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Internet of Medical Things: Classifications and applications in real system

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ABSTRACT: The paper begins the exploration of IoMT by introducing a taxonomy of implementation scales for various healthcare environments, ranging from individualized personal healthcare solutions to expansive, interconnected healthcare systems that span entire communities. This categorization is essential to understanding the breadth of IoMT applications and their potential impact on healthcare delivery. Additionally, the abstract outlines the layered architecture that underpins IoMT, highlighting the layered structure that enables the seamless integration of medical and non-medical devices, data processing and healthcare services. Recent years have witnessed notable advances in the field of the Internet of Things (IoT), driven by developments in communication protocols, sensing technologies, computing capabilities, next-generation wireless technologies, big data analytics and in artificial intelligence techniques. These advancements have brought about a paradigm shift in the world of technology and have paved the way for several opportunities in various sectors, one of which is the burgeoning domain of Internet of Medical Things (IoMT). IoMT, as well as its subfields such as mobile health (mHealth) and digital or electronic health (eHealth), have emerged as significant frontiers in the field of healthcare and digital transformation. This paper provides a broad overview of the IoMT landscape and introduces a comprehensive classification system to delineate primary users and their roles within smart healthcare system.

I. INTRODUCTION

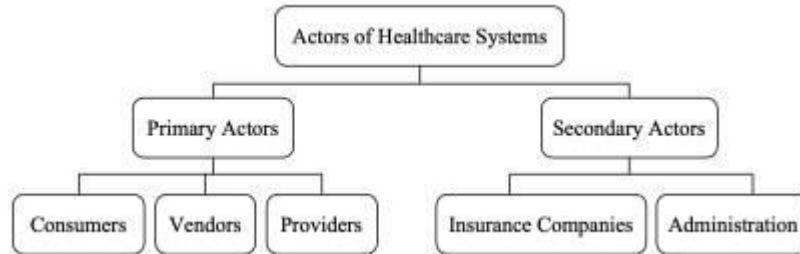
The different spaces we live and work in, from small-scale homes and offices to large-scale cities, are full of devices. These devices range from simple sensors and actuators to home appliances and cars. The Internet of Things (IoT) is an umbrella keyword that refers to the different technologies and techniques used to expand our traditional Internet to include such different cyber-physical devices, referred to as things. These things—equipped with processing powers and communication capabilities—form dynamic ad-hoc networks to interact with users and collect data from the surrounding environment. The collected data is then processed and transformed into valuable knowledge to be acted upon and to guide the decision-making process. Such a process changes our spaces into smart spaces. IoT covers a wide range of fields, including transportation, industry, education, and even advertisement. One of the critical and core IoT fields is the medical and healthcare field—referred to as the Internet of Medical Things.

II. HEALTH CARE MAIN ACTORS & DEPLOYMENT SCALES

Before we discuss the system architecture of an IoMT ecosystem along with the different medical devices, sensors, and services, we need first to discuss two main parameters that divide the landscape of any healthcare system: who are the main actors (or users); and what are the different deployment scales of healthcare environments. In this section, we classify the main actors of a healthcare system and then provide taxonomy for healthcare systems according to the deployment scale

MAIN ACTORS

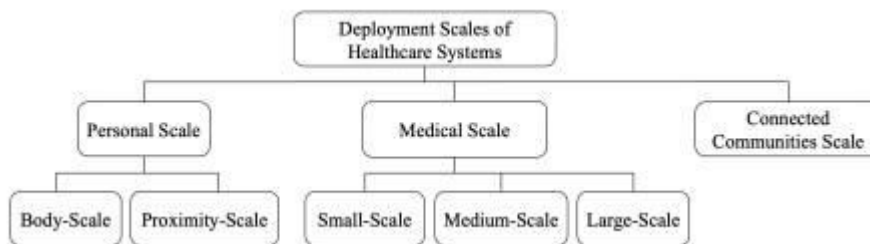
To design and build smart healthcare systems, it is important to know the different actors who participate in and use the healthcare systems. The actors are classified according to their roles that reflect the degree of their involvement, participation, engagement, and interaction with other actors. Two main categories of actors: primary and secondary actors. The actors are classified based on their roles, which reflect the degree of their involvement, participation, engagement, and interaction with other actors.



DEPLOYMENT SCALES

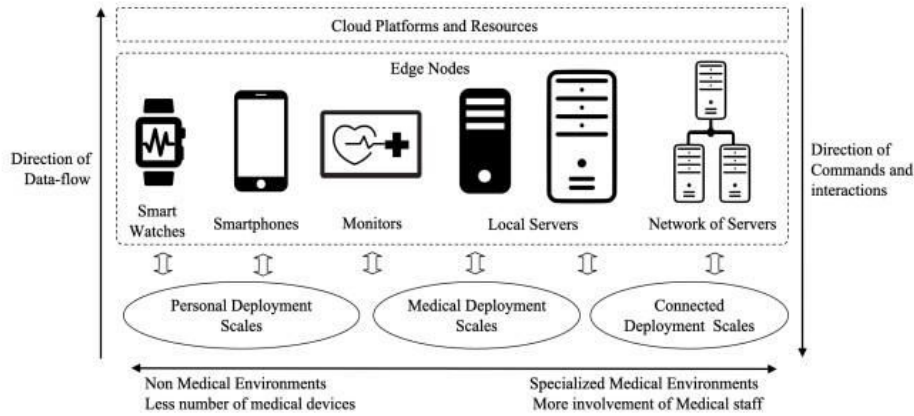
Healthcare environments are classified with respect to the deployment scale from less clinical to a more medical and specialized type of environments [8]. In this paper, we define a deployment scale according to a number of parameters that include: 1) the number, complexity, and specialty of devices and sensors used to provide the required medical service and care; 2) the active actors along with the depth of their roles, participation, and intervention; 3) the communication technologies, protocols, and standards used; 4) the scope of the expected medical applications and services along with the number of expected consumers; and 5) the volume of data collected and analysed. In this subsection, we provide —given the deployment scale parameters mentioned above— taxonomy that categorizes healthcare systems into three main scales: personal, medical facilities, and connected communities, The deployment scale is determined by several parameters:

- Number, complexity, and specialty of devices and sensors
- Active actors and their roles and participation
- Communication technologies, protocols, and standards
- Scope of expected medical applications and services
- Volume of data collected and analysed



III. OVERVIEW OF IOMT ARCHITECTURE

An IoT ecosystem in general, and IoMT in particular, follows a layered architecture style where each layer provides a set of services and functions to the adjacent layers. Utilizing a standard architecture to build smart healthcare and eHealth systems enables the widespread and seamless adoption of the different IoMT communication, sensing, and processing technologies and techniques. Architecture for IoMT can be logically illustrated as a multi-tiered n-layer system. There are multiple proposals for standard architectures in the literature where each proposal is designed to address specific requirements, achieve certain goals, and host various IoT applications and services. In this section, we provide an overview of the commonly used reference three-tier architecture with respect to the offered functionalities and the utilized technologies per layer. There are three main layers: 1) the lower layer—also known as the physical layer; 2) the middle layer—also known as the edge layer; 3) the upper layer—also known as the cloud layer. We then discuss the 5 and 7-tier architectures as extended versions of the reference architecture used in certain scenarios and cases.



IV. DEVICES AND SENSORS

IoMT includes a wide range of medical and non-medical devices and sensors that support medical applications, services, and research. Medical devices provide health-aware information about the patient, while non-medical devices provide context-aware information about the surroundings and living environment. Devices can be actuators, sensors, or hybrid types. An actuator converts electrical signals into physical events or actions. A sensor detects and measures physical phenomena and converts them into electrical signals. Sensors should be sensitive only to the measured phenomenon and should not modify it during the measurement process. The human body provides several biological and physiological signs that are the focus of healthcare systems and the different healthcare-related services and applications. There is a wide range of such vital signs, from common signs like heart rate, blood pressure, respiratory rate, and blood oxygen saturation to more specific and advanced signs like pain and level of consciousness. Monitoring these signs with appropriate and accurate sensors enables: healthcare consumers to be in the centre of the healthcare process, track and manage their health, and interact with care providers; and healthcare providers to provide medical help and care when needed and to evaluate such vital medical information for operations like monitoring neurological functions, rehabilitation procedures, and sports performance. In this section, we propose a taxonomy to classify the different devices utilized and used in healthcare systems with respect to a set of aspects and properties. We then present a subset of medical devices and sensors currently used in healthcare environments.

EXAMPLES OF IOMT DEVICES

Whether something constitutes an “IoMT device” is not merely about its designed purpose — it’s about how it’s used. While a blood glucose monitor is quite obviously an IoMT device, is an Apple Watch? Well, if that Apple Watch is sharing data with the wearer’s medical provider via a connected telehealth layer, yes! This is where lines can get a bit blurry. Here are some IoMT devices, some of which only meet that definition depending on a specific context.

- **Glucose monitor / insulin infusion pump:** A Bluetooth-enabled continuous glucose monitor (CGM) like a [Dexcom](#) reports blood glucose levels in real-time to an application, often on a patient’s connected smartphone. An insulin infusion pump (“closed loop”) system can talk to this CGM to adjust the frequency and level of insulin given, as well as report all monitored data back to the provider.
- **Heart rate monitor:** A heart rate monitor, whether a wearable or a dedicated chest HRM, can report a patient’s heart rate and rhythm and monitor for irregularities, such as after surgery or a coronary event.
- **Smart pill:** In place of an invasive surgery or endoscopic procedure, a sensor or camera-equipped “[smart pill](#)” can be ingested by a patient to report various data back to a provider — whether a series of still images or the detection of chemical markers inside a patient’s digestive tract.
- **Smart pacemaker:** An implanted pacemaker can communicate [using Bluetooth](#) and report diagnostic data via a connected smartphone, reducing the need for in-person checkups.
- **Smart scale:** An internet-connected scale can monitor weight or body conductivity fluctuations. Some scales have even started exploring measuring nerve conduction for early detection of neuropathy (for example, in diabetic patients).

- **Smart CPAP:** A Bluetooth-enabled CPAP can capture breathing and other diagnostic data to detect the frequency and severity of sleep apnea in a patient.

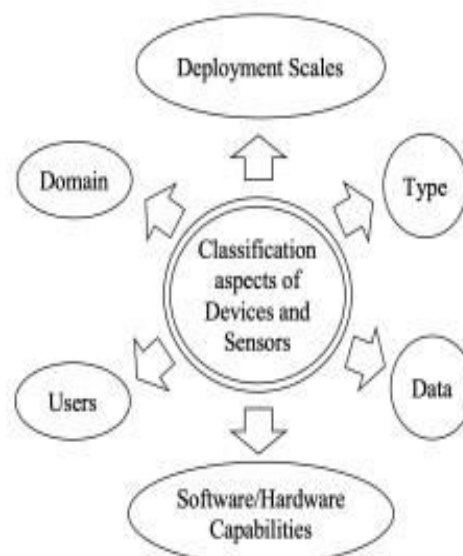
V. CLASSIFICATION ASPECTS

The taxonomy for different medical and non-medical devices and sensors guides the development of applications and services for smart healthcare systems. There are 6 essential aspects to classify different medical and non-medical devices. Devices are classified first by domain which determines the possible services a device can engage and participate in. There are several domains related to healthcare which include: Activity domain which includes devices and sensors to monitor the different physical activities performed by individuals throughout the day. Devices and sensors such as gyroscopes, accelerometers, and sleep monitors are used in many applications to monitor health and fitness, monitor hydration, and measure calories burned. Other devices such as motion sensors and movement disorder monitors are used in medical applications such as fall detection for the elderly.

- Health domain that includes devices and sensors to measure various biological, physiological, biochemical, and electrical vital signs of the human body. There is a wide range of medical devices that fall into this category, including glucose monitors, heart rate monitors, and blood pressure monitors. These devices are used in applications such as patient monitoring, elder monitoring, medication management, early warning systems, and in more specialized medical applications.

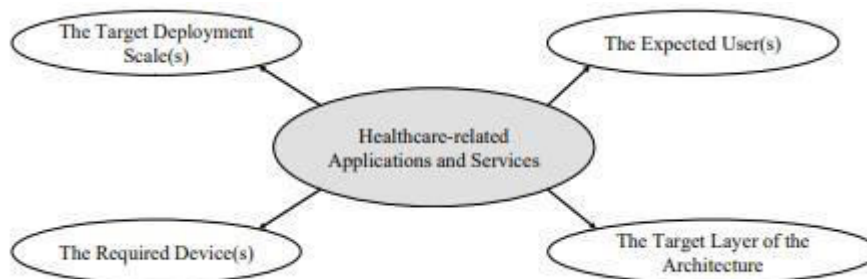
- Nutrition-domain where the need to analyse the process of the human digestive system is important to find which food provides sufficient nutrients. Ingestible sensors, capsules, and smart pills are designed and developed to be swallowed by a patient to monitor the digestive system. These sensors and pills then communicate the collected data and images through wireless communication technologies to a receiver like a smartphone or monitoring system.
- Ambiance-domain which includes sensors that collect non-medical and context-aware information about the patient's surroundings and living environment. A wide range of sensors addresses this domain, from GPS and proximity sensors for location information to humidity, noise, temperature, gas, pollution, and radiation sensors for information about the surrounding environment. Knowing the context of the medical data is critical in some scenarios and applications as it:

1) completes the picture of patients' medical information; and 2) allows medical staff to determine the actual need for assistance and to provide efficient medical care and the expected services. Outdoor daily activities and rehabilitation exercises rely on ambiance sensors like temperature and humidity to evaluate dehydration. The continuous monitoring of air pollutants, as an example, is vital due to its association with cardiac and pulmonary diseases. Ambiance parameters (e.g., light, sound, and temperature) are also essential to studying



VI. APPLICATION AND SERVICES

Designing healthcare-related applications and services is a primary and essential goal of building smart healthcare systems. These applications and services utilize the different medical and non-medical devices and sensors to address the different requirements and needs with respect to the expected actors (users) and the target deployment scale. There are no precise definitions and clear differences between services and applications. The two are software programs but with different goals and requirements. A service usually performs a few specialized operations and is accessed by other services as well as applications. On the other hand, an application usually performs a wider range of operations and functions targeting a whole problem and often has an interface to be accessed by users. Throughout this paper, we will use both applications and services interchangeably. In the context of healthcare systems, a wide range of applications utilizes the different medical and non-medical devices and span across the different layers of the IoMT architecture. In this section, we propose and present four main dimensions to define the scope of a healthcare-related application.



VII. CHALLENGES AND RESEARCH DIRECTIONS

Traditional healthcare systems are based on physical visits to medical facilities. These visits shape the patient's relationship with the healthcare system. In such systems, medical care providers may not monitor patients outside medical environments. Challenges arise as number of patients and aging population continues to grow. The introduction of IoT technologies in healthcare provides a new consumer-oriented relationship. Healthcare systems offer personalized and customized health services. New healthcare systems offer personalized and customized health services. Healthcare consumers use IoMT technologies to monitor their health and receive quality care. IoMT faces challenges in building secure, safe, and flexible healthcare systems. The main goal is to provide reliable and secure healthcare with low latency and power consumption. IoMT targets the challenges a traditional healthcare system may face with medical devices, sensors, applications, and services. However, compared to the traditional healthcare systems, IoMT faces different challenges in building secure, safe, accessible, flexible, efficient, and high-quality healthcare systems for the different consumers and on the different deployment scales. These challenges span the architecture's layers and the different aspects from design and implementation to physical deployment, accessibility, and usability. The main goal of addressing these challenges is to provide the required quality of service (QoS), reduce transmission delay, enable low latency, and enable low power consumption and operations for a reliable and secure healthcare system. In this section, we discuss the main challenges and critical obstacles that face smart healthcare systems.

VIII. CONCLUSION

In this paper, we provided an overview of a major subfield of IoT: the Internet of Medical Things (IoMT). The recent research efforts and advances in the field of IoMT generated a wide range of potential opportunities, devices, and services for the field of healthcare along with related subfields like mobile Health (mHealth), digital or electronic Health (eHealth), and personal healthcare. Many survey papers in the literature focused on similar points; however, up to our knowledge, this is the first paper to present taxonomies and classifications for a set of IoMT essential topics. The presented taxonomies and classifications provide a deeper understanding of the healthcare systems' landscape to address different requirements and demands. The overview presented a set of classifications to discuss the different roles and users along with the deployment scales of the different healthcare systems. The deployment scales range from personal to widescale connected healthcare systems. The overview also discusses the n-tier architecture of IoMT, and then presents a set of taxonomies and classifications on the different medical



devices used in healthcare systems as well as non-medical devices used to provide context-aware information about the surrounding environment. The paper then concludes the overview by presenting the different healthcare-related applications and services, a comparison between traditional and smart healthcare systems, and the different obstacles and challenges in the field of IoMT to guide the development of new services and devices.

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