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Everything You Wanted to Know About Smart Health Care

Evaluating the different technologies and components of the Internet of Things for better health.

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THE INTERNET-OF-THINGS (IoT) has taken over the business spectrum, and its applications vary widely from agriculture and health care to transportation. A hospital environment can be very stressful, especially for senior citizens and children. With the ever-increasing world population, the conventional patient–doctor appointment has lost its effectiveness. Hence, smart health care becomes very important. Smart health care can be implemented at all levels, starting from temperature monitoring for babies to tracking vital signs in the elderly.

The complexity and cost of implementation varies based on the required precision of the individual devices, functionalities, and sophistication of the application for which they are used. Smart health care also falls under vertical areas such as very-large-scale integration, embedded systems, big data, machine learning, cloud computing, and artificial intelligence. This article discusses the importance, requirements, and applications of smart health care along with the current industry trends and products. It gives a deeper insight about the different platforms across which more research can be pursued in this dynamic domain.

OBJECTIVES AND CLASSIFICATIONS FOR SMART HEALTH CARE

Traditional health care is unable to accommodate everyone's needs due to the tremendous increase in population. Despite having an excellent infrastructure and cutting-edge technologies, medical services are not approachable or affordable to everyone. One of the goals of smart health care is to help users by educating them about their medical status and keeping them health aware. Smart health care empowers users to self-manage some emergency situations [1]. It provides an emphasis on improving the quality and experience of the user. Smart health care helps in utilizing available resources to their maximum potential. It aids in remote monitoring of patients and in reducing the cost of the treatment for the user. It also helps medical practitioners to extend their services without any geographical barriers. With an increasing trend toward smart cities, an effective smart health-care system assures healthy living for its citizens.

Connected health, in general, refers to any digital health-care solution that can operate remotely, with additional components of continuous health monitoring, emergency detection and can alarm capabilities. Connected health mainly focuses on the mission to improve the quality and efficiency of health care by enabling self-care and complementing it with remote care. It has its origin in the era of telemedicine, where users are educated about their health and are given feedback whenever required. While smart health care refers to solutions that can operate completely autonomously, connected health care offers approaches that provide users with

feedback from clinicians. The most important classification, which redefines the economy of smart health care, is the end-user market. Depending on whether the health-care network is implemented for individuals or hospitals, the cost, power, and architecture varies widely.

Figure 1 shows the broad classification of the smart health-care market based on the services, medical devices, technologies used, applications, system management, and end users. Connectivity technologies that are used play a vital role in expanding the applications for which the health-care system is designed. The efficient integration of small devices through wireless technologies can help in implementing remote health monitoring through the Internet of Things (IoT) [2]. If a personalized monitoring device such as a wrist band is used, a Bluetooth module, Internet protocol version 6 (IPv6) over low-power wireless personal area networks (6LoWPAN), or radio-frequency identification (RFID) can be used to connect the device to the Internet. But in a hospital scenario where a health-care network is managed, Wi-Fi and ground cables are required to maintain constant Internet connectivity and support heavy data traffic.

The medical devices used to implement smart health care can be classified as on-body sensors or stationary medical devices. On-body sensors are usually biosensors that are attached to the human body for physiological monitoring. These sensors can be further classified into in vitro and in vivo sensors. In vitro sensors are externally attached to the human body and help in reducing the involvement of lab or hospital facilities in health care. In vivo sensors are implantable devices that are placed inside the body after fulfilling the regulations and standards on sterilization.

SMART HEALTH-CARE ARCHITECTURES: REQUIREMENTS, COMPONENTS, AND CHARACTERISTICS

Requirements of smart health care can be broadly classified into functional requirements and nonfunctional requirements,

as shown in Figure 2. Functional requirements address specific demands of a smart health-care architecture. For example, if a temperature-monitoring system is deployed, based on the application for which it is used, the range of operation of the thermistor/thermometer, data collection mechanism, and frequency of operation might vary. Hence, functional requirements are specific to each component applied in that health-care system based on their application.

On the other hand, nonfunctional requirements are not very specific. Nonfunctional requirements refer to attributes based on which the quality of the health-care system can be determined. On a broader perspective, nonfunctional requirements of smart health care can be classified into performance requirements and ethical requirements. Due to the large number of verticals involved in designing a complete smart health-care system, performance specifications can be further classified into software and hardware requirements. The imperative criteria for an efficient smart health-care system are

- ▼ low power
- ▼ small form factor
- ▼ system reliability
- ▼ quality of service
- ▼ enriched user experience
- ▼ higher efficiency
- ▼ ability to interoperate across different platforms
- ▼ ease of deployment
- ▼ popularity of the smart health-care system to offer continuous support
- ▼ scalability of the system to upgrade to newer versions and technologies
- ▼ ample connectivity.

Essentially, the very prime motive of designing smart health care is to ensure prompt medical service. In advanced applications, along with these requirements, the system also needs to have ambient intelligence to improve the quality of service.

Perspectives of smart health care widely vary among researchers and industries based on the chosen goal to be

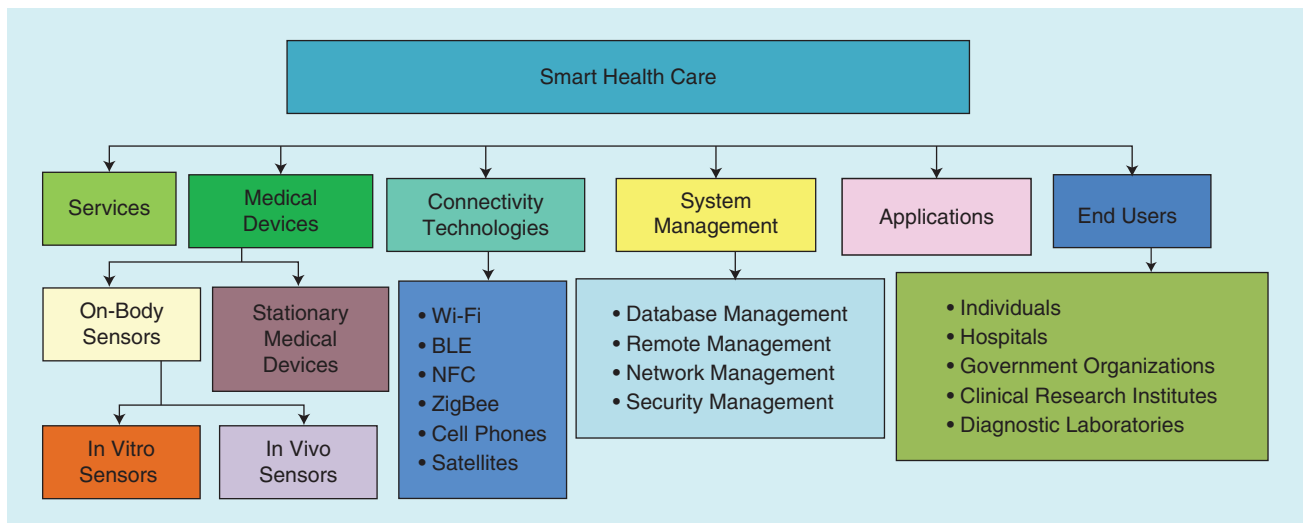


FIGURE 1. A classification of smart health care. BLE: Bluetooth Low Energy; NFC: near-field communications.

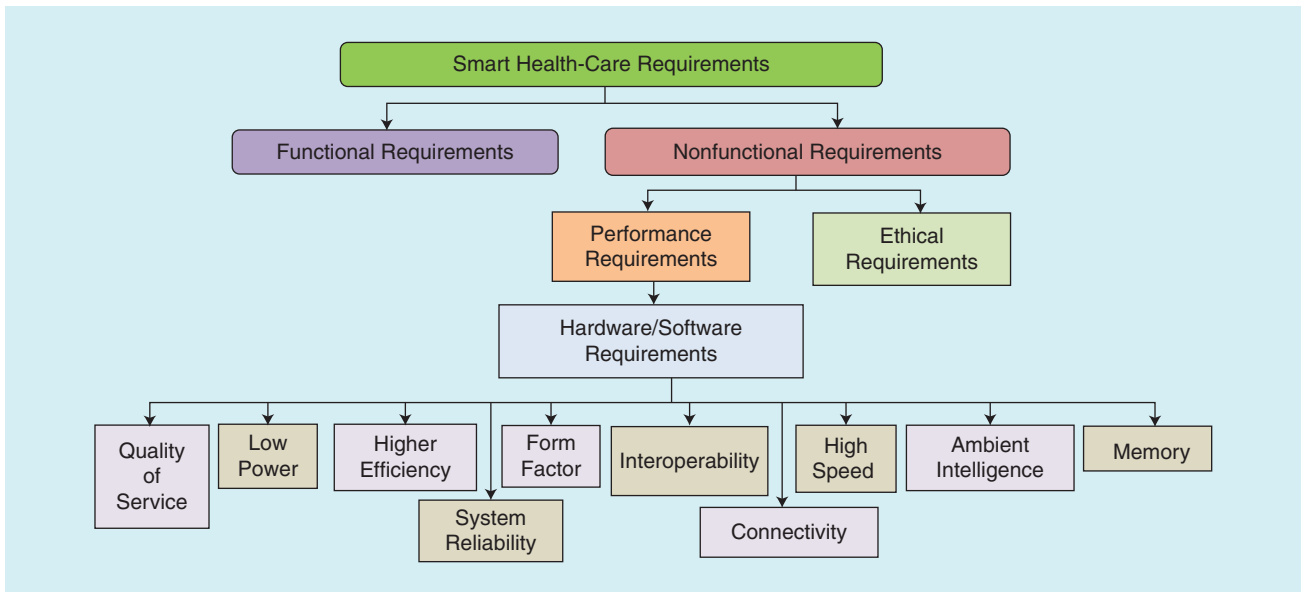


FIGURE 2. The requirements in smart health care.

achieved. Components of the smart health-care system can be classified based on the sensors or actuators, computing devices, data-storage elements, and networking components. A sensor is an analytical device that combines with a biological element that creates a recognition of events [3]. Sensors or actuators vary based on the monitoring systems.

Temperature sensors, electrocardiogram (ECG), blood pressure, blood glucose, electromyogram, heart rate, oxygen saturation, gyroscope, motion sensors, and accelerometers are the common sensors used in smart health care. Computing devices deployed in the present era range from smartphones, tablets, and personal digital assistants to complex and advanced devices such as super computers and servers. Memory plays a very important role in smart health care, since storing the information is the most important function of these systems.

Data-storage components in the smart health-care network cover a broader spectrum, including embedded memory on

the sensing devices and large servers that are used to handle big-data analytics. Networking components vary from link sensors to routers and base stations. Depending on the severity of the problem addressed, the sophistication of the components varies. Wireless technologies are the backbone of a smart health-care network. Different wireless technologies such as Wi-Fi, Bluetooth, 6LoWPAN, and RFID, as shown in Figure 3, play vital roles in exchanging the information among different physical elements that are configured to form the health-care network.

The most important characteristics required for a smart health-care system are shown in Figure 4, and they can be broadly classified based on three categories: app oriented, things oriented, and semantics oriented. App-oriented architectures need to ensure a reliable transmission between the applications in smart phones and the sensors, establish a personalized network between the sensors and the user's computing

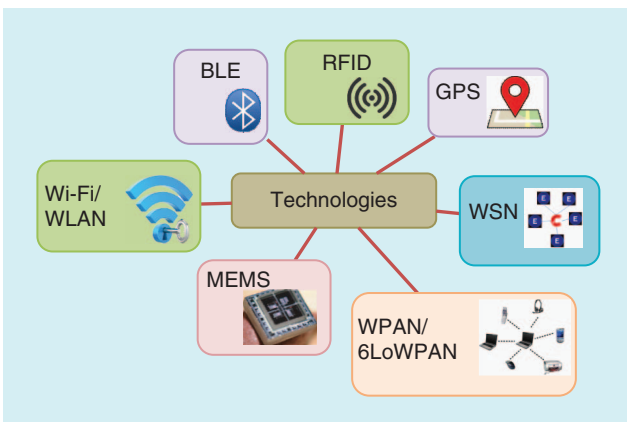


FIGURE 3. The different technologies used to deploy smart health care. GPS: global positioning system; WLAN: wireless local area network; WSN: wireless sensor networks; MEMS: microelectromechanical systems; WPAN: wireless personal area network.

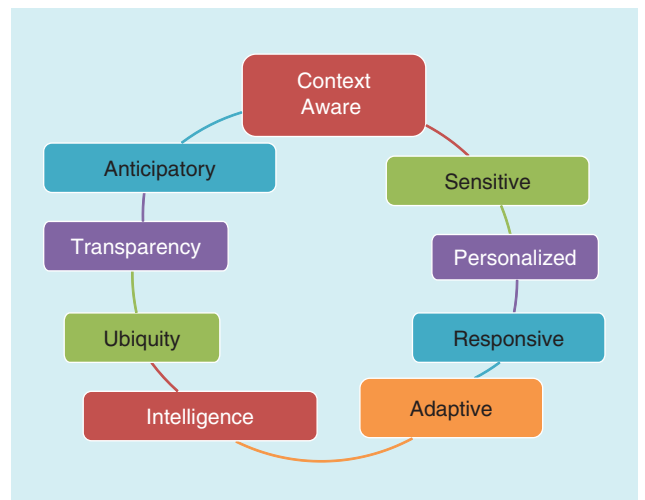


FIGURE 4. The characteristics of smart health care.



FIGURE 5. The attributes of smart health care.

device, and secure the information. Things-oriented architectures need to be adaptive based on the application, real-time monitoring, on-time delivery, higher sensitivity, maintain higher efficiency at lower power dissipation, and embark on intelligent processing. Semantic-oriented systems should be able to develop behavioral patterns based on the previously acquired information, process natural-language processing techniques to enrich user experience, and have ubiquitous computing capabilities [4], [5].

In addition, other significant characteristics include heterogeneous computing, spontaneous interaction across all of the elements in the network, location-aware computing, dynamic networks that can accommodate a large number of devices as required, and resource constrained computing with higher efficiency.

SMART HEALTH-CARE NETWORKS: CONFIGURATION, ORGANIZATION, AND FRAMEWORK

Wireless sensor networks (WSNs) were the initial research effort for the IoT. Using WSNs in different applications led to efficient architectures for health-care applications [6]. There are many dimensions to the architectures and platforms used to deploy smart health care. Research in health-care networks can be categorized into three major dimensions: configuration, organization, and framework. *Health-care configuration* refers to the assembly of different physical elements in appropriate applications that can be used to address key issues. By placing the right sensors/actuators in environments, heterogeneous computing grids can be set up to use such configurations in seamless health-care computing environments [7].

On the other hand, the organization groups the specifications of the health-care physical elements along with the hierarchy of the design. Smart health-care architectures need to

be interoperable across different technologies. For example, the sensors used in the body would communicate among one another through a personal-area network or body-area network. This information would be transferred to a smartphone through a Bluetooth or Wi-Fi technology and will be further processed across the network through IPv6 [8]. Thus, organization helps in discussing the working principles and techniques involved in the network architectures. Research on exploring big-data techniques in health-care services, using cloud-assistive architectures and integrating multiple technologies to assure quality of service, has been constantly gaining more attention from researchers worldwide [9], [10].

The framework for a smart health-care architecture includes the libraries and environments in which it is used. Health-care platforms can be widely classified into network platforms, computing platforms, and service platforms. *Network platforms* refer to the libraries used to interconnect different architectures. Computing platforms can widely vary based on the technologies used. Due to diversity in the application environments of smart health-care networks, the frameworks for computing platforms are usually an intersection of wider concepts such as database management, optimization, human-machine interface, and machine-learning algorithms [11]. A *service platform* refers to the support layer that acts as a middleware between the technologies and the users.

This support layer can either be agents or call-center representatives or, in advanced applications, robots or algorithms with cognitive and behavioral perspectives. A framework for processing health information using the IoT has been proposed in [12]. Figure 5 shows the various attributes that are to be considered before modeling the frameworks, organizations, and platforms, specifically for smart health care.

SMART HEALTH CARE: SERVICES AND APPLICATIONS

From the health-care perspective, services can vary from push notifications on a health-care mobile app to cross-connectivity protocols required for linked devices, as shown in Figure 6. Modifications in already existing systems might help to integrate these features into smart health care. In addition to being secure and fast, these services should also be easily accessible to the patient. Context-aware products rely on the current location of the user to provide additional services. This could be employed in mobile or wearable sensors. For example, based on the information received from the sensor, the walking trail can be tracked to analyze the number of miles covered. In some cases where the user needs additional help to call an ambulance or a paramedic, the required assistance can be provided based on the geographical data obtained from the user. Embedded context predictions provide a framework with appropriate mechanisms that can be used to build context-aware systems, which can operate in ubiquitous environments [13].

Semantic processing is a behavior of the human brain to understand colors, patterns, and objects based on the context that helps in deeper processing. For example, when a familiar word is heard, the brain translates its meaning based on

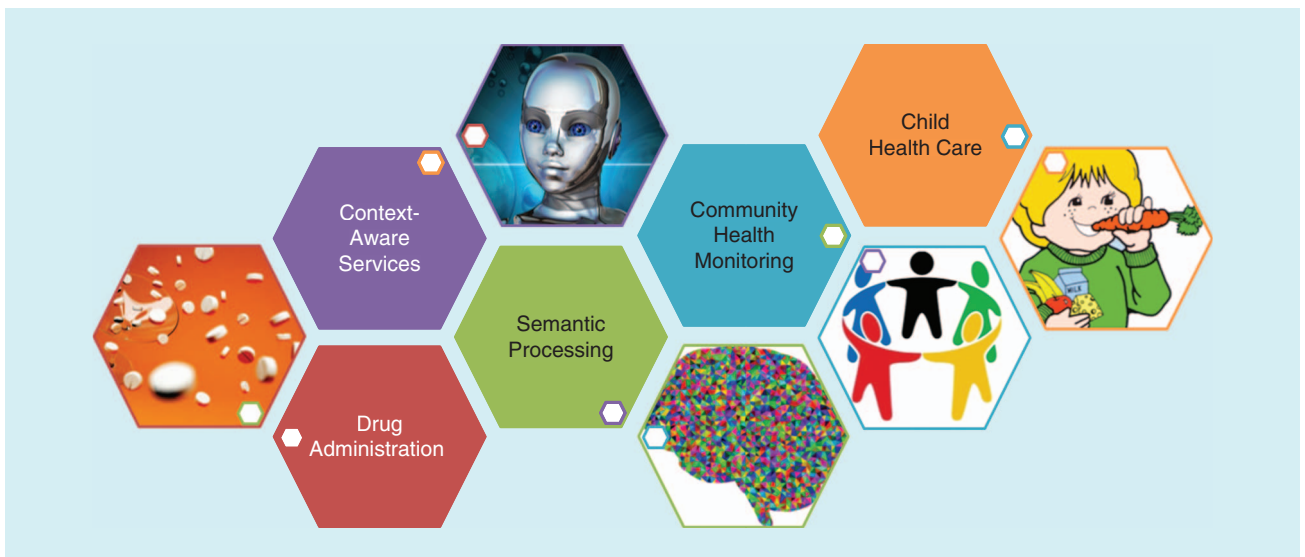


FIGURE 6. The services available through smart health care.

semantic memory, which involves common knowledge. In smart health care, the use of semantics and ontologies has led to a service called *semantic medical access*. This assists in processing ubiquitous data that is available in the medical cloud and providing emergency services by integrating these features [14], [15].

Wireless body area networks (WBANs) are the basic components of community health-care monitoring, which helps in creating a network around a local area or neighborhood. Multiple WBANs constitute these health-care networks, which can collectively form a cooperative system. A community health-care network might include schools, residential areas, and hospitals, which can help in providing energy-efficient monitoring in a rural area.

Figure 7 demonstrates the applications of smart health care, which start at fitness monitoring on one end of the spectrum and progress to vital-sign monitoring in hospitals. Based on the application, the quality of health-care systems is improved with additional machine-learning algorithms and artificial intelligence. The wide range of applications can be grouped into interbody sensing, intrabody sensing, and environmental management [16], [17].

Intrabody sensing applications refer to those that help in monitoring multiple vital signs. For example, in fitness tracking through a smart watch, along with parameters such as the number of calories burned, steps taken, and active hours, it is also important to track the pH sensitivity of the sweat, oxygen intake of the body, and heart-rate monitoring.

To meet the competitive smart health-care market, companies are trying to incorporate as many sensors as possible to offer ubiquitous monitoring. Heart-rate and remote-ECG tracking through wearables have offered cost-

effective solutions in smart health care [18]. In smart watches, it is also necessary to review the previous monitoring analysis. Algorithms that incorporate cognitive and behavioral processes are being deployed in these sensors to discover patterns. Such patterns from various users can help researchers and industries to develop models that can be deployed to improve treatments for assorted conditions. Examples for this group of applications can be again found in fitness monitoring through smart watches where, with the emergence of virtual reality, these applications are used to set a walking or hiking trail.

Along with providing features such as localization and tracking, they help in monitoring the fitness of the user. Creating sensitive and responsive digital environments has made the smart health-care domain a multidisciplinary and interdisciplinary research area [19]. Mobile applications that are associated with wearables learn from the users the reasons regarding their intentions of using the device and help them plan in achieving their fitness goals [20]. Environmental management applications help in establishing communication between the hospital and the patient. Monitoring the first responder's health status in an endemic or epidemic outbreak, getting ambulance

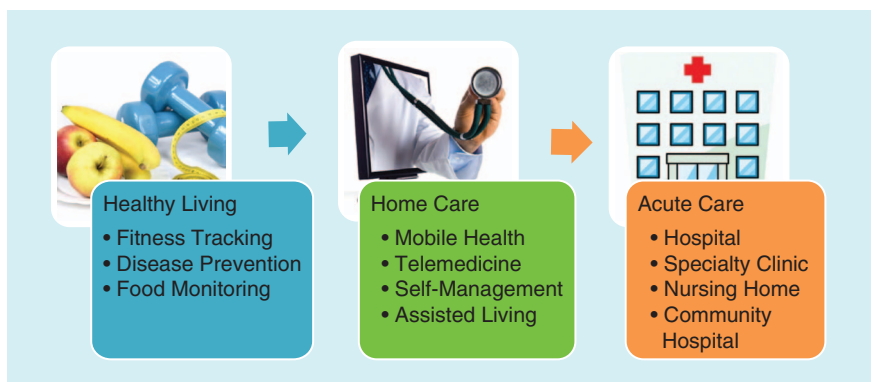


FIGURE 7. The application domains in smart health care.



Frost and Sullivan predict smart health-care market value to reach US\$348.5 billion by 2025.

assistance in case of an emergency, developing evacuation schemes for disaster management in hospitals, maintaining active databases to ensure the correct delivery of organs/blood to the people in need, and providing accurate billing of surgical procedures through RFID tags are some of the significant applications in environmental management.

THE IoT IN SMART HEALTH CARE

The IoT is a combination of ubiquitous communication, connectivity, and computing along with ambient intelligence. It refers to a cyberphysical paradigm where all of the real-world components can stay connected. The IoT gives users the ability to plan each day, and it integrates real physical-world elements such as electronic devices, smartphones, and tablets that can communicate both physically and wirelessly. The IoT helps in managing virtually any number of devices. It aims to extend the benefits of the Internet such as remote access, data sharing, and connectivity to various other application domains including health care, transportation, parking activities, agriculture, and surveillance [21].

With enormous benefits and attributes such as identification, location, sensing, and connectivity attached to the IoT, it is the integral component of smart health care, as shown in Figure 8. In implementing a smart health-care system, the IoT can be broadly implemented in a wide range starting from calibrating medical equipment to a personalized monitoring system. The IoT plays a significant role in health-care applications, from managing chronic diseases at one end of the spectrum to monitoring day-to-day physical activities that could help in maintaining an individual's fitness goals [22].

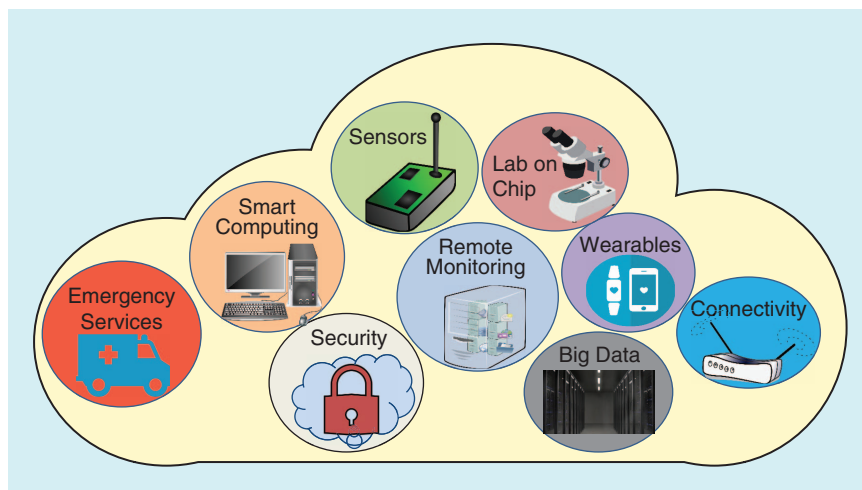


FIGURE 8. The IoT in smart health care.

The IoT can be used to track the process of production and trace medical equipment deliveries. Furthermore, IoT-based architectures can be used to collect medical information from the user. The IoT functions as a bridge between the doctor and the patient by providing remote access, which can help the doctor continuously monitor the patient and give remote consultations. Combining sensors, actuators, micro-controllers, processors, and cloud computing, the IoT assists in obtaining accurate results and makes health care attainable to everyone.

Using the IoT in health care has led researchers worldwide to design promising frameworks and technologies that can provide at-ease medical assistance to everyone. In addition to enriching the user experience, the IoT also urges the industry to become automated, providing more research across different cross-platforms. The integral components of the IoT in smart health care are a sensor/actuator, a local area network or in some case a body area network, the Internet, and the cloud. Depending on the application and requirements of the specific health-care system, the specifications of each of these four integral components can vary widely.

BIG DATA AND ARTIFICIAL INTELLIGENCE IN SMART HEALTH CARE

In health-care data, three main challenges need to be addressed: quantity, variety, and velocity. There are enormous applications and services that require the storage of patient information, and each time a service is used or the patient visits the health-care facility, the information needs to be updated. Currently, with the increase in smart sensors, social networks, and web services, mobile devices are estimated to generate more than 2.5 quintillion bytes per day [1]. Hence, traditional databases and data storage mechanisms might not prove efficient in handling such large amounts of data.

To address these challenges, a mix of nonrelational and relational databases needs to be used to store clinical data that are present in electronic formats. Data collected by the smart health-care systems must be consistent. A high level of semi-structured databases enabling a multitude of queries are required. Cloud computing technology makes on-demand services scalable to large amounts of users. It has many features such as virtualization, scalability, pay-per-use, and multitenancy. Cloud-assistive treatments can help medical professionals offer services to users irrespective of the geographical location. Combining big-data techniques with cloud computing helps in achieving better analysis.

Assisted living, especially for the elderly, has been a primary research area involving artificial intelligence in smart health care. A system with ambient intelligence can increase the quality of life and ensure the safety of elderly

people. Along with the benefits it offers for the individual, it also helps in providing higher effectiveness of limited resources and improves the living standards.

SMART HEALTH CARE: INDUSTRY TRENDS AND PRODUCTS

The scope of smart health-care products has expanded its horizons and has been predicted by Frost and Sullivan to be a US\$348.5 billion market by 2025. With a large amount of ongoing research and a scope to address new issues, entrepreneurs and well-established industries are competing with remarkable creativity. Smart syringes, pills, and RFID cabinets are gaining everyone’s interest in the smart health-care domain. RFID has been widely used for infection safety, radiology, and the control of infections such as tuberculosis [23]. Electronic health records are the most significant products of smart health care that have given a new perspective for addressing big-data issues. These products fall across different verticals such as health data and storage, monitoring and treatment, and inventory management.

In the present digital-health revolution, Intel is leading the way with its foundational background in the industry [24]. The company is constantly coming up with innovative technologies for data analytics, assistive technology, and improving the home environment for the elderly population. IBM’s Watson, an artificially intelligent computer system, can more efficiently study the content of the patient’s health record and relevant medical information to provide better health-care models. IBM has partnered with Apple, Johnson & Johnson, and Medtronic to continue their digital-health research on a large scale. Google has a life-sciences division dedicated to developing and researching new technologies in digital health. Qualcomm Life helps in capturing the medical device data and delivers it to the nearby database partner through a wireless medical device and secures the information.

This platform offered by Qualcomm provides a high range of system interoperability and security. Microsoft’s connected health platform helps in offering digital health services through desktop frameworks. Microsoft Lync is used by doctor’s to offer medical services to patients in rural areas. Samsung has a US\$50 million investment in digital health through its digital health initiative, which is a collaboration of smart sensors, algorithms, and data-processing techniques through open-source hardware and software platforms. Apple has an open-source framework, ResearchKit, which aids researchers in developing apps that can facilitate medical research.

From a retail perspective, Amazon offers a unified health-care platform where the users can access information, availability of the latest products, health insurance, and on-demand services. Wearables, especially in the form of smart watches or bands, have been revolutionizing the market. Notable products include the Fitbit, Moov, Proteus, Pebble Time, Withings AliveCor Health monitor, and Beddit. Significant among the health-care products are smart watches, which are becoming more ubiquitous, as shown in Figure 9. The projected annualized rate is expected to reach 70 million

units at a growth of 18% by 2021. Apple is expected to have a hold of the larger share in the market, but Android devices are continuously emerging. Apple’s iWatch offers a package of built-in global positioning system and heart rate sensors with a fast dual-core processor.

SMART HEALTH CARE: CHALLENGES, VULNERABILITIES, AND OPPORTUNITIES

Although smart health care helps in providing better health care worldwide, it also becomes more vulnerable to threats. Due to the dynamic nature and smaller form factors, the security requirements in smart health-care systems vary from the traditional security techniques [25]. Figure 10 shows the key security requirements or challenges in maintaining a secured smart health-care system, because health-care networks contain personal information that can be easily manipulated. To reduce the cost of the design, the processors used in smart health-care systems are low-speed and have low on-device memory, which cannot accommodate additional security mechanisms [26].

Health-care devices are mobile, which leads the user to connect to different networks such as those in the home, office,



FIGURE 9. The features of a smart watch.

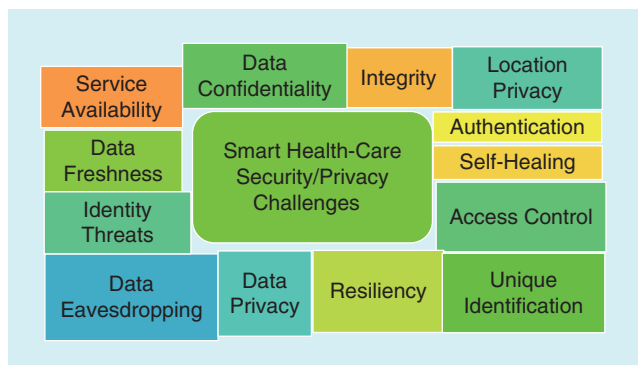


FIGURE 10. The security requirements of smart health care.



The vision and long-term success of this dynamically growing industry lies in the synergy of researchers, health-care professionals, and the public.

and in public. This increases the chance of attacks on the device. Due to the growth in the number of IoT devices in the health-care network, it is a very challenging task for developers to provide dynamic security updates or a sound solution for multiprotocol information. Smart health-care systems are vulnerable for security attacks at various levels of the system. To maintain data freshness in the health-care network, the passwords and keys need to be updated frequently. Attacks targeting data transmitted in the network can include interruption of the service availability, modification of original data, forging messages, and replaying the messages to disrupt the flow of data and create a false impression. Attacks can also tamper with the hardware, i.e., the interconnected physical devices or the software, i.e., the operating systems and applications.

A specific example of tampering with a personal medical device, an insulin delivery system, is now discussed [27]. In this system, a personal digital device (such as a cell phone), an insulin pump, a continuous glucose sensor, and a remote-con-

trol device are all connected through a wireless Personal Area Network (PAN), as illustrated in Figure 11(a). Possible security attacks on this system can be active, passive, or both, as depicted in Figure 11(b). An example of a passive attack is to intercept the communications in the PAN between the remote control to the insulin pump with the objective of reverse engineering the communication protocol. On the other hand, an active attack is to use this reverse-engineered protocol to attach an impersonating remote-control device to the insulin pump. This allows the attacker full control of the insulin pump with potentially lethal consequences for the patient. Two different defenses for these attacks are rolling code protocols, and body-coupled communication. The rolling code encoder, as presented in Figure 11(c), generates rolling codes which avoids the system's dependency on a fixed device PIN every time. Since the rolling sequence is random (but known to the receiver and synchronized with it), a security breach is nearly impossible. This approach is equivalent to the use of one-time pad cryptography, universally considered as the strongest possible cryptographic protocol. As illustrated in Figure 11(d), the data are decrypted in the insulin pump using the shared key. The decrypted sequence number is then compared to the receiver's counter. If the difference between the two is within a certain range, to allow for small timing differences, then the insulin system validates the received control code, synchronizes the sequence counter, and performs its task. On the other hand, a security model based on body-coupled communication as defense reduces the signal strength, which makes passive attacks

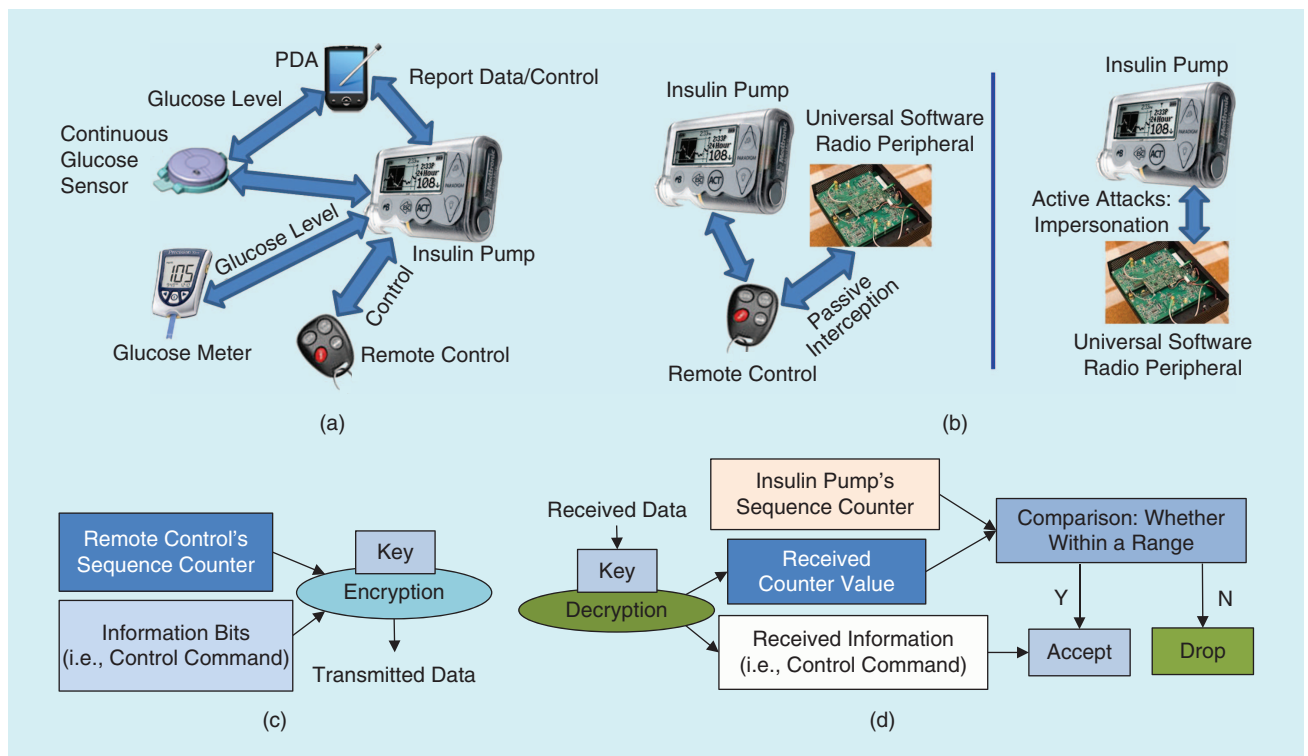


FIGURE 11. A specific example of security attack on a medical device. (a) An insulin delivery system, (b) passive and active security attacks on the insulin delivery system, (c) the rolling-code encoder in the remote control, and (d) the rolling-code decoder in the insulin pump.

very difficult unless the attacker is in physical contact with the patient, which is normally not possible.

Confidentiality is a key security requirement in smart health care. Data, which include private information about the user, needs to be shared with only authorized users, and only authorized nodes and users should have access to the services or resources. Consequently, at least a two-level authentication process needs to be implemented to ensure the identity of the peer.

Integrity needs to be maintained in the health-care network, assuring the users that the data that are transmitted and received are not altered or compromised. If the data of the interconnected device are breached, then the security system should ensure that there is no attack on the information or device in the health-care network. The interconnected devices need to be self-healing to some degree, which ensures that if a device fails, it has minimum impact on the health-care network.

NANOSMART HEALTH CARE

Consumer electronics empowered with the latest wireless technologies and seamless architectures help in improving one's quality of life through smart health care. One such example is the pill camera. Endoscopy or colonoscopy are procedures that are generally used by doctors for monitoring the internal organs for any gastrointestinal infections [28]. It is generally prescribed for patients with colon cancer, irritable bowel syndrome, stomach ulcers, tumors, and piles. These procedures are not just expensive; they also make the patient uncomfortable, as a long tube is put inside him/her.

A pill camera makes the job easier for both the patient and the doctor. It is as simple as swallowing a pill and getting high-resolution pictures of the internal organs. Figure 12 shows the overall architecture of the pill camera. It is a light device with image sensors to capture the footage and a radio-frequency transmitter and antenna to wirelessly send this acquired data in real time to the data recorder, which is a waist belt or a shoulder strap. The magnetic strips help in activating the camera when required. The light-emitting diodes (LEDs) are timed in such a way that when the camera reaches the appropriate position, they are turned on to monitor the exact location and obtain better images. This camera is either powered by a small battery or through induction charging with the help of the data-recorder strap. As there is no onboard memory in the pill camera, it is very light to navigate through the intestine. Although pill cameras have been around for almost a decade, the latest advancements can produce over 800,000 images in 8 h, with the camera turning approximately 60° every 12 s.

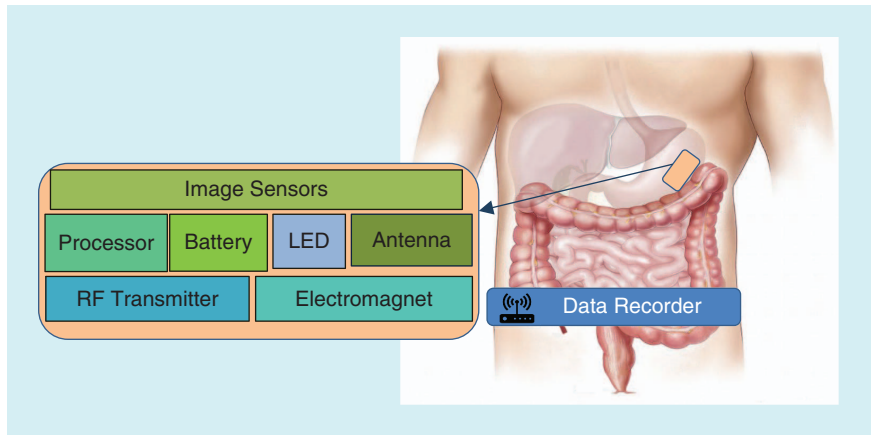


FIGURE 12. A pill camera.

CONCLUSION AND FUTURE DIRECTIONS

This article provided an extensive survey on the current research trends along with the challenges and opportunities available in smart health care. Needleless and cost-effective health-care solutions have always been in great demand. With enormous funding and increasing attention aimed toward the smart health-care domain, there are numerous products and applications available for users. As smart health care has multidimensional applications, it offers a large scope for researchers to constantly innovate new products and improve the already existing architectures.

The transition toward smart health-care services is a slow and steady process. This is mainly because health-care professionals need to be constantly educated and convinced to adapt to the digital era. By bridging the gap between researchers and health-care professionals, more research problems and diseases can be addressed and smarter lifestyles can be adapted. Although the smart health-care solutions backed by the IoT can improve revenue and increase quality of life, the benefits can be easily overshadowed if security is compromised. Additional measures need to be taken to handle threats and secure the potential information at both the customer and developer ends. Thus, the vision and long-term success of this dynamically growing industry lies in the synergy of researchers, health-care professionals, and the public.

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