health (e-health) has recently gained lot of consideration. A lot of IoT based solutions have been explored in various biomedical applications [Figure 1, 2]. E-health is deeply dependent on IoT, which provide advantages in terms of cost effectiveness, better accuracy, reliability, efficiency, real time monitoring and minimal human effort in healthcare. IoT results in improving production efficiency, real-time monitoring, automation, sharing the data and subsequently scheming various functions, and analysis efficiently. Along with the increasing population and the influence towards the modern lifestyle there is also a massive

development in the medical field which can be observed through the increase in the life expectancy rate. But, along with this increased population there is also raise in the diseases such as chronic diseases, cancers, tuberculosis, heart attacks etc. IoT have recently shown promising advancement the healthcare sectors [17, 19].

#### **IV. INTERNET OF DIAGNOSTIC THINGS**

Recently with the advancement of technology and communication using IoT, sensors, wearable devices, and smart phones bring point-of-care scope to diagnostic sector. Several studies were reported showing IoT based vision towards smart and connected precision molecular diagnostics of infectious and chronic diseases. Molecular diagnostic chips, intelligent connected IoT based devices and their optimal application in cervical cancer screening and infectious disease detection were reported in past [40-41]. Dental diseases and issues are common which require concern in modern lifestyle. Liu et al 2019 have reported smart dental health-IoT application. This system utilizes intelligent hardware, deep learning along with mobile terminal with great potential for home-based smart dental healthcare. Authors have explored the practicability of its application in dental healthcare. Their studies suggest potential assortment of IoT for screening, diagnosis for dental disease. They have designed and developed a smart dental IoT based device to perform the image acquisition of teeth. Briefly, data set of 12, 600 clinical images were collected by the proposed device and utilized for detection and subsequently classified for various dental diseases such as decayed tooth, dental plaque, fluorosis and periodontal disease, with the diagnosis accuracy of 90%. The device has shown high sensitivity and high specificity. Furthermore, application software (App) on mobile terminal for client-side and for dentist-side is implemented to provide service of pre-examination, consultation, appointment, and evaluation [42]. Smartphones have a growing and insidious persuade on modern life, with the rapid development technologies such as microfluidics technology, the incorporation of microfluidics technology with smartphone-based detection/testing technology have given scope of inexpensive, smart and connected IOTH and e-healthcare [43]. Gupta et al 2020 has suggested scope of IoT and mobile devices in radiology for medical application. Currently, several practice of radiology are internet based and their integration into imaging workflow has improved the diagnostic and medicine sector. Portable wearable devices, smartphone and IoT-enabled technology is revolutionizing healthcare towards personalized healthcare systems. They have discusses the significance of IoT in daily imaging workflow and future prospects, how mobile devices can

be integrated into radiology workflows, and their impact of the on radiology based imaging [44]. The digital biomarker based IoT devices could be used for real-time diagnosing. There are reports that suggest IoT and digital biomarkers application in the spine studies which demonstrated the real-time monitoring of physical activity or spinal posture. The digital biomarker based IoT devices could be used for real-time diagnosing and testing. There are studies that suggest IoT and digital biomarkers application in the spine studies which demonstrated the real-time monitoring of physical activity or spinal posture. The digital biomarker based IoT devices could be used for real-time diagnosing [45].

Kumar et al 2018 have summarized significance of cloud and IoT based disease prediction and diagnosis system using Fuzzy neural classifier. They have applied systematic approach for the diabetes diseases. Specific medical data were collected using the UCI repository dataset and sensors based real health data for diabetes patients were collected from various hospitals. Moreover, they have proposed a new classification of algorithm called Fuzzy Rule based neural classifier for diagnosing and identifying the complexity of the disease [46]. IoT based diagnostic integrates different components such as appliances, sensor, smart devices, and objects to interact and communicate via particular networking technologies. Diagnostic devices and systems make use of interconnected smart devices to establish an IoT network for testing, diagnosis, monitoring and analysis for efficient and authenticate prediction of diseases and its complexities. The IoT healthcare market is classified on the basis of component, application, the technology used, end-use, and region. Various hardware, software, and service are the integral part of IoT based platform. Hardware segment consist of portable smart diagnostic devices, wearable sensors, monitoring device and non-portable diagnostic devices. Telemedicine, clinical management, clinical operations, diagnostic labs, and connected imaging are some segments of health market while Bluetooth, Wi-Fi, NFC, Zigbee, RFID are few networks which could be used.

#### **V. IOTH: DIGITAL HEALTH AND BIOMEDICAL APPLICATION**

Remote Health Monitoring System and emergency notification system to track the health condition of the patient/person are crucial. Health monitoring system or Early Sense Monitory System can be used to monitor the heart rate, respiration rate, blood pressure and bed motion for patients. Additionally could also help to handle the big scale numbers of patient's medical history and helps to find the accurate cause and prevention of the diseases. Such system provides regular update of heart beats in every 8 seconds and in

every one and updates with the patient's respiratory pattern too. If any discrepancy/disturbance/odd is found in the heart pulse rate and respiratory pattern, the health monitoring system immediately sends the emergency alert or report to the nurse/doctor under observation [47].

Recently, IoT has been applied the healthcare system to collect ECG signals for heart disease diagnosis by reducing the noise produced in ECG for better analysis. Hasan et al 2019 have reported application of patch-based hybrid OCC/BLE networks and IoT for real-time healthcare data transmission and remote patient monitoring. Optical camera communication (OCC), which uses a camera to receive data from LED, has value in digital healthcare but certain limitation is associated such as high signal-blockage probability. Therefore, authors have proposed a hybrid OCC/BLE system to ensure efficient, remote, and real-time transmission of a patient's ECG signal to a monitor. Briefly, a patch circuit integrating an LED array and BLE transmitter chip were developed where patch collects the ECG data. Network selection algorithms developed for a new network access, camera applied for data reception and mechanism suggested to ensure efficient network allocation considering the patient's mobility. Simulations were conducted to validate the performance and reliability of this system [48].

Telemedicine System for ECG System: This system monitors the ECG of the patient during daily activities. This system consists of 8-bit single chip microcomputer embedded in the ECG chest electrodes to record the patient's heart beat's rate. If any kind of variations is found in the heart rate then the patient can switch on the recording machine and the machine sends the data the doctor. The doctor, from their respective mobile phones, can monitor the heart rate. Such device has great impact on improving and preventing critical patients [49]. Jovanov (2019) summarized the significance of wearable monitoring, mobile health (m-health) and IoT based revolution in the digital healthcare, diagnostics and R&D industries. "Things" with embedded activity and vital sign sensors (smart stuff) can interact with wearable and ambient sensors. A dynamic, ad-hoc personal area network capable of scanning multiple domains, impeding and processing in synergistic personal area networks—SPANs was proposed and its applications, feasibility were studied. A smart water bottle can collect vital signs of the users. Synergistic processing of sensors from the smart-watch and other daily items can be used for the identification and assessment of specific parameters that individual sensors could not generate e.g Pulse Wave Velocity (PWV), temperature or blood pressure etc. This work emphasis that SPANs could be used for efficient monitoring the vital signs. SPANs also provide opportunity for ad-hoc integration with other sensors of

interest around the user, wherever they go. Subsequently could yield better scope towards personalized feedback to improve health [50]. Dimitrov (2016) reviewed the prospect of IoTM and big data in healthcare field. It is quite evident that IoTM has transformed e-healthcare. They have proposed IoT scope towards "personalised preventative health coaches" (Digital Health Advisors) [51]. Additionally, simulation solutions are making medicine participatory, personalized, predictive and preventive (P4 medicine) via IoTM [52]. Studies have done on detection of Sleep Apnea Syndrome using the Cloud computing platform for detecting sleep behavior and chronic disease collaborative research sensing via bed sheet texture to record patient's sleep behavior [53]. It also led to the development of the wearable respiratory monitoring system that detects sleep apnea syndrome. It consists of Piezo electric sensor which is kept or installed closer to chest and records the patient's body movement. If the device records the low frequency of the body movement generated due to respiration, then the piezoelectric sensor, a 8-bit microcontroller chip, sends the signal to EEPROM in every 5 minutes and detects through Time-Series Analysis whether how many times the has patient has breathed in the defined time and can be used for monitoring the critical condition of the patients and improving the decision making.

Chiang et al 2018 have proposed a suitable robust IoT-based nursing-care support system with smart bio-objects that could have great potential on the next generation of nursing-care service systems by providing efficient and secure communication among mobile bio-sensors, intelligent devices, the IoT gateway and on-demand nursing-care service [54]. For providing system security and computation efficiency, lightweight cryptographic modules for data protection were designed in this nursing care support system. Ullah et al 2016 have suggested medical imaging technologies for IoT Based wireless patient monitoring in digital health era. Recently, IoT have shown enormous impact on medical imaging and monitoring technologies that facilitated high-speed access to medical information related to patient healthcare [55-57]. Cloud platform and wireless networks provide way to collect, store, and share and analyses the healthcare data in efficient and robust model. Briefly, technologies utilizing wireless body area network (WBAN) is bounded by the patient, which provides easy, secure and safe communication and better accuracy. Gope and Hwang (2016) have reported a BSN-care: a secure IoT-based modern healthcare system using body sensor network. Briefly, proposed a secure IoT-based healthcare system using BSN, called BSN-Care taking care for patient privacy. The body sensor network (BSN) technology with IoT

provides a smart way for monitoring via tiny-powered and lightweight wireless sensor nodes [58].

## **VI. IOTBT: APPLIED AND INDUSTRIAL BIOTECHNOLOGICAL SCOPE**

The IoT is the giant network of connecting "THINGS" be it devices like cellphones, washing machines, headphones, coffee makers, bands/any wearable devices, in health monitoring systems, diagnosis, agriculture, security alert system, wireless sensors or R&D instruments [1,10,12]. The devices that are connected to internet in order to share the information/data are known as "Smart Devices". IoT provides a relationship between people-people, people-machines, and machines-machines smart communication. IoT could greatly impact diverse industries by reducing cost pressures, automation and by improving value-based solution and outcome bring about transformational change in several sectors [2, 4,17,21]. IoT platform for digital biotech and R&D has been applied to connect lab equipment, devices, data storage, data transmission to the cloud for research and analysis. Research industries, pharma companies and biotech sector are exploring and expanding this horizon for various applications [Figure 3]. Xu et al 2019 has summarized IoT role for marine environment monitoring and also briefed technologies such as advanced Big Data analytics and their applications. IoT-based technologies and smart sensor could be useful for monitoring and protection of marine environment [59]. Likewise, considerate the effects and reaction of animals caused due environment change are imperative to study. Guo et al 2015 have reported the application of IoT for animal biology studies. Networked sensor technology applied to measure wildlife and environmental parameters with accuracy, real-time and huge data that could be utilized for monitoring, research and conservation of wildlife. Briefly, they have focused on areas such as conventional detection technology, concepts and applications of IoT in animal ecology [60].

Kim et al 2018 have demonstrated IoT-based strawberry disease prediction smart system. They have used cloud-based technology for the collection, analysis, and prediction of agricultural environment data on common platform. This system was confirmed through design and analysis of a strawberry infection prediction system. Briefly, Farm as a Service (FaaS) integrated system, chains high-level farm services, managing associated devices, data, and a model was developed. Additionally, this could also register, connects, and manages IoT devices and analyzes agricultural environmental data. IoT-Hub network model were also developed that supports efficient data transfer to each IoT device that exhibits high communication reliability and ensure the constancy for

agricultural environments [61]. Giovanni et al 2017 have summarized studies on smartphone-based food diagnostic technologies. Smartphone based sensing and diagnostic approaches provide advantages over conventional methods in terms of speed, cost, control, convenient handling, data sharing and data management. Advanced sensing technologies based on smartphone have been reported for several broad applications such as lab-on-smartphone sensing/diagnostic platforms, medical diagnosis, smart spectrophotometer, environmental monitoring, food safety analysis and beverages/milk quality check [62-65]. IoT plays crucial and promising role in such applied area. Smartphone devices usually comprise of various components like detectors, sample processors, disposable chips, batteries and software for data collection, monitoring and analysis using IoT. Popescu et al 2020 have reported an advanced UAV-WSN system (unmanned aerial vehicles and federated wireless sensor networks WSNs) for smart monitoring in precision agriculture which could results in high-performance, high-productivity, and sustainable agriculture. Their studies showed a hierarchical structure based on the integration of between UAVs, WSNs and IoT for crop monitoring in precision agriculture. This system provides smart, robust and competent way for online data collection, analysis, storage and decision making for sustainable agriculture. The system is well designed to collect online data, central monitoring and managing the network data load through optimized UAV trajectories and *in situ* data processing. Their outcome established that the UAV-WSN-IoT approach enhance and improves the performance in both precision agriculture and ecological agriculture [66].

## **VII. DISCUSSION**

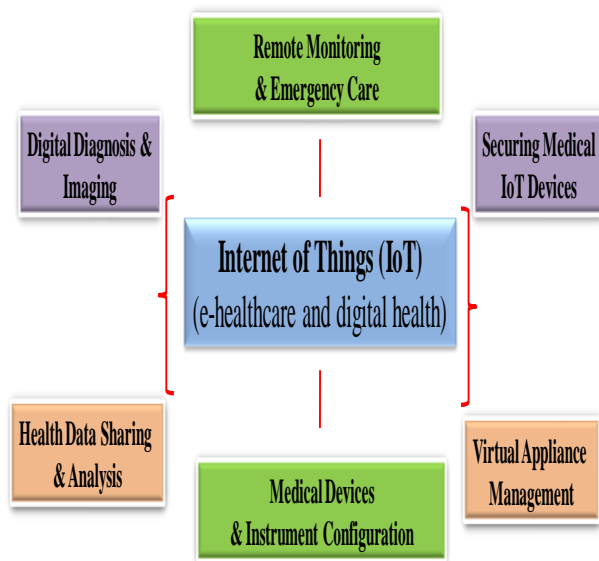
This is well established that wearable sensing device and network has potential in modern healthcare systems for real time monitoring of the vital health conditions like heart rate, blood pressure, glucose level, and oxygen saturation etc during chronic and critical diseases [39, 50, 56,58]. Smart apps and software are central components of IoT system. This allow better communication and better outcome with lessen operator intervention. Integration of software modules, analysis, algorithms and combinational logic are used based on various applications. Additionally, IoT help in diagnosis the disease in earlier stage and provides the better solution using network connection and deep learning algorithm. Furthermore, IoT has remarkable prospects in applied biomedical and clinical research. IoT, smart devices, smart phone based technology; sensor and combination of such platforms could bring potential scope for solving several biotechnological and biomedical issues. Additionally, development of

advanced effective smart IoT platforms is desirable that could revolutionize automation of R&D, digital diagnosis, e- health sector, precision farming and agriculture areas. Using AI to enable IoT and diagnostics, smart devices to deliver precision and personalized healthcare care at comprehensive extent has tremendous potential in digital and big data era. Portability, connectivity and security for the next generation point-of-care diagnostics platforms based on capillary-driven microfluidics and IoT provides intelligent, connected, sensitive, inexpensive, faster, secured and advanced way of diagnostics. Technological advancement and current development of point-of-care IoT devices have demonstrated improvement of health sector but further improvement are required to scale these devices and platforms by focusing on systematic healthcare workflows, policies, and clinical protocols, guidelines for its global utility to improve the patient health. Advancement of IT potential horizon and emergence of “big data” analysis gives platform to explore novel prospect for IoT, AI and machine learning for the benefit of R&D, biotechnology, clinical and pharmaceutical section and subsequently improving digital biomarker, digital diagnostic, digital therapeutics and digital healthcare.

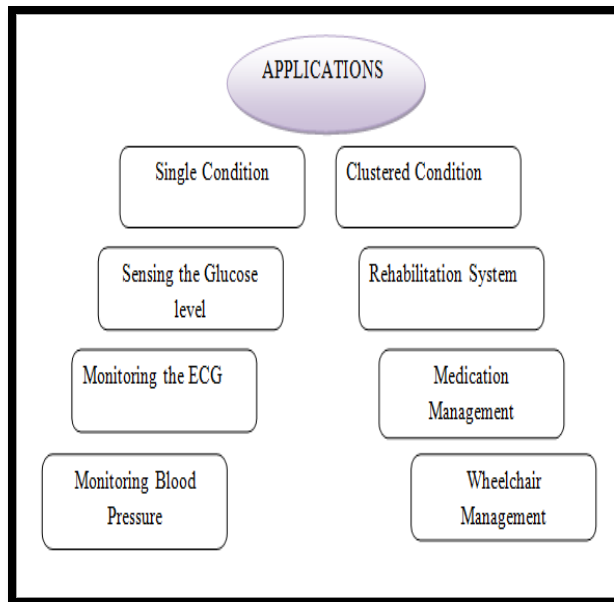
**VIII. CONFLICT OF INTREST**

The authors declare no conflict of interest.

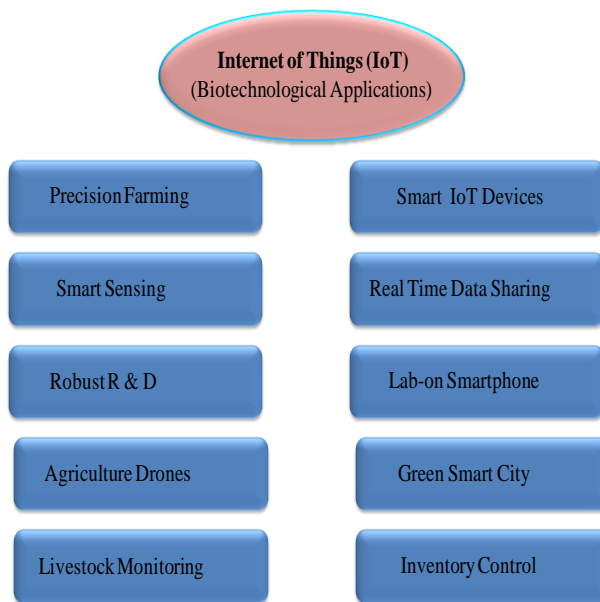
**IX. FIGURE**



**Fig. 1: Schematic overview of implication of Internet of Thing (IoT) for healthcare application.**



**Fig. 2: Application of Internet of Thing (IoT) for healthcare application in two ways.**



**Fig. 3: Overview of various prospects of Internet of Thing (IoT) for biotechnology application.**

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