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Research Article

Smart Healthcare Systems: Digital Health and Medical 4.0 Integration

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Abstract:
The Fourth Industrial Revolution has the potential to benefit various sectors and industries, but its impact on healthcare will be particularly profound. Medical 4.0 represents the fourth revolution in healthcare, leveraging cutting-edge technologies to drive major advancements. These innovations have progressed rapidly, encompassing everything from mobile computing to cloud computing for wearable and non-wearable sensors. Medical 4.0 reduces the strain on healthcare systems in well-developed nations while improving access to high-quality, comprehensive care in developing countries. This digital transformation enables the electronic collection of patient data, which technology utilizes to enhance disease diagnosis and understanding. Additionally, this data serves as a valuable knowledge base for further research and study. This paper presents Smart Healthcare System with Medical 4.0 framework and knowledge discovery model to manage and analyze healthcare data.

Keywords: Medical 4.0, Smart Healthcare System, Knowledge discovery model, digital medicine

I. Introduction:

Digital medicine refers to integration of digital technologies like softwares, sensors and analytics into healthcare practices. Focus of digital medicine is on digitizing medical information and processes. When the broader term is used as Medical4.0 it emphasizes on holistic approach of digital data enabling predictive, preventive and personalized healthcare approaches. Digital medicine can be one part of Medical 4.0 for connected and ubiquitous patient care. [1]

The goal of digital medicine as well as Medical 4.0 is to improve patient outcomes and to facilitate healthcare practitioners. Examples of digital medicines applications cover remote patient monitoring, medication adherence apps, telehealth consultation etc. Examples of Medical 4.0 applications cover AI-powered diagnostic tools to analyze medical images for early disease detection, robotic surgery, personalized treatment plans etc. [2]

Digital health innovations are used to reduce time of treatment, improve accuracy and efficiency. Medical 4.0 is similar to Industry 4.0. Industry 4.0 enables customers to build intelligent products to monitor and maximize performance. Industry 4.0 consists of connected machines and robots. On similar lines, Medical 4.0 aims to monitor patient remotely or in supervised environment promising faster, efficient and effective treatment. Medical 4.0 uses modern technologies to connect patients and healthcare professionals with each other. Medical 4.0 technologies are evolving with patient-centric approach in which innovations can be brought with cutting-edge technology. [3] This paper proposes Medical 4.0 Ecosystem with the research domains of Digital Health.

This paper explores the evolution of health practices with Medical 4.0 framework. Section II explains components of digital health, the advances from healthcare 1.0 till healthcare 4.0 along with supporting Internet of Medical Things architecture. Section III explains the Knowledge Discovery in Medical 4.0 Ecosystem forming smart care unit. Section IV concludes the research along with importance of new trends in healthcare.

II. Literature Review:

A. About Medical 4.0:

Medical 4.0 technologies or Digital Health assist patients through mobile medical applications in secured environment. Medical 4.0 help hospitals to manage supply inventories, chemicals, electronic medical records of patients etc. Medical 4.0 help physicians and doctors with Electronic Health Records in making better and faster diagnosis of the disease.

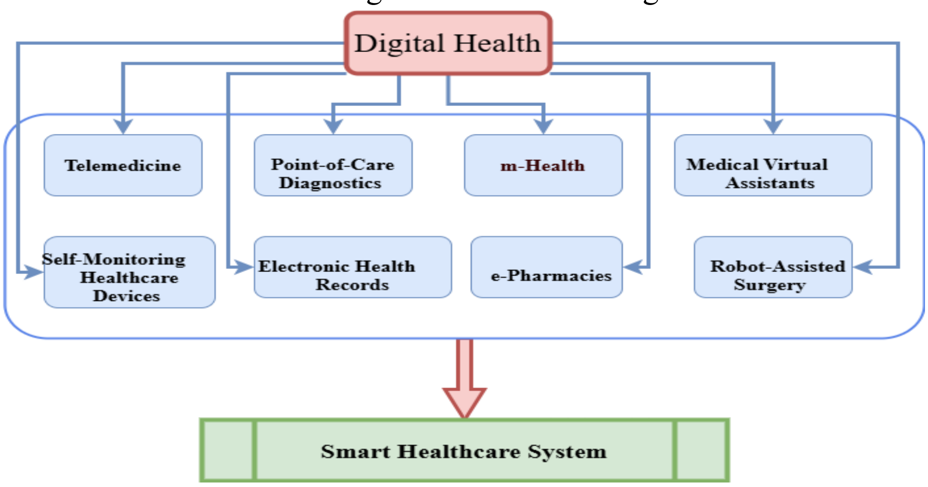

Figure 1: Components of Digital Health forming Smart Healthcare System

As shown in figure1, Digital Health uses modern technologies to connect patients and healthcare professionals for advanced treatment technique. Digital Health uses global research domains such as sensors and wearables, 3D scanning and imaging, telemedicine through IoT devices, RPA and virtual reality and Internet of Behaviour to key applications to manage health and wellness. These research domains help for focused, effective and accurate healthcare delivery.

Digital Health covers following key applications:

1. **Telemedicine:**
   Telemedicine is the use of telecommunication technologies to connect patients with healthcare professionals. Tele-radiology, tele-consultation, tele-nursing, tele-ICU and tele-surgery are different aspect of telemedicine.

2. **Point-of-Care Diagnostics**
   It provides accurate diagnostics using automated technologies based on artificial intelligence and/or machine learning algorithms. The diagnostics results can be used by patients to approach doctors for further treatment and medicine. It also enables tracking, monitoring and management of the disease which can directly aid medical decision making of the patient and prognosis of physicians since it generates large data sets of minute health changes. This key application is suitable for countries where high-grade medical facilities and infrastructure are not available in rural area. With the help of telemedicine facilities, point-of-care diagnostics can reach well to remote patients.
3. **m-Health:**
   It is the provision of Digital Health services on a mobile platform for countries like India which is the 2nd largest smartphone market in the world,

4. **Medical Virtual Assistants**
   This key application facilitates for services like physical appointments, prompting prescription, providing information on medical conditions, appointment scheduling, maintain health records and other administrative tasks. These assistants are AI based softwares to enable the processing of large data sets and provide personalised advice and administrative tasks at hospitals and other healthcare institutions.

5. **Robot-Assisted Surgery**
   This key application facilitates minimally invasive surgeries. These surgeries help to reduced loss of blood, better pain management and quicker recovery for the patient. With deep learning algorithms, robots would be able to observe and replicate procedures that are simple and repetitive, while the surgeon concentrates on more complex, intelligent tasks.

6. **Self-Monitoring Healthcare Devices**
   Wearable sensors detect various physiological changes in the body such as tracking weight, sleep patterns, blood pressure, glucose levels, posture, diet and exercise. The monitored data will be collected and can be used to self-monitor by detecting various health symptoms and alert the user in case of potential issues.

7. **Electronic Health Records ("EHR")**
   An Electronic Health Record (EHR) is a digital version of a patient's medical history that can be accessed anytime, regardless of when or where the data was collected. This allows doctors to review a patient's complete medical history, even if they are seeing them for the first time or if the patient cannot communicate. EHRs help minimize duplicate tests and enable secure information sharing, ultimately improving patient care and reducing healthcare costs.

8. **e-Pharmacies**
   An e-pharmacy, or online pharmacy, is a digital platform that sells medicines over the internet and delivers them via mail, courier, or delivery personnel. This model enables pharmacists to serve a wider range of patients by eliminating the geographical limitations of physical pharmacies.
   With above key applications of Digital Health, Smart Healthcare System can be formed with following features:
   i. **Enhanced access to healthcare:** Through facilities like telemedicine, remote monitoring and e-Pharmacies, patients get easy and enhanced access of healthcare services.
   ii. **Improved patient engagement and self-management:** Due to remote monitoring and m-Health applications, patients get aware about their own health and their engagement for maintaining good health increases.
   iii. **Enhanced Monitoring and Early Intervention:** Wearable and remote monitoring systems allow healthcare professionals to continuously track patients' health and detect potential organ complications at an early stage.
   iv. **Data-Driven Personalized Care:** EHRs and data analytics help identify valuable patterns for diagnosing and treating patients, leading to more personalized treatment. This personalization is based on factors like genetic differences, lifestyle, and individual patient choices.
   v. **Reduced Healthcare Costs:** Due to telemedicine and tele-monitoring, face-to-face visits are reduced. [4]

B. Healthcare Revolution from Traditional Care models to Medical 4.0

- Healthcare 1.0 refers to typical clinical interaction. During such interaction, patient meets physician. Through consultation, testing and diagnosis, the clinical team used to provide prescription for medication, a care plan and follow-up plan. This model was executed for long time world-wide.

- Healthcare 2.0 refers to major developments in health, life sciences, new medical equipments etc. These developments are used in medical treatments like imaging test equipment (e.g. MRI, CT Scan), monitoring devices like pulse oximeter and surgical and life support equipments are increasingly used in hospitals.

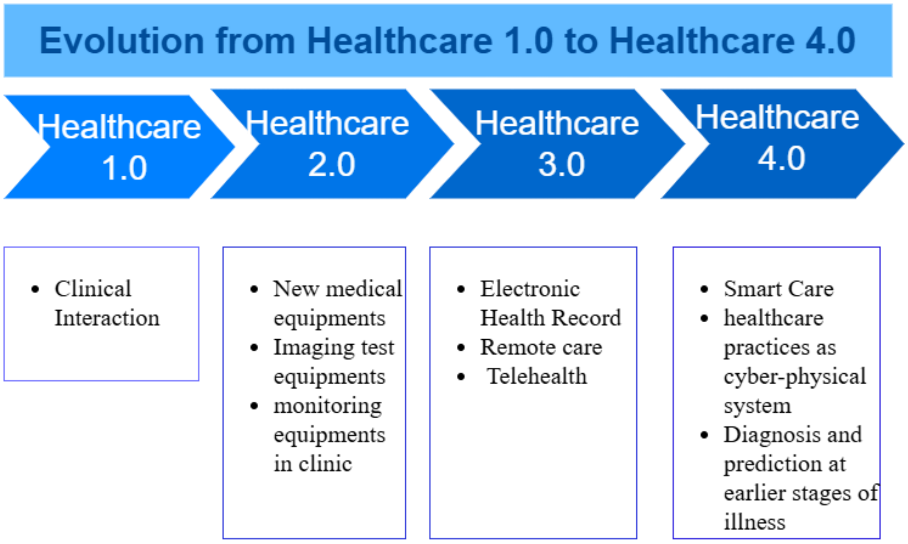

Figure 2: Evolution from Healthcare 1.0 to Healthcare 4.0

- Healthcare 3.0 aligns with the period of last 10 years covering advancement of information systems, EHR and EMR are implemented to manage patients' information across departments of healthcare organization. Many manual processes are automated using networks, telehealth practices. Covid-19 pandemic initiated electronic visits through patients portal or online consulting practices.
- Healthcare 4.0 visualizes delivery of healthcare practices as cyber-physical system equipped by IoT, RFID, wearables, intelligent sensors, medical robots implemented with cloud computing, wireless sensor networks, big data analytics and decision support system designed by AI techniques. Healthcare 4.0 proposes connected environment where healthcare organizations are connected with patients and patients' home. Patient related information like medical history, diagnostics notes, lab results, treatment plans, insurance claims are shared with all medical practitioners by following all security concerns. [5][6]

C. **Internet of Medical Things (IoMT)**

IoMT is the complicated, interconnected structure of all devices used for health monitoring and streamlining health services. IoMT devices with the support of artificial intelligence techniques form intelligent system. This ubiquitous and intelligent system can monitor all body parameters for remote treatment as well as provides alert and alarm system to caregiver of a patient and concerned physician. IoMT-driven systems provide right treatment to a patient at any place, at any time. The IoMT ecosystem mainly comprises of three components: Data acquisition, communication gateway and Cloud storage. Figure 3 shows architecture of IoMT ecosystem.

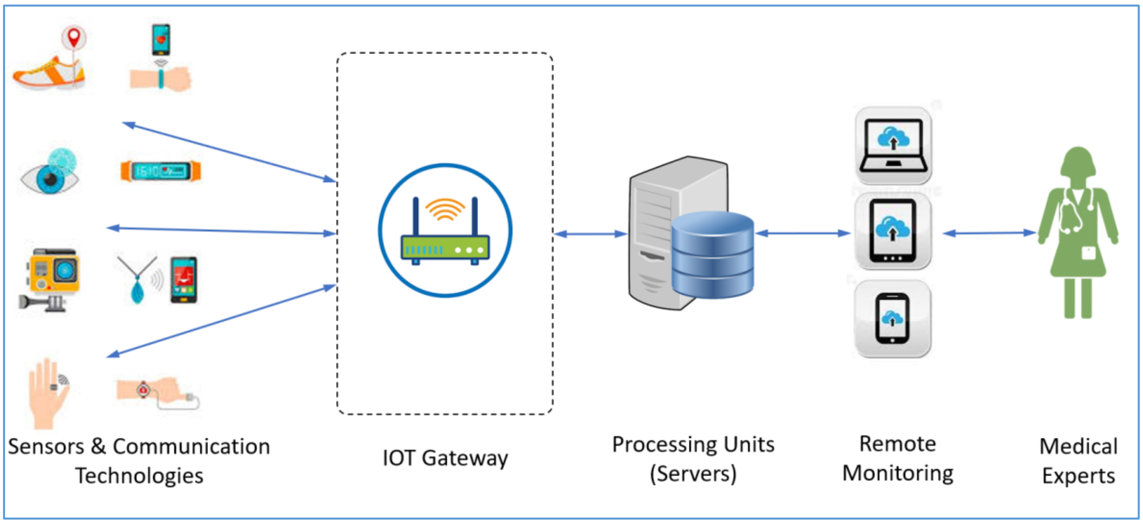

Figure 3: Architecture of IoMT System

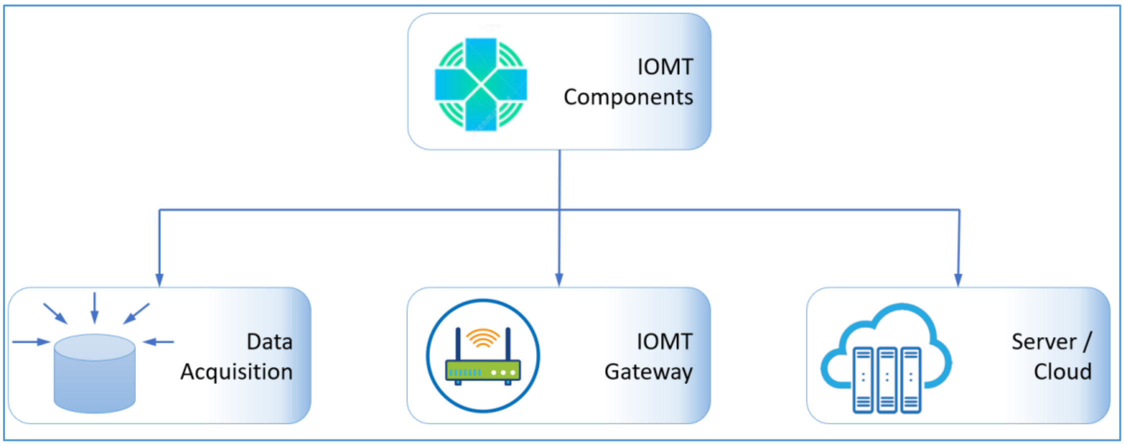

Figure 4: IoMT Components

Figure 4 shows components of IoMT. Data acquisition occurs through sensors/wearables of the system. After preprocessing of data, data is sent to cloud storage through communication gateways. At cloud data is used for further analysis and specific indicators are generated for the patient's health. [7]

a. **Data Acquisition in IoMT System :**

In the IoMT ecosystem, there are important tasks like monitoring body parameters of patient/ user, preprocessing the data, removing noise and sending it to cloud storage. For monitoring body parameters, bio-sensors are used. These devices capture body parameters Some bio-sensors have the capability to generate alert/ alarm if monitored data is presenting abnormal patterns. [7][8]

b. IoMT Gateways :

The smart devices dont have capability to transfer data to server, so IoMT gateways are physical devices or software programs which connect bio-sensors with the remaining IoMT application.

c. Cloud Storage :

The servers are part of the cloud storage device of IoMT, which is core part of a complete system responsible for decision of diagnostics and prescribing further treatment based on monitored data. They implement signal processing techniques and covert data into a desired format, data mining algorithms for right predictions, neural networks for discovering patterns of monitored data to recognize any abnormal pattern.

In this way, IoMT forms architecture for Medical 4.0.

III. Research Design for Knowledge Discovery in Medical 4.0 Ecosystem

The figure 5 describes design of Knowledge Discovery in Medical 4.0 Ecosystem which consists of main two layers:

1. Sources of data acquisition:

a. **Patients past history** is collected through EMR (Electronic Medical Records) which include patient information, history, diagnosis, treatment, test results, medical imaging data and laboratory results. EMR (Electronic Medical Records) is defined as as electronic record of health related information of an individual which can be created, gathered, managed and consulted by authorised clinician and staff within health care organization. [10]

b. Sensing: Bio-sensors which are wearable and non-wearable sensors are responsible for sensing and monitoring patient's physiological data.

. **Wearable Sensors :**

Wearable sensors are smart sensing devices used to monitor patient's physiological data. They function without human intervention to capture body parameters. Table 2.1.2.1 shows some of the wearable sensors [11]

Wearable Sensor	Monitoring parameters
Bio-impedance Sensor	respiration rate, heart rate and cardiovascular pressure (CVP)

Accelerometer	Fall detection, ECG, Heart rate, cardiac rehabilitation programs and monitoring performance of athletes
Photoplethysmograph	heart rate variability (HRV) calculations, pulse rate, breathing rate, and perfusion measurements
Pulse Oximeter	To monitor respiratory functions, human blood oxygen level

Non-Wearable Sensors:

Non-wearable sensors are also smart sensing devices but cannot be worn on human body and work without human intervention [11]. They are fixed around human body to monitor activities of patient/user. Some of the non-wearable sensors are mentioned below:

Non-Wearable Sensor	**Monitoring parameters**
Smart bed	respiration rate, temperature, sleep pattern, etc. specially for pandemic situation
Human Activity Detection	useful in treatment of cardiovascular disorders, stroke, senior citizens care or parkinsons, etc.

2. Second layer represents **Smart Care Units of Medical 4.0 system**. Smart Care Units are responsible for knowledge discovery from captured data and past history of patient. Mainly three knowledge discovery tasks are involved in smart care units – prediction, Anomaly detection with subtask of raising alarm and diagnosis. Most monitoring applications work remotely (may be in home environment) with prediction and anemology detection whereas as applications in clinical environment are involved in diagnosis and decision making. Prediction and diagnosis can occur in offline manner but anomaly detection with alarm generation happen in online manner with continuous monitoring.

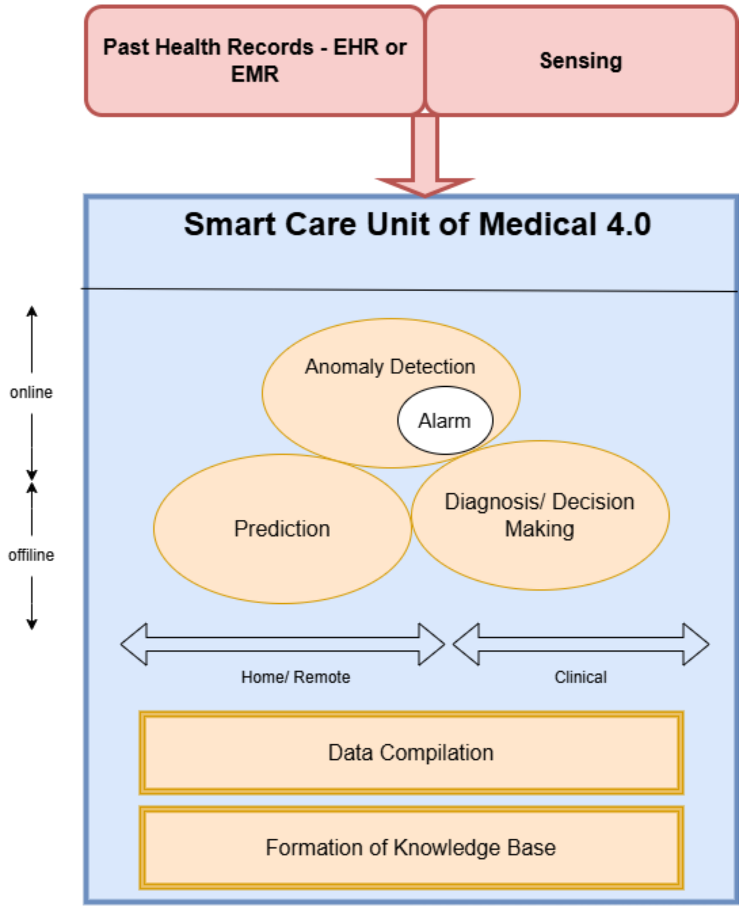

Figure 5 Knowledge Discovery in Medical 4.0 Ecosystem

a. **Anomaly Detection:** Anomaly detection involves recognizing irregular patterns that deviate from the normal or expected behavior within a dataset. The irregular patterns can be related with ECG pulses, SpO2 signal, blood glucose level, sleep episodes, hazardous stress levels.
b. **Prediction:** Prediction is a commonly used technique in data mining that helps identify future events before they happen. This approach is gaining increasing attention from healthcare providers in the medical field, as it aids in preventing chronic conditions and supports decision-making for prognosis. The prediction data mining includes feature extraction, training and testing etc.
c. **Diagnosis/Decision Making:** In clinical monitoring systems, decision-making in diagnosis is a key task that relies on retrieved knowledge from vital signs, electronic health records. This process is closely linked to anomaly detection in data mining, as it helps to identify significant patterns in sensor data, such as events and alarms, which are crucial for making medical decisions.
d. **Data Compilation:** The smart care unit also has to compile the monitored data, abnormal pattern identified, any specific diagnosis identified for abnormal pattern.

The compilation of this varied data can be implemented by Data Preprocessing Algorithms, Clustering Algorithms and Data Integration & Fusion Techniques.

e. **Formation of Knowledge base:** In Medical 4.0, a knowledge base is an organized repository of medical data that aids in decision-making, diagnosis, and treatment by leveraging intelligent automation and data-driven analysis. Medical 4.0 Knowledge Base will consists of:

i. AI-Powered Decision Support
ii. Electronic Health Records (EHRs) Integration
iii. Anomaly Detection and Predictive Analytics
iv. IoMT Data Utilization
v. Personalized Medicine
vi. Clinical Knowledge Sharing
vii. Automation in Diagnosis & Treatment

With the above knowledge discovery model, medical 4.0 can offer healthcare services to society in clinical as well as non-clinical environment.

IV. Conclusion:

The aim of this study was to introduce Medical 4.0 ecosystem as digital health innovation. The paper presents knowledge discovery model for Medical 4.0 which generates knowledge base for better diagnosis, treatment resulting in wellbeing of society. Medical 4.0 generates various functionalities in healthcare domain which were not achievable earlier. The paper also explores IoMT architecture which can be base for Medical 4.0 system along with use of Data Mining algorithms in Smart Care Unit. Humans including patients, caregivers, healthcare workers should be center element of Medical 4.0 framework. Furthermore, the development of a Medical 4.0 user interface in regional languages to enhance accessibility across all areas of the country, along with the sustainability of the Medical 4.0 framework, can be explored further.

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