Enhancing Patient Health Through Smart IoT Technologies in Healthcare

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***Abstract*—Health care has been revolutionized by this rapid change in the field of the Internet of things that enable smart connected devices that provide better patient monitoring, diagnosis and treatment. IoT technologies facilitate collection of real time health data and remote patient monitoring, as well as prediction, thus improving overall healthcare outcomes. The ideas and concepts related to Chronic diseases, Diseases, Emergency, Detection and its management are greatly transformed by the presence of Wearable sensors, Smart Hospital infrastructures and AI powered Analytics. Meanwhile, healthcare systems driven by IoT are more efficient, reduce number of hospital readmissions, and provide telemedicine services. But, IoT in healthcare comes with a lot of challenges such as IoT security risks, patient privacy issues and multitude of interoperability problems. In this paper a comprehensive review of smart IoT technologies in healthcare, their applications and the type of benefits that weigh them for the patient care is provided. Along with exploring the role of data analytics in the IoT based decision making, data handling ethical implications and security threats in IoT healthcare systems introduced here. Moreover, beyond this, they discuss future directions including integration of AI, 5G enabled telemedicine, and blockchain for secure patient data management. This makes IoT an ideal candidate for healthcare transformation — one that addresses existing challenges and capitalize on emerging innovations to go from more efficient, more accessible, and definitely more patient-centric healthcare.**

Keywords*—IoT in Healthcare; smart technologies; remote patient monitoring; data security; AI in healthcare; telemedicine; healthcare analytics

I. Introduction

IoT integration in healthcare has revolutionized patient care by making patient care smart and connected systems that offer the real time monitoring, the diagnostic accuracy and treatment efficiency. The IoT offers the global healthcare systems a way out of the increasing problems like increased aged populations, high cost of living and prevalence of chronic conditions. The technology in an IoT driven world enables healthcare professionals to remotely monitor patients, real time analysis of health data and user interface to make decisions that result in prompt interventions. Such innovations in wearable sensors and smart hospital infrastructures, to AI powered analytics, brings a fresh perspective to the healthcare, offering personalized, data driven treatments and improved overall medical efficiency [1]. These technologies are also benefiting those who receive them, since they permit patients to conduct continuous health monitoring, reduce hospital visits, and push proactive health management.

IoT in health exist in the universe of connection devices, cloud computing and artificial intelligence coexisting to construct an intelligent health system. By wearing smartwatches and biosensors, ones the most critical health parameters like heart rate, blood pressure, oxygen levels, blood glucose levels are being tracked and these critical parameters can give real time insights to concern one medical condition. RPM has also evolved into a go to for patients with chronic illnesses, and on top of that, remote patient monitoring (RPM) can do just that.. IoT helps healthcare professionals keep track of patients at a distance and prevent hospital admissions, so that the required medical attention is given before they are in a worse condition. Another very major application of IoT is that of telemedicine where the IoT is used to bridge the gap between patients and the healthcare providers, making it easier and faster for medical consultations [2].

Due to the adoption of IoT in hospitals, medical environments with a smart approach have emerged that are based on automation for improving medical workflow process. Smart beds in the hospitals connected via IoT, automated medication dispensers and RFID based inventory management systems are offered with improved efficiency and lesser human error and thereby higher patient safety. The impact of IoT and artificial intelligence comes to play even bigger as artificial intelligence further takes advantage of the high volume of patient data to which it has access to predict health trends, personalize treatment plan and identify at risk patients earlier than critical situation happens [3]. Through implementing IoT and AI and machine learning into the healthcare systems, healthcare systems can be tipped towards predictive and preventive medicine and ultimately reduce healthcare costs and improve the welfare of patients.

Despite its huge potential, implementing IoT in healthcare sector poses problems, specifically concerning security, privacy and interoperability [4]. Cyberattacks and data breaches on connected medical devices have become an increasing threat as reliance on connected medical devices grows. The patient health data that has to be processed here is very sensitive and any compromise in the security would have disastrous consequences. To secure patients' trust and data on the patients' personal health information, the providers of healthcare should also adhere to strict data protection regulations such as HIPAA

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and GDPR. The second issue with IoT devices is the tremendous variety of standards and lack of standardization; this poses problems for compatibility between various manufacturers as well as with system. In the absence of universal standards on integrating IoT devices seamlessly into current healthcare framework, it remains a big hurdle. Furthermore, the cost of taking IoT to the healthcare industry is an impediment for most of the healthcare institutions, including developing regions. This makes it even more difficult for widespread adoption as you need advanced infrastructure, high-speed internet and bear the heavy burden of secure cloud data.

And as IoT is still evolving, future innovations will solve these issues and open several new doors for healthcare. One would expect 5G technology would greatly improve the speed and reliability of the IoT enabled healthcare applications with the ability to transmit data in real time as well as to conduct remote surgeries. In addition, blockchain technology is also attracting a solution to enhance data security and to keep the health record transcripts accurate, transparent and HALON free [5]. Additionally, AI driven IoT systems will improve upon predictive analytics to a degree that will enhance the accuracy and porosity of personalized medicine. As edge computing grows, data processing will become more and faster, with less latency in important cases of healthcare.

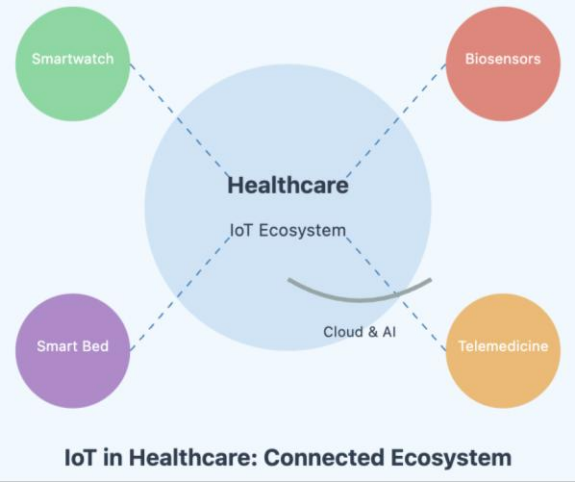

Fig. 1. IoT Healthcare ecosystem - Interconnected devices transforming patient care.

It is in Fig. 1 that the Internet of Things (IoT) has the potential to transform healthcare, as a dynamic ecosystem of connected technologies, represented in Fig. 1. Four key healthcare IoT devices, namely smartwatches, biosensors, smart hospital beds and telemedicine centers, respectively interlock around a main healthcare hub to indicate the omnidirectional and integrated concept of modern medical service. IoT based healthcare system is represented by the dotted line which shows the flow in the data and communication flow between the devices without interruption. Essentially, Cloud & AI technologies are the intelligent brains that take real time health data, process and analyze it to make it possible for predictive diagnostics, personalized treatment and proactive health management. Essentially, this paper's main argument is encapsulated in this visualization: IoT is revolutionizing healthcare by making it a much more connected, streamlined and patient centered way of monitoring and intervening in medical care [6].

In this paper, we discuss how smart IoT technologies can be applied to benefit the healthcare and the challenges that are impacted due to their implementation. IoT in Realtime Health Monitoring, Predictive Analytics and Remote Patient Care explores the role of IoT in real time health monitoring, predictive analytics and remote patient care by discussing how these are changing the modern healthcare. Another part of the study looks into security risks and ethical considerations that are associated with IoT driven medical systems and recommends building strong regulatory framework. Finally, it concludes with the future direction that IoT will take on in the healthcare domain, especially with the coming of the technologies that are AI, blockchain, and 5G that will add to the efficiency and security of the IoT powered healthcare systems. Stakeholders will be able to leverage smart IoT technologies to create better, more connected, efficient and patient-centric health care ecosystem by knowing opportunities and challenges.

The novel contributions of this paper are:

- In this paper we showcase a detailed description of the impact that IoT technologies bring to healthcare by real time patient monitoring, smart hospital infrastructure, and with the help of AI diagnostics. Unlike previous reviews that are focused on individual aspects of IoT in healthcare, this work presents the synergy between wearable devices, telemedicine, predictive analytics and hospital automation.
- To date, as adoption of IoT in healthcare surges, security and ethical matters continue to severely impede IoT adoption. This paper assesses emerging cybersecurity threats, data privacy risks and ethical assessment of IoT healthcare applications in a novel way. In this study, gaps exist in existing studies, and it proposes a framework that is based on a security through blockchain integration combined with AI based anomaly detection and regulatory compliance.
- The idea of this research is to explore how artificial intelligence helps in IoT based healthcare by making it possible to predict a disease, do an automated decision making and suggest personalised treatment. Unlike the normal studies that treat AI and IoT as two separated things, this paper focuses on the merged potential of the AI and IoT in disease forecasting, patient risk evaluation, and personalized healthcare interventions.
- Next, this study provides a forward view on the future of IoT in healthcare and how the next generation technologies like 5G, edge computing, and blockchain overcome the current one. This paper, by presenting a structured roadmap, is a guide for the practitioners of healthcare, researchers and policymakers to optimize IoT implementations to improved patient outcomes and system efficiency.

This paper is organized as follows. Section II describes IoT in healthcare through a general discussion of its architecture, a list of its key components, and the associated technological

enablers. In Section III, we cover on the various application of smart IoT technologies in the healthcare area: wearable health monitoring, telemedicine, and hospital automation. In Section IV, IoT's role in healthcare data analytics and decision making is discussed including AI driven predictive modelling and real time health insights. IoT driven Healthcare System: Section V studies the IoT driven health care systems security, privacy, and ethical challenges showing risks and their counter strategies. In the last Section VI, the conclusions of this study are drawn, a summary of the main findings and their implications are presented. In the last section, Section VII portrays the future directions and what these emerging technologies, like 5G and edge computing and blockchain, bring to the future of IoT based healthcare solutions.

II. Overview of IoT in Healthcare

The Internet of Things (IoT) has revolutionized healthcare, as it links medical devices with doctors and patients in the most efficient way or you can say it enhances the connectivity and makes the link seamless. Integration of smart sensors, real time data analytics and cloud based platforms has made a remarkable difference to patient care, operational efficiency and medical decision making through IoT. The arrival of IoT driven healthcare solutions has led to new possibilities of real-time monitoring, predictive diagnostics and remote treatment, which has changed the way healthcare was delivered. Wireless communication, artificial intelligence, as well as big data analytics advancements drive the growing adoption of IoT in healthcare that make medical practice automated as it relies on data [7]. However, this further increased the demand for IoT oriented system that provides proactive and efficient healthcare services as a result of the increasing demand for personalized healthcare and the growing prevalence of the chronic diseases.

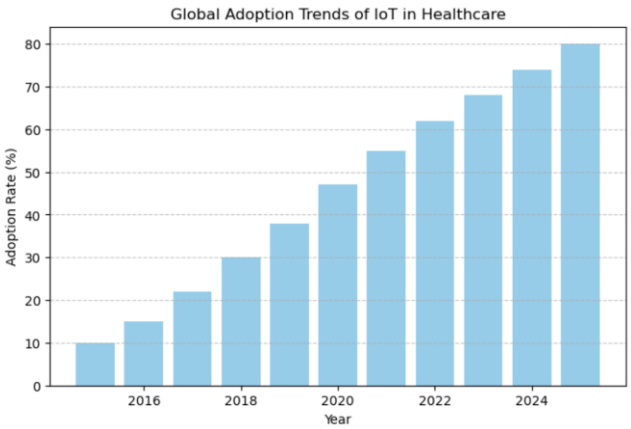

Fig. 2. Global adoption trends of IoT in healthcare (2016-2024).

Fig. 2 shows a very steep upward trajectory of Internet of Things (IoT) in healthcare from 2016 to 2024. The graph starts at around 10-15 % adoption rate in 2016 and progressively and greatly increases to almost 75-80 % in 2024. This visualization powerfully showcases how only one decade of healthcare developments has seen excessive expansion of the IoT technologies in this area. The steady year on year growth is on account of the rising perception of IoT's revolutionary capability in medical monitoring, patient treatment, and health system adaptation, as similarly observed in agriculture sector adoption [8]. But each successive bar bears not only technological advancement but also waning of institutional initial lack of trust in IoT's potential to improve diagnostic precision, patient outcomes, and operational efficiency in healthcare institutions. While a compelling visual testament to what is occurring in the global space where healthcare systems are all going through a digital transformation around innovations in connected medical technologies, the graph also sets the tone, period.

A. Architecture and Components of IoT in Healthcare

IoT healthcare architecture is responsible for multiple connected layers working hand in hand to deliver the information seamlessly among the patient, medical devices, healthcare providers, and the cloud computing platform. The basic premise of this ecosystem lies in smart sensors and medical devices that are producing patient health data like heart rate, blood pressure, oxygen level and glucose levels continuously. All of these devices are embedded with wireless communication technologies – Bluetooth, Wi-Fi or 5G – to be able to transmit data in real time. The collected data is then processed through the edge computing or cloud computing systems where the artificial intelligence algorithms are used to analyze patterns, identify anomalies and generate actionable insights. This data can be accessed by healthcare professionals through hospital information systems, mobile applications, and can be used for medical interventions at the time occasioned and remote patient monitoring.

Interoperability is an important part of IoT in health care as it supports between different medical devices and systems. The standardized protocols and secure APIs permit no language and no platform barrier of exchanging the information between different platforms and hence removing the risk of information silos and making the medical records in better accuracy. Further, cloud computing contributes to storing and managing huge amounts of health data as needed, thereby, making it real time available to the medical professionals. In addition to improving data security, data security provides a tamper proof ledger for medical records in IoT healthcare system blockchain integration adds further security. Because healthcare providers want to be able to scale IoT in their system, the overall architecture of IoT in healthcare is designed to be scalable, keeping new technology from interfering with existing workflows.

B. Role of IoT in Healthcare Transformation

IoT is one of the key drivers of transforming the classic healthcare eco-system to be automated, to be involved in remote observation, and to create usage of predictive analytics. The remote patient monitoring (RPM) is one of the most important pieces of the IoT in healthcare because it lets patients treat their medical issues in the convenience of their own houses [9]. More specifically, this technology is valuable to persons with chronic illnesses like diabetes, hypertension, and respiratory disorders since it can track vital signs on a continuous basis without needing to visit the hospital frequently. Patient health data is collected by wearable devises and biosensors and transmitted to healthcare providers for the purpose of making informed decisions and adjusting treatment plans. Not only does this improve patient outcomes but it also lessens the burden on the hospitals by minimizing hospital readmission.

IoT also has an impact on emergency medical response, which is another kind of transformation. Smart ambulances have real time communication systems that enable the transfer of data on patient to hospitals before the patient arrives, so that medical teams are able to be ready for immediate treatment. In case of cardiac arrests or strokes, real time monitoring and auto alerts could help a lot in survivals by allowing rapid medical interventions. Apart from that, it has improved hospital management by optimizing resource allocation, tracking medical equipment, and proper flow of patients. IoT for Smart hospitals rely on using IoT enabled RFID tags to supervise the availability of beds in a hospital and also the medical inventory and streamline administrative processes to enhance overall efficiency in healthcare services.

The good news is that besides patient monitoring and hospital automation, IoT has also started to change drug management and personalized medicine [10]. IoT-enabled smart pill dispensers can provide alerts to patients when to take their medication at the accurate time and decrease chances of missed doses and medication errors. Along with this, predictive analytics powered by IoT help the pharmaceutical companies monitor the efficacy of the prescribed treatments in real time and enable the development of personalized medicine targeted at individual patient needs. Using IoT insights, the healthcare providers can now take a more proactive approach towards disease prevention and move away from reactive treatment to the preventive care strategies.

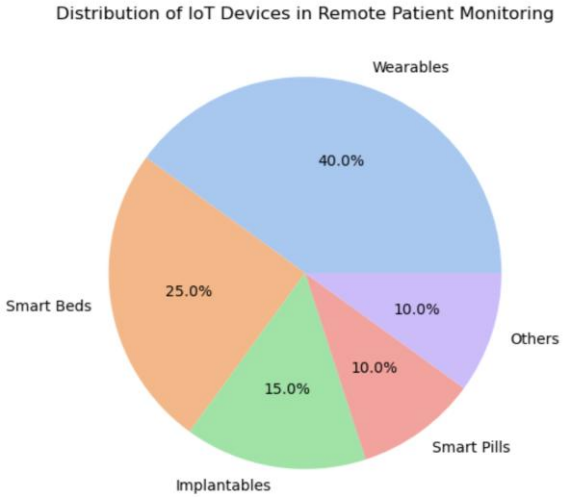

Fig. 3. Distribution of IoT devices in remote patient monitoring.

Fig. 3 shows a complete classification of IoT device types used in remote patient monitoring, revealing the general research environment for the modern healthcare. 40 percent of IoT devices are wearables due to its popularity along with ease in continuous health monitoring. About 25 percent of the ecosystem are smart beds, and these serve a critical purpose of monitoring patient conditions in hospital and home care settings. The 15 percent of the distribution of implantable devices indicates that medical technology is becoming increasingly sophisticated at measuring health from within the body [11]. The shares of smart pills and all other miscellaneous IoT devices is 10% each, representing emerging and innovative measurement of the patients. In the chart, you can see the many ways that IoT in healthcare works — for example, multiple technologies being combined to provide complete, real time patient care for many different medical contexts.

C. Challenges and Barriers to IoT Adoption in Healthcare

Although IoT has so many benefits, there are hurdles that block its widespread adoption in healthcare settings. Data security and privacy remain one of the main concerns, since the presence of IoT devices brings along with it an enormous amount of sensitive patient information that can be an easy target to cyber threats. It is a big risk for patients and healthcare providers to have unauthorized access, data breach, and ransomware attacks. Robust cybersecurity measures can be the answer for the above threats, such as end to end encryption, multi factor authentication, and AI driven threat detection system. Data protection regulations including the Health Insurance Portability and Accountability Act (HIPAA) and the General Data Protection Regulation (GDPR) need to be complied with to protect patients' privacy and ensure proper way of handling their medical data.

A third barrier to healthcare IoT adoption is interoperability as there is often proprietary communication or protocols among medical devices and platforms and cannot easily exchange data says. Unfortunately, the absence of standardized frameworks means that it is a challenge for healthcare providers to realize integration of IoT solutions for existing health care systems. To solve this issue, it's going to take cooperation from the industry level in order to define universal standards to allow these different healthcare technologies to be interoperable. Further, the development of adaptive algorithms that interpret multiple sources of information increases the possibility for improvements in data harmonization based on artificial intelligence and machine learning.

Challenge for the widespread IoT deployment in healthcare, especially in developing region comes from cost and infrastructure limitations. The development and implementation of IoT solution requires high costs to acquire hardware, cloud infrastructures, and network connectivity, which makes it difficult for resource limited healthcare center to adopt this technologies. Moreover, rural or remote areas with poor connectivity or interrupting high speed network limits one of the reliable data transmission to real time data via continuous internet connectivity. Using faster data processing and reduced reliance on single cloud centers as being offered by 5G technology and edge computing, there are potential solutions that may emerge [12].

III. Applications of Smart IoT Technologies in Healthcare

Smart IoT technologies are now applied in healthcare, have revolutionized the patient care, hospital management and medical decision making. In the context of IoT, these medical devices, real-time health monitoring and AI-powered analytics have made healthcare more accessible, efficient and personalized. These technologies permit continuous monitoring of the patient, immunological accuracy, optimization in the hospital work processes, and provide remote healthcare services [13]. As IoT adoption in healthcare technologies grows, medical practitioners now have better sources of informational feedback

to make and patients acquire proactive healthcare follow. Weighting the benefits of data integration into healthcare systems from a practical viewpoint, the integration of IoT in healthcare systems has improved patient outcome as well as reduced operational costs and minimized the hospital admissions.

A. Remote Patient Monitoring and Wearable Healthcare Devices

Remote patient monitoring (RPM) is one of the most impactful applications of IoT in healthcare which allows healthcare providers to monitor the health status of a patient in real time without the need for him to visit a medical facility. In particular, RPM has proved to be extremely useful in managing some chronic conditions such as diabetes, hypertension and cardiovascular disorders by enabling early detection of anomalies, and consequent timely medical interventions. They are wearable healthcare device such as a smart watch, biosensor and a fitness tracker that measure the vital signs, continuously like heart rate, blood pressure, blood glucose level, oxygen saturation and other body temperature [14]. Data transmitted by these devices reaches cloud-based platforms where AI algorithms apply to the information and find possible health risks. Thus, healthcare professionals can use this data remotely to suggest personalized treatment and early intervention before the disease has advanced to a critical state [14].

Additionally, wearable devices powered by IoT have been of great importance for postoperative care and rehabilitation. At home, patients can be monitored after surgeries so that they do not have to stay in the hospital for prolonged periods. IoT sensors are used by smart rehabilitation systems to track a patient's progress and ensure they adhere to their prescribed exercises and recovery protocols. Furthermore, medication adherence with IoT is enhanced by such IoT driven medication adherence systems that remind patients to take the medications at the right time thereby reducing chances of missing the dose and hence good treatment adherence. In other words, smart home IoT solutions (such as the fall detection sensor and emergency alert systems) give real time assistance to elderly and disabled individual; hence improving the safety and quality of life.

B. Smart Hospitals and IoT-Enabled Healthcare Infrastructure

Apart from caring for an individual patient, the IoT has revolutionized hospital management through optimization of workflows, improved resource utilization and reduced operational inefficiencies. IoT has made its presence in smart hospitals by deploying IoT enabled medical devices, RFID based tracking systems and automated workflows to make healthcare process an easy ride. For instance, IoT enabled smart beds automatically change in order to provide the patient with maximum comfort while monitoring vital parameters like heart rate and respiratory rate. Later, should the beds detect irregularities, the staff get alerted to act in time. IoT enabled RFID and GPS tracking systems have also brought great enhancement in medical inventory and asset management [15]. With hospitals currently monitoring the availability and location of medical equipment from ventilators to defibrillators and infusion pumps to ensure their proper use and reduce delays in such critical situations, this time is proving far too soon. IoT integrates with smart medication dispensers that can track drug usage and avoid medication shortage, error. Inventory management in hospitals is automated for minimizing wastage and efficiency, as well as overall cost.

In hospitals one of the most crucial IoT application is infection control. Environmental sensors that are smart monitor air quality, humidity, and temperature to guarantee the execution of hygiene standards and decrease the spread of episodes [16]. IoT is being used to keep track of sanitation schedules and to run automated disinfection systems to make certain hospital rooms and surgical instruments are cleaned punctually. Furthermore, IoT based facial recognition and biometrics' access control system can also improve hospital security to restrict the access of unauthorized individuals to critical areas like ICUs and operating rooms.

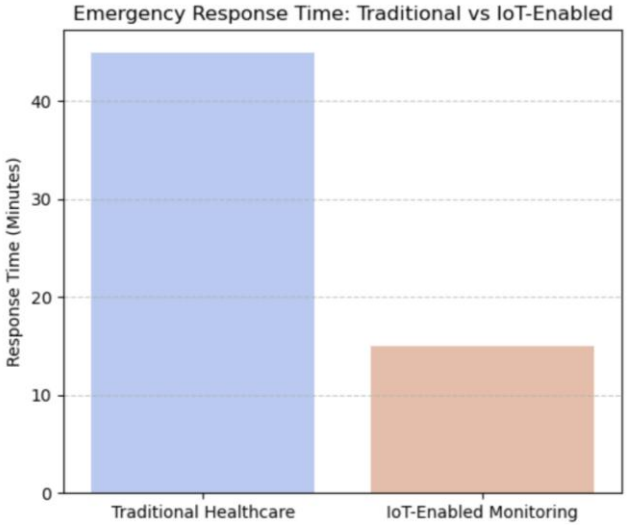

Fig. 4. Emergency Response Time Comparison - Traditional vs. IoT-Enabled Healthcare

The Fig. 4 shows a compelling graphical contrast in emergent response time of traditional medical care system and the one that is IoT enabled. The respective traditional healthcare area is represented by a blue bar with an almost 45 minute response time while IoT enabled monitoring area has an almost 15 minute response time. IoT technology in healthcare finds its efficiency in this visualization powerfully. Realtime monitoring, rapid speed of information transmission, and initially proactive applications of the Internet of Things devices allow for what would be an almost 70% reduction of emergency response time. IoT helps in faster detection of medical issues, bringing immediate alerts, and faster intervention thus making emergency medical response no more reactive but rather predictive and preventive. The graph itself proves on why adopting IoT in healthcare to save time, reduce complications and ultimately improves patient outcomes.

IV. IoT Data Analytics and Decision-Making in Healthcare

Though, integration of IoT in healthcare has not only enhanced connectivity in between healthcare devices and healthcare providers but also made a way for data driven

decision making. Real time patient data is created by IoT devices in huge volumes and when properly analysed, can enrich the diagnostic data, predict disease progression and will help in better optimizing treatment plans and improving healthcare outcome. These data enable healthcare providers to use advanced data analytics techniques, for example: machine learning, artificial intelligence and cloud computing to extract meaningful insights about the particular data [17][18]. IoT driven analytics lets hospitals and medicals professionals transition from reactive to proactive and predictive healthcare which provides better patient care, reduced operational cost and time.

A. Real-Time Data Collection and Processing in IoT Healthcare

For example, healthcare environments constantly 'spout' vast amounts of patient related data: whether it is vital signs and activity levels, environmental factors and medication adherence etc., from IoT devices deployed. Continuous real time health data streams are being produced from wearable devices, biosensors, smart implants and remote monitoring systems that are transmitted to centralized cloud platforms or edge computing systems for immediate processing. This real time data collection allows health care providers to collect the patient conditions in real time, detect anomalies and take proper actions in time to avoid medical complication.

Edge computing is critical to making IoT generated data go through the processing in event, and with as small latency as possible. Proceeding with critical health alerts which can be instantaneous at, say, the edge of the algorithm, on a wearable device or even a local hospital server, rather than pushing data up to the cloud, allows for crucial data to be processed closer to the source. Imagine, for example, a patient with a heart problem that causes irregular heart rhythms, and the use of IoT-enabled pacemaker to suddenly call for the help of the healthcare professionals and trigger an emergency response. Similarly, real time glucose monitoring systems can give alerts to diabetic patients about the time of the insulin and it also saves from medical emergencies.

Interoperability in data processing from the IoT is another critical issue. In the healthcare domain, the data from the sources such as electronic health records (EHRs), medical imaging systems, and wearable sensors should be integrated by the healthcare IoT systems. It should be standardized for interoperability in these systems as the protocols should be standardized and a robust data governance frameworks should be in place. In the cloud your healthcare platform relies on application programming interfaces (APIs) to have EHRs communicated seamlessly from one provider to the other. By enhancing clinical decision making, this interoperability gives doctors the holisitic possiblity to see a patients medical history and the present health status and potential risks [19].

B. Predictive Analytics and AI-Driven Decision Support Systems

However, the true power of IoT in healthcare truly lies in the ability it can give towards enabling predictive analytics, and AI and decision making. Machine learning and deep learning algorithms, widely applied in both healthcare and agricultural disease detection [20–22], can be applied to vast quantities of IoT generated health data in order to generate predictive models for the prediction of disease progression [23], for identifying high risk patients, and as recommendations for personalized treatment strategies [24]. Health care providers with good predictive analytics will change from a reactive mode of treating illnesses after symptoms are present to a proactive mode in which diseases are discovered and handled before they become very severe [25].

This, for example, are AI powered IoT systems that process data from heart rate monitors, blood pressure sensors etc. and predict the probability of cardiovascular diseases. Patient and doctor's with these systems can be warned about the possibility of risk as to intervene early and minimize the possibility of heart attacks or strokes. Like in oncology, IoT based predictive analytics is used extensively in the use of artificial intelligence models to run on genetic data, medical imaging scans, patient histories to predict the cancer progression and formulate a personalized treatment regimen [26].

The other role played by IoT analytics in hospitals is to improve hospital management by optimizing resource use and patient floor. These systems analysis patient's admission rate, bed occupation rate and emergency department's workflow, and predict the hospital resource demands. Forecasting the patient influx allows hospitals to put in staff, medical supplies, and ICU beds in order to minimise wait time and give the best patient care. During public health crises, pandemics for instance, predictive capability is very important to managing healthcare resources in a strategically limited way to avoid overcrowding and failure of the system.

On the other hand, AI is being used in IoT system which supports the personalized medicine by tailoring the treatment plan based on study of individual patient data. But, IoT driven analytics gives healthcare an approach that is more customised compared to what is possible with traditional healthcare approaches. AI takes genetic data, lifestyle habits, as well as real time health metrics and can suggest personalized drug dosage's, lifestyle changes, and rehabilitation plans. Such level of precision medicine improves treatment efficiency by minimizing side effects and adverse reactions.

V. Security, Privacy, and Ethical Challenges

It has definitely pushed healthcare into the Era of IoT integration where patient monitoring, diagnosis and treatment have been improved greatly [27]. Yet, it has also raised a number of security, privacy and ethical issues that need to be resolved in order for these technologies to be used safely and effectively. IoT devices have huge amounts of sensitive patient data collected and transmitted to them; and as a result, they are an obvious cyber threat, unauthorized and data breach targets. Furthermore, on top of that, one can make ethical arguments regarding the patient consent, data ownership and how the potential biased AI driven healthcare decisions might make the use of IoT in medical environment even more difficult. To address these challenges, we must employ advanced and secure cybersecurity measures along with strict regulatory compliance on ethical measures that strike the perfect balance between technological significant advancement and patient's right protection.

A. Security Threats and Cyber Risks in IoT Healthcare

Connected medical devices and data transmission networks in the IoT in healthcare are one of the serious issues concerning the system's vulnerability to cyberattacks. Cloud platforms, wireless communication, and interconnected devices characterize IoT healthcare systems, which along with a multitude of other entry points, make IoT healthcare systems very vulnerable to cybercriminals. Security loopholes irresponsibly open up for hackers to gain unauthorized access to sensitive patients' data as well as manipulate medical equipment and launch ransomware attacks against healthcare institutions. Such cyber threats have unfortunate implications, including various types of undermined patient safety, financial loses, and loss of trust in health care technologies.

One of the main security vulnerabilities in IoT healthcare is the interception of medical data in transit, right in the process of transloading the data between devices. Patients expose themselves to identity theft or insurance fraud if health records including diagnostic reports, treatment histories and genetic data are exposed. Also, these unsecure IoT devices can be forced to read false, modify medication dosages, or can lead to interference with lifesaving medical interventions. One example of a compromised insulin pump, for example, might mistake the variable for a dose and administer incorrect amounts to a patient, putting a patient's life in jeopardy. What further amplifies these risks? The lack of regular security update for IoT medical devices which leaves most of these devices vulnerable for exploits even after they are being deployed as many devices have security exploits that go undetected for long periods of time.

To counter these threats, there has to be robust cybersecurity frameworks that are adopted in IoT healthcare networks. Measures that can help safeguard the patient data and also device functionality include the end to end encryption, secure authentication protocols, and intrusion detection system. The promise of Blockchain technology in protecting IoT healthcare transactions using data integrity as well as decentralized control has also been realized in this [28][29]. On top of that, anomaly detection using AI can be used to identify unusual activities within IoT networks in advance in order to issue alerts to security teams once breaches may escalate to severe incidents.

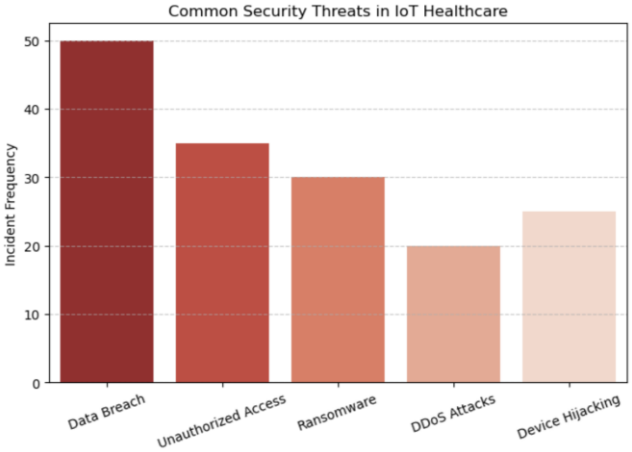

Fig. 5. Common security threats in IoT healthcare systems.

Fig. 5 provides an all-around picture of cybersecurity threats to IoT healthcare technologies with data breaches as the most frequent issue [30]. Fifteen security challenges are depicted on the visualization, where bar heights indicate the frequency of their occurrence with smallest being most frequent. Nearly 50 incidences belong to data breaches, 35 unauthorized access incidences and about 30 ransomware incidences. DDoS attacks and the device hijacking both represent significant, though lower occurring threats with frequencies of 20 and 25, respectively. The graphic points out the importance of having robust cybersecurity in place in an IoT healthcare system, noting that there can be many ways of having digital vulnerability. Dark to light red gradation of colors highlights the disparity in level of threat which are a visual cue to the plaguing risks with regard to the protection of sensitive medical data and of the healthcare infrastructure in a more and more connected ecosystem.

B. Privacy Concerns and Data Ownership in IoT Healthcare

Due to the concerns of privacy within the use of IoT, in healthcare, it is critically important to design a system that collects, stores and shares the patient data safely. Real time health information like biometric data, vital signs and medical history are collected by the IoT devices continuously. This data is critical to the improvement of patient care, but especially when stored in cloud platforms and healthcare databases, allows the risk of unauthorized and misuse of such data to rise. Who patients are and how they can control how their data is shared are ethically awkward issues of consent, data ownership and privacy.

Unlawful transfer of patient information to third parties including pharmaceutical companies, insurers, or research organizations is the truly greatest one. Healthcare institutions can share anonymized data without explicit patient consent for commercial purposes that can ultimately cause discrimination in the relative premiums on insurance or better employment possibilities. Moreover, when the health care systems are breached and patient records are exposed to malicious actors, there are further privacy violations.

These privacy concerns need to be addressed by healthcare organizations by adopting very strict data governance policies and compliance with the global regulatory frameworks such as General Data Protection Regulation (GDPR) and Health Insurance Portability and Accountability Act (HIPAA). It is the mandate of such patients, to make them explicit consent for collecting data and organizations have to follow strict controls on the access to that data and the encryption mechanism. Both differential privacy and homomorphic encryption will also aid in the analysis of patients data while maintaining confidentiality. Blockchain and all its capabilities allow patients to have more control on their data through blockchain based personal health records (PHRs) and enhance transparency and trust in IoT healthcare solutions.

Fig. 6 shows an evolutionary outlook for the technology of IoT, on a healthcare base, from the present state to some main markers until 2034. A progressive and exponential way of moving into the IoT healthcare technologies is shown in the upward trajectory. Beginning from the current IoT implementation, the graph demonstrates improvements, along with their technological breakthroughs such as AI integration,

5G telemedicine, blockchain security and the smart hospital implementation. Significant milestones along the function of becoming a digital healthcare leader represent strategic steps in digital healthcare transformation with a steepening curve that indicates greater speed in the field of technology. The figure incorporated in the paper visualizes its forward looking view and shows how the development of the emerging technologies will keep shifting healthcare delivery. To emphasize that the every technological milestone embarks on a smooth, ascending line and each is built on the foundation of the previous innovations to the creation of more sophisticated, efficient and patient centric healthcare ecosystem.

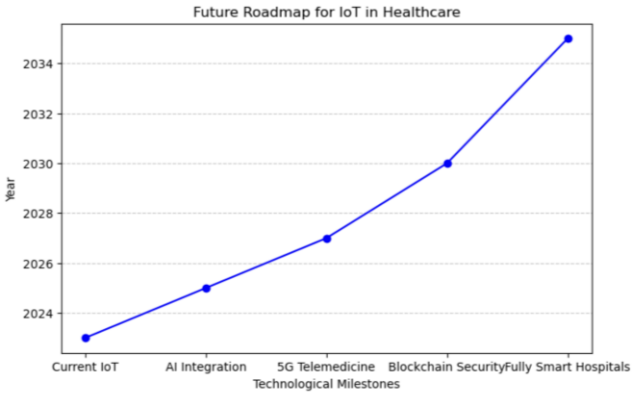

Fig. 6. Future roadmap for IoT in healthcare.

C. Ethical Considerations in AI-Driven IoT Healthcare

But aside from security and privacy, IoT healthcare systems need to be carefully probed on ethical ground. The concerns around bias, accountability and transparency arises as AI and machine learning algorithms are being built and used all the time with IoT healthcare data [31]. If the AI model was trained with a biased dataset, there is a potential that it will generate a discriminatory outcome, the amounts may vary between one patient group and another group based on race, gender or socio-economic status. For instance, an AI-based diagnosis system that is trained primarily on Caucasian patient population will have a lower sensitivity in detecting diseases in non-Caucasian people, thus creating differences in the process of healthcare delivery.

Automating the medical decision making is another ethical concern. However, while AI and IoT help with diagnostic accuracy and treatment planning, it would be a crime if those algorithms would be blamed for questionable diagnosis or poor treatment recommendation. When critical error occurs during an AI-powered IoT system and harms a patient, it becomes a legal and ethical problem as to who is legally and ethically responsible — if it is the healthcare provider, software developer or device manufacturer.

Transparency and explainability should be prioritized to bring up ethical AI deployment in IoT healthcare. The way AI algorithms work should be designed so as to be interpretable so that medical professionals can understand how decisions are made instead and don't blindly rely on recommendations generated by machines. Moreover, discrimination in AI based health care systems should also be detected and audited fairly regularly to eradicate it. It must be made clear to regulatory bodies that clear ethical guidelines are required to govern the use of AI in making medical decisions so that human oversight is always important.

The second important ethical question revolves around the digital divide in relation to enabling IoT-based healthcare solutions. Although IoT can hold great promise in bettering healthcare access especially in areas of low connectivity and reach, inequalities in technological infrastructure and digital learning may limit the physical and intellectual aspects of healthcare accessibility to those desiring to embrace the new technology. This implies that governments and healthcare organizations are lacking when it comes to investing in affordable IoT healthcare solutions and digital health education programs.

VI. Conclusion

Integration of IoT in healthcare has completely transformed patient care by allowing for real-time monitoring, predictive analytics and personalized treatment strategies. Ensuring that smart IoT technologies can be available and necessary for everyone to ensure availability of healthcare, operational efficiency and medical decision making. Faster, better and cheaper—this has been the case for healthcare providers who have been able to collect and analyse vast amounts of real time health data on patients, allowing detection of a disease early and enabling to use it for optimization of a treatment plan and improving the outcomes for the patients. Although these advancements are helpful, issues concerning security, privacy, interoperability, and ethical issues are still the most severe barriers to the wide adoption of them. Threats from cyber, data breaches and unauthorized access of sensitive patient information comes with huge risks, therefore, encryption, access control methods and regulatory compliance needs to be well implemented in order to maintain data security. Additionally, ethical issues such as biases in AI's decisions regarding healthcare should be addressed to prevent the mistreatment of any patient group. With the advancement of IoT, it is expected that the collaboration among healthcare professionals, technologists and policymakers would be indispensable to overcome these challenges and keep the IoT driven healthcare solutions secure, ethical, and viable. With the help of implementing stringent security, increasing AI transparency, and the adoption of standardized interoperability framework promises the future of IoT in health holds the potential of developing the IoT based medical services for healthcare on a more efficient, personalized, and patient centric base.

VII. Future Directions

In particular, nanotechnology and a combination of artificial intelligence, 5G connectivity, edge computing, along with blockchain technology are expected to shape the future of IoT in healthcare. With AI power, further development in disease forecasting, personalized treatment and early intervention strategy will move from reactive to proactive healthcare. 5G networks deployability will facilitate real time data transmission, reduce latency in remote patient monitoring and/or medical devices connectivity in the cloud. Furthermore, edge computing will help eliminate the use of the centralized cloud infrastructures and will allow the real time data processing at the

device level and will result in faster response times and the reduced Bandwidth. With regard to the data security, blockchain will ensure transparency and will allow decentralized, private patient health records within the regulatory compliance. In addition, federated learning will reduce the adoption of AI models that can train on decentralized healthcare data while upholding the confidentiality of the patient. It will be crucial that the digital divide is addressed and that IoT healthcare solutions are accessible to everyone. The future research should research towards the development of standardized IoT frameworks, mitigation of cybersecurity threats and improving AI interpretability to generate safe and ethical IoT driven healthcare systems that are useful for the patients across the globe.

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