Review Article

A Comprehensive Review of Architecture, Classification, Challenges, and Future of the Internet of Medical Things (IoMTs)

M. J. Sudha, S. Viveka

HELYXON Healthcare Solutions Private Limited, IIT Madras Research Park, E-Block, Module No. 9, 1st Floor, Kanagam Road, Taramani, Chennai, [1]Department of Anatomy, Azeezia Institute of Medical Sciences, Kollam, Kerala, India

Downloaded from http://journals.lww.com/mjby by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC1y0abggQZXdtwnfKZBYtws= on 12/08/2024

Abstract

Background and Objectives: The healthcare industry is fast accepting the benefits of Internet of Medical Things (IoMTs) and incorporating the services in day-to-day activity. The objective of this review was to comprehensively review the IoMTs, briefly revisit the functioning architecture, classify, list the challenges and possible solutions, and suggest the future trends among IoMTs usage and implementation. **Materials and Methods:** During April 2021, an extensive search for articles for Internet of Medical Things (IoMTs), medical devices, Internet of Things (IoTs) with biosensors either in title or in keywords was done using PubMed, ScienceDirect, Google Scholar, and Web of Science databases. Studies were categorized into two types: those evaluating the clinical outcomes of IoMTs and those evaluating the technological basis of IoMTs. **Results:** IoMT architecture was reviewed under four headings: sensors, IoT gateway/framework, machine learning, and reporting tools. IoMT classification based on place of usage (body centric IoMTs, hospital IoMTs with point of care kiosks, and ubiquitous IoMTs), based on the system-wise application (cardiovascular, renal, pulmonary, endocrine, medication) and based on outcomes (fitness-alone IoMTs, clinical grading and monitoring IoMTs, and remote patient monitoring IoMTs) is proposed. **Conclusion:** IoMTs can be classified based on the place of usage into body centric, hospital-based, and ubiquitous systems. Classification based on the body systems and sensors aids in first-hand information about the existing IoMTs. Challenges for effective implementation of IoMTs are interoperability, data privacy, security, regulatory, and infrastructural costs. The future is promising for IoMTs with robust technological improvement and effective implementation.

Keywords: Biosensors, classification criteria, Internet of Things (IoT), key challenges, medical devices

Introduction

Medical devices that can independently connect to internet and communicate with healthcare information technology constitute Internet of Medical Things (IoMTs).[1] The healthcare industry is fast accepting the benefits of IoMTs and incorporating the services in day-to-day activity. One estimate mentions that 60% of the global healthcare organizations are already making attempts to use IoMTs.[2] Even though the penetration of IoMTs is steadily increasing, there are inherent challenges in implementation, data management, and design.[3]

Technology has revolutionized the way we live on the earth. It has aided in effectively and efficiently transforming healthcare sector toward better patient care and management. Health care of the future will be digitally connected and driven by robust real-time data. Growing trends of the technological ingrowth into the individual patient monitoring, diagnosis, treatment, and rehabilitation are astonishing. Renewed interest among technology giants including Microsoft and Google in this space is fueling more innovation and interest among young minds.

Access this article online

Quick Response Code:

Website: www.medjbabylon.org

DOI: 10.4103/MJBL.MJBL_5_22

Address for correspondence: Dr. S. Viveka, Department of Anatomy, Medical Education Unit, Azeezia Institute of Medical Sciences, Kollam, Kerala, India.
E-mail: vivekabharathi@gmail.com

Submission: 10-Jan-2022 **Accepted:** 26-Jan-2022 **Published:** 29-Sep-2022

This is an open access journal, and articles are distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 License, which allows others to remix, tweak, and build upon the work non-commercially, as long as appropriate credit is given and the new creations are licensed under the identical terms.

For reprints contact: WKHLRPMedknow_reprints@wolterskluwer.com

How to cite this article: Sudha MJ, Viveka S. A comprehensive review of architecture, classification, challenges, and future of the Internet of Medical Things (IoMTs). Med J Babylon 2022;19:311-7.

Downloaded from http://journals.lww.com/mjby by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC1y0abggQZXdtwnfKZBYtws= on 12/08/2024

With the existing pressure on the medical infrastructure, under the COVID-19 pandemic, there is increased felt need for automation, remote patient monitoring, and virtual hospital environment. There are many review articles reporting Internet of Things (IoTs) in the healthcare sector.[1-4] However, it was noted that a systematic classification based on the patient-related and clinician-related outcomes is not reported. A broader classification based on point of care, sensors, and body systems shall comfort any newbie to get acquainted with IoMTs instantaneously. This, coupled with a brief overview of technology architecture, methods of connectivity, and types of sensors used, provides a broad understanding of type of functioning and potential for future use. With this background, the objective of this review was to comprehensively review the IoMTs, briefly revisit the functioning architecture, classify, list the challenges and possible solutions, and suggest the future trends among IoMTs usage and implementation.

Materials and Methods

Study source

During April 2021, an extensive search for articles for IoMTs, medical devices, IoTs with biosensors either in title or in keywords was done using PubMed, ScienceDirect, Google Scholar, SciELO, EMBASE, and Web of Science databases.

Search criteria

To include all relevant studies, a comprehensive search for all articles related to IoMTs and medical devices was carried out, and all articles with reference to IoMTs were included. The search terms were restricted IoMTs, medical devices, biosensors, and IoT sensors. Only articles in English (both originals and translations) were included in the review.

Study selection

All articles irrespective of the date of publication were included in the review. Original research and case reports were included in this study.

Data collection and data items

Studies were categorized into two types: those evaluating the clinical outcomes of IoMTs and those evaluating the technological basis of IoMTs. Data regarding the total number of cases (sides) studied, percentage of beneficial effects and improvement in patient outcomes, and any special comments either in the Results section or Conclusion section are noted.

Synthesis of results

In this review, results were broadly presented under four headings as depicted in Figure 1.

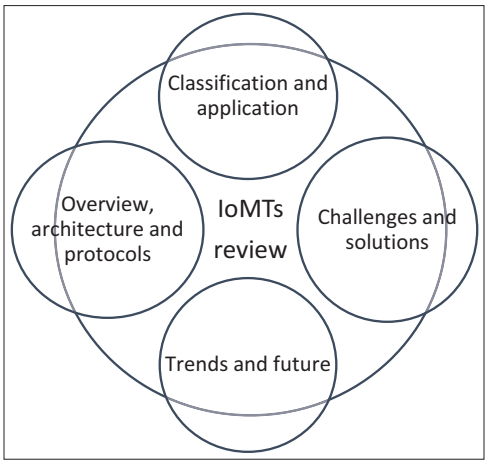

Figure 1: Schematic outline of review of IoMTs

Results

Overview, architecture, and protocols

The IoMT architecture may consist of different components and services.[4] The following are the list of IoMTs that are currently used.

- *IoT sensors*: This includes pulse-oximeter, electrocardiogram, thermometer, fluid level sensor, and sphygmomanometer. Wearable sensors[5] and implanted sensors[6] are a subset of these IoMT devices and are making a revolutionary change in fitness and individual patient care. Use of radiofrequency identification in these IoMTs is also maturing.[7]
- *IoT framework/gateway*: This provides a connectivity to the IoMT devices and services, integrates, modulates, and controls the related sensors.[8] In addition to the conventional cloud computing paradigm, fog computing infrastructure is also gaining popularity among healthcare IoT providers.[9]
- *Machine learning*: This involves applied computing and computing methodologies in allowing prediction of algorithms and execution of data.[10] The application of machine learning to medical data holds the transformation of patient risk stratification, especially in infectious diseases.[11]
- *Reporting tools*: These tools hold and store the data; batch processing and consolidation promises better reporting and management of data.[4]
- *User management*: Services can allow restrictive and compartmental grouping of users.

Generally, time-based and event-driven architectures power the processing of IoMTs. The event-driven process involves sensors transmitting data when the sensor is appropriately stimulated.[12] During time-based architecture, it sends signals at the specified time interval.[13] It can send queries to the endpoint device or sensor and collect the required data at regular and defined time intervals.[14]

Downloaded from http://journals.lww.com/mjby by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC1y0abggQZXdtwnfKZBYtws= on 12/08/2024

The process of IoMT services typically starts with IoT sensors sending data over internet to the cloud system, in which it is analyzed and interpreted and the outcomes are justified. This is conveyed both to the clinician and to the patient with an application platform and at times on a unified display setting within a product infrastructure environment [Figure 2]. Generally, constrained application protocol, message queue telemetry transport, extensible messaging and presence protocol, and advanced message queuing protocol are used to send out data from the IoT sensors to the servers.[15]

Classification and application

Based on the site of usage, Table 1 classifies IoMTs into three main categories. As the demands and training needed for effective handling and interpretation of the outcomes from IoMTs will be different based on the place of usage, this classification effectively summarizes the broader horizons of the outcomes of these devices.

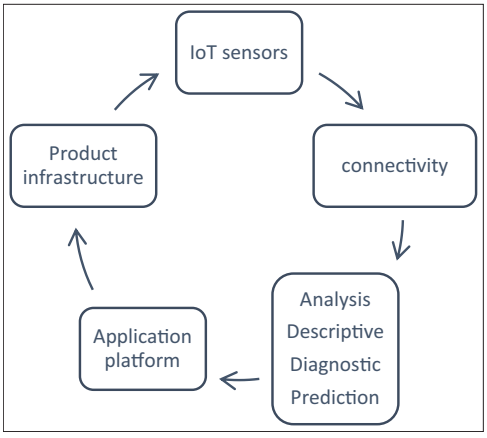

Figure 2: Schematic representation of IoMT architecture

Few IoMTs concentrate only on the fitness, and few others on the clinical grading and monitoring. Based on such outcomes, IoMT classification can be classified as fitness-alone IoMTs, clinical grading and monitoring IoMTs, and remote patient monitoring IoMTs. The devices mainly recording and interpreting heart rate, respiratory rate, ECG are fitness-alone IoMTs. Clinical grading IoMTs include those used to intermittently or continuously monitor temperature, glucose, airflow, oxygen saturation, neural and cochlear IoMTs. Remote patient monitoring IoMTs use a combination of clinical grading IoMTs with clinician or hospital within the networking loop. With such remote monitoring, meaningful and early intervention is possible, especially in the prevailing COVID-19 pandemic.

Based on their applications, IoMT classification is provided in Table 2. System-based classification aids in easy and swifter review of IoMTs available in a particular healthcare segment.

Challenges and solutions

With use of technology, there will be many intrinsic challenges. The following are the list of challenges and possible solutions for the effective use and implementation of IoMTs in health care [Table 3].

Despite the use of wide sensors, not all health parameters can be effectively detected and monitored. Tun *et al.*[48] listed 38 parameters that cannot be collected using IoT devices. This includes readings about liver function test, thyroid function test, screening of sepsis, certain infections such as malaria and tuberculosis, which cannot be detected so far with available technology. Similarly, imaging technology, even though machine learning has made significant incremental progress, falls short of arrival effective diagnosis at the individual patient level. Many

Table 1: Classification of IoMTs based on the place of usage

Place of use	Examples of devices and services
Body centric IoMTs	Wearable IoTs[16]
	• Body position—patient position sensor by Arduino[17]
	• ECG-AD8232 ECG Module[18]
	• Airflow—sleep apnea devices[19]
	• Body temperature—wireless IR temperature sensor devices[20,21]
	• Blood pressure—MPX5050DP and NodeMCU sensors[22]
	• Glucose—continuous glucose monitoring with NodeMCU[23]
	• Galvanic skin sensors—stress sensor using ZigBee[24]
	• Oxygen saturation—continuous monitoring with pulse oximeter,[25,26] implantable IoTs[27]
	• Chemical sensors,[28] glucose,[29] and oxygen sensors for diabetics, neural implants,[30] and cochlear implants[31]
Hospital centric	• IOT-based smart hospital—Lei Yu[32]
IoMTs and point of care kiosks	• Mobile electronic medical healthcare system based on IOT—Singh *et al.*[33]
	• IoT-based medical healthcare—Chandel *et al.*[34]
	• Medical bot—Michael Fischer[35]
	• Medical Nursing System—Huang and Cheng[36]
Ubiquitous IoMTs	• Ubiquitous Medical Healthcare Monitor System (UbiHeld) for chronic diseased patient—Ghose *et al.*[37]

Downloaded from http://journals.lww.com/mjby by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC1y0abggQZXdtwnfKZBYtws= on 12/08/2024

aspects of human behavioral traits, including depression, anger, hallucination, hypotonia, and similar neurological manifestations, cannot be detected with IoMTs.

There are many IoMTs lacking critical data to effectively implement in clinical setup. Unlike other IoTs, these medical devices have to be convincingly shown to be of better value than the conventional methods before, which can be used in the clinical setup. IoMTs regarding ECG, urine output, fluid balance, and postural instability need further testing before it can be widely accepted alternatives.[48]

As IoMT devices generate a huge amount of data in varied formats, data compilation and interoperability are a major issue. IoMTs inherently depend on network for exchange of data. Use of fog and edge computing decreases the network traffic and results in effective usage of resources overcoming bandwidth limitations.[9,49] Interwoven device operability within the fog and edge environment can bring about collaborative and distributed framework enabling horizontal integration. To achieve this pyramid resource management with interoperability stack, integrated resource managers are proposed.[50]

Healthcare data are significant and confidential information about one's body and health condition. Privacy and security of healthcare data are not only important from ethics point of view but also important regarding data theft. Stealing data, manipulation, and damaging data lead to significant financial losses and emotional turbulence. Well-designed access control, physical security of devices, awareness about the security, encrypted data transfer in terms of https, firewalls, ingress/egress filtering structures, and internet protocol security can improve privacy and security of healthcare data.[51]

All medical devices have to undergo device and process validation. There are regulatory policies overlooking such validation process. In India, medical device validation is under "The Medical Device Rules, 2017 (MDR)."[52] There are guidelines for importing, manufacturing, and selling medical devices. In addition, MDR classifies the devices under four categories according to the risk involved from low, moderate, moderate-high, and high. From time-to-time, the health ministry is updating new devices notifications. There are some relaxations on regulatory compliance in the view of COVID-19 pandemic as well.[53]

With increase in healthcare demand, especially during the COVID-19 pandemic, the infrastructure spending is also increasing. To meet the demands of IoMTs incorporation in medical services, the public–private partnership model may be followed at the initial phases of implementation. Domestic manufacturing of the components of IoMTs significantly reduces the implantation expenditure.[54]

Trends and future IoMTs

Reinvent, reposition, reconfigure is the mantra proposed by van den Heuvel *et al*., for medical devices of 2030[55]: reinvent in connection with the existing patients, customers, and consumers; reposition and realign the devices in line with new technology and newer markets; recognize the companies with significant value addition to healthcare management. These are the key callouts for improving IoMTs for the future.

IoMTs quest for inclusion of the health parameters hitherto not routinely sensed shall continue and result in newer arenas of device penetration. Wide acceptance purely driven by efficient clinical judgment and clinical outcomes shall pave inroads for these devices deep with

Table 2: Classification of IoMTs based on the system-wise application

System	Examples of devices and services
Cardiovascular	• Remotely ECG monitoring system based on cloud—Chavan *et al.*[38]
	• Inexpensive Cardiac Arrhythmia Management (ICarMa) System—Puri *et al.*[39]
	• Apache HBase and Apache Mahout for prediction of heart diseases in a community—Kumar and Devi Gandhi[40]
Renal	• IOT-based kidney abnormality detection system using ultrasound imaging—Divya Krishna *et al.*[41]
Nervous system	• Decision-making and home-based medical health monitoring system for neurological disabled patients—Chiuchisan and Geman[42]
	• Autistic patient monitoring medical healthcare system using IOT—Sundhara Kumar and Bairavi[43]
Endocrine	• Diabetes therapy management in ambient-assisted living—Jara *et al.*[44]
Rehabilitation	• Smart Rehabilitation System—Fan *et al.*[45]
Sleep	• Monitoring of obstructive sleep apnea diseased patient—Kumar[46]
Medication	• Smart pills, RFID technology-enabled drug monitoring—Laranjo *et al.*[47]

Table 3: Tabulation of challenges and solutions for IoMTs

Challenges	Solution
Interoperability	Interoperability data stacks with integrated managers in fog and edge framework
Data privacy and security	Well-designed access control, physical security of devices, awareness about the security, encrypted data transfer
Regulatory challenges	Time-to-time amendment of Medical Drug Rules (MDR), 2017
Infrastructure cost	Incentivize infrastructure development through PPP mode

Downloaded from http://journals.lww.com/mjby by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC1y0abggQZXdtwnfKZBYtws= on 12/08/2024

the healthcare management. Increased investments and spending on the research development of affordable technologies by tech-giants improves the industry interest. Many start-ups will target exclusive IoMT sector for their operations and services.

Use of extremely low-strength electromagnetic wave in the early detection of breast cancer shall change the way cancer is perceived and managed.[56,57] Biosensors capable of detecting certain viral infections including Ebola, Corona, and Zika virus can bring a big change in the management of pandemics.[58] Use of extracellular matrix-based, composite, and stimulus responsive material is changing the way 3D bioprinting of human tissue was earlier perceived.[59] NASA Smart Probe using neural networks and multiple microsensors is aiding differentiating between normal cells and cancer cells.[60] This shall change the detection of normal margin during tumor resection, leading to reduced relapses. Use of electromagnetic acoustic techniques is revolutionizing the blood flowmetry, thermometry, and dosimetry during cancer radiotherapy, sensing the saturation pressure of oxygen in the blood.[61] Perfluorocarbon nanoparticles (NPs), cerium oxide NPs, and platinum NPs cross blood–brain barrier and aid in diagnosis and treating of stroke.[62]

Discussion

IoMTs have improved efficiency. As the devices and services use built-in sensors and technology, the outcomes are accurate and consume less time. Manual errors in data management and handling are reduced. According to one estimate, the automation and independent IoMTs can save 300 billion USD in health care every year.[1] Such low-cost health care is near impossible without use of smarter technology. IoMTs lead to swifter per-patient implementation.

IoMTs allow remote monitoring of patients. Such remote monitoring is a boon at times of prevailing COVID-19 pandemic.[63] Contactless camera-based patient monitoring, especially under intensive care units, has provided opportunity to healthcare systems to effectively cater the needs of infective patients. Trends in remote patient monitoring indicate that more than 88% of the healthcare providers are willing to invest in the IoMTs.[64]

With the advent of new sensors and embracement of newer technology, there is need for extensive training of healthcare providers in utilizing these technologies. The healthcare fraternity needs to be sensitized in all emerging IoMTs. Tailored and customized hands on training program shall prepare the clinicians and auxiliary healthcare personnel for superior adoption of the newer methods. In addition, properly designed clinical studies and utilization studies, especially concentrating on the clinical outcomes and patient satisfaction regarding newer medical devices, shall provide stronger evidence for the effective and efficient implementation of IoMTs. This needs a proper understanding of the prevalent medical devices' regulatory guidelines. The regulatory bodies also play a vital role in IoMTs utilization. Broader acceptance and proper utilization of IoMTs in the health care not only changes the individual patient care but also meets the regional and national health goals.

Conclusions

IoMTs can be classified based on the place of usage into body centric, hospital-based, and ubiquitous systems. Classification based on the body systems and sensors aid in first-hand information about the existing IoMTs. Challenges for effective implementation of IoMTs are interoperability, data privacy, security, regulatory, and infrastructural costs. The future is promising for IoMTs with robust technological improvement and effective implementation. The healthcare sector in the next decade shall change completely with effective use of IoMTs.

Acknowledgments

Nil.

Financial support and sponsorship

Nil.

Conflicts of interest

The authors declare no conflict of interest.

Ethical consideration

Not applicable.

Authors' contribution

- Conception and design of the study: SV, SMJ;
- Acquisition of data: SV, SMJ;
- Analysis and interpretation of data: SV, SMJ;
- Drafting the article: SV, SMJ;
- Critical revising: SMJ;
- Final approval: SV, SMJ.

References

1. Joyia GJ, Liaqat RM, Farooq A, Rehman S. Internet of Medical Things (IOMT): Applications, benefits and future challenges in healthcare domain. J Commun 2017;12:240-7.
2. Internet of Medical Things (IoMT): New Era in Healthcare Industry [Internet]. Fuzon. Available from: https://www.fuzon.io/insight/iomt-in-healthcare-industry/. [Last accessed on 2021 May 7].
3. Al-Turjman F, Nawaz MH, Ulusar UD. Intelligence in the Internet of Medical Things era: A systematic review of current and future trends. Comput Commun 2020;150:644-60.
4. Hassan R, Qamar F, Hasan MK, Aman AHM, Ahmed AS. Internet of Things and its applications: A comprehensive survey. Symmetry 2020;12:1674.
5. Yao S, Swetha P, Zhu Y. Nanomaterial-enabled wearable sensors for healthcare. Adv Healthc Mater 2018;7:1700889.

Downloaded from http://journals.lww.com/mjby by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC1y0abggQZXdtwnfKZBYtws= on 12/08/2024

6. Wu T, Redouté JM, Yuce MR. A wireless implantable sensor design with subcutaneous energy harvesting for long-term IoT healthcare applications. IEEE Access 2018;6:35801-8.
7. Amendola S, Lodato R, Manzari S, Occhiuzzi C, Marrocco G. RFID technology for IoT-based personal healthcare in smart spaces. IEEE Internet Things J 2014;1:144-52.
8. Sigwele T, Hu YF, Ali M, Hou J, Susanto M, Fitriawan H. Intelligent and energy efficient mobile smartphone gateway for healthcare smart devices based on 5G. In: 2018 IEEE Global Communications Conference (GLOBECOM). Abu Dhabi, UAE, December 2018. p. 1-7.
9. Akrivopoulos O, Chatzigiannakis I, Tselios C, Antoniou A. On the deployment of healthcare applications over fog computing infrastructure. In: 2017 IEEE 41st Annual Computer Software and Applications Conference Workshops (COMPSAC). Italy, July 2017. p. 288-93.
10. Ahmad MA, Eckert C, Teredesai A. Interpretable machine learning in healthcare. In: Proceedings of the 2018 ACM International Conference on Bioinformatics, Computational Biology, and Health Informatics [Internet]. New York, NY, USA: Association for Computing Machinery; 2018 [cited May 7, 2021]. p. 559-60. (BCB'18). Available from: https://doi.org/10.1145/3233547.3233667.
11. Wiens J, Shenoy ES. Machine learning for healthcare: On the verge of a major shift in healthcare epidemiology. Clin Infect Dis 2018;66:149-53.
12. Almeida RB, Junes VRC, da Silva Machado R, da Rosa DYL, Donato LM, Yamin AC, *et al*. A distributed event-driven architectural model based on situational awareness applied on Internet of Things. Inf Softw Technol 2019;111:144-58.
13. Windley PJ. API Access Control with OAuth: Coordinating interactions with the Internet of Things. IEEE Consum Electron Mag 2015;4:52-8.
14. Hu B, Guan ZH, Chen G, Shen X. A distributed hybrid event-time-driven scheme for optimization over sensor networks. IEEE Trans Ind Electron 2019;66:7199-208.
15. Bahashwan AAO, Manickam S. A brief review of messaging protocol standards for Internet of Things (IoT). J Cyber Secur Mobil 2019;8:1-14.
16. Petrellis N, Birbas M, Gioulekas F. On the design of low-cost IoT sensor node for e-Health environments. Electronics 2019;8:178.
17. Patient Position Sensor (Accelerometer) for e-Health Platform [Biometric/Medical Applications] [Internet] [cited May 9, 2021]. Available from: https://www.cooking-hacks.com/patient-position-sensor-accelerometer-ehealth-medical.html. [Last accessed on 2021 May 9].
18. AD8232 ECG Module Pinout, Features & Datasheet [Internet]. Components 101. [cited May 9, 2021]. Available from: https://components101.com/modules/ad8232-ecg-module. [Last accessed on 2021 May 9].
19. Brock D. Sensors for Sleep Apnea and Sleep Study Equipment White Paper [Internet] [cited May 9, 2021]. Available from: https://www.te.com/usa-en/industries/sensor-solutions/insights/sensors-sleep-apnea-white-paper.html. [Last accessed on 2021 May 9].
20. BeanAir. Wireless Industrial IOT Infrared Temperature Sensor | Human Body Temperature Screening | Medical Precision | Overview—BeanAir | Wireless IIOT Sensors [Internet] [cited May 9, 2021]. Available from: https://www.beanair.com/wireless-ir-temperature-sensor-human-body-temperature-screening-overview.html. [Last accessed on 2021 May 9].
21. IoT Based Contactless Body Temperature Monitoring using MLX90614 Infrared Temperature Sensor, Raspberry Pi with Camera and Email Alert [Internet] [cited May 9, 2021]. Available from: https://circuitdigest.com/microcontroller-projects/iot-based-contactless-body-temperature-monitoring-using-raspberry-pi-with-camera-and-email-alert. [Last accessed on 2021 May 9].
22. Shihab K, Perdana D, Sussi S. Design and implementation of IoT based blood pressure monitoring tools. Int J Simul Syst Sci Technol 2020;21:3.1-3.5.
23. Valenzuela F, García A, Ruiz E, Vázquez M, Cortez J, Espinoza A. An IoT-based glucose monitoring algorithm to prevent diabetes complications. Appl Sci 2020;10:921.
24. Villarejo MV, Zapirain BG, Zorrilla AM. A stress sensor based on galvanic skin response (GSR) controlled by Zigbee. Sensors (Basel) 2012;12:6075-101.
25. Ramallo-González AP, González-Vidal A, Skarmeta AF. CIoTVID: Towards an open IoT-platform for infective pandemic diseases such as COVID-19. Sensors (Basel) 2021;21:484.
26. Remote Monitoring [Internet]. HELYXON Healthcare [cited May 9, 2021]. Available from: https://helyxon.com/remote-monitoring/. [Last accessed on 2021 May 9].
27. Dinis H, Mendes PM. Recent Advances on Implantable Wireless Sensor Networks [Internet]. Wireless Sensor Networks—Insights and Innovations. IntechOpen; 2017 [cited May 9, 2021]. Available from: https://www.intechopen.com/books/wireless-sensor-networks-insights-and-innovations/recent-advances-on-implantable-wireless-sensor-networks. [Last accessed on 2021 May 9].
28. Frost MC, Meyerhoff ME. Implantable chemical sensors for real-time clinical monitoring: Progress and challenges. Curr Opin Chem Biol 2002;6:633-41.
29. McKean BD, Gough DA. A telemetry-instrumentation system for chronically implanted glucose and oxygen sensors. IEEE Trans Biomed Eng 1988;35:526-32.
30. Wise KD, Anderson DJ, Hetke JF, Kipke DR, Najafi K. Wireless implantable microsystems: High-density electronic interfaces to the nervous system. Proc IEEE 2004;92:76-97.
31. Bazaka K, Jacob MV. Implantable devices: Issues and challenges. Electronics 2013;2:1-34.
32. Yu L, Lu Y, Zhu X. Smart hospital based on Internet of Things. J Netw 2012;7:1654-61.
33. Singh R. A proposal for mobile E-care health service system using IoT for Indian scenario. J Netw Commun Emerg Tech 2016;6:21-3.
34. Chandel V, Sinharay A, Ahmed N, Ghose A. Exploiting IMU sensors for IOT enabled health monitoring. In: Proceedings of the First Workshop on IoT-enabled Healthcare and Wellness Technologies and Systems [Internet]. New York, NY, USA: Association for Computing Machinery; 2016 [cited May 9, 2021]. p. 21-2. (IoT of Health '16). Available from: https://doi.org/10.1145/2933566.2933569.
35. Fischer M. Symptom-Diagnosis-Care: A Framework for a Collaborative Medical Chat Bot [Internet]. 2016 [cited May 9, 2021]. Proceedings of the International Conference on Advanced Intelligent Systems and Informatics 2016. Available from: https://link.springer.com/epdf/10.1007/978-3-319-48308-5_52. [Last accessed on 2021 May 9].
36. Huang CH, Cheng KW. RFID technology combined with IoT application in medical nursing system. Bull Netw Comput Syst Softw 2014;3:20-4.
37. Ghose A, Sinha P, Bhaumik C, Sinha A, Agrawal A, Dutta Choudhury A. UbiHeld: Ubiquitous healthcare monitoring system for elderly and chronic patients. In: Proceedings of the 2013 ACM Conference on Pervasive and Ubiquitous Computing Adjunct Publication [Internet]. Zurich, Switzerland: ACM; 2013 [cited May 9, 2021]. p. 1255-64. Available from: https://dl.acm.org/doi/10.1145/2494091.2497331.
38. Chavan P, More P, Thorat N, Yewale S, Dhade P. ECG-remote patient monitoring using cloud computing. Imperial J Interdiscip Res 2016;2:368-72.
39. Puri C, Ukil A, Bandyopadhyay S, Singh R, Pal A, Mandana K. iCarMa: Inexpensive cardiac arrhythmia management—An IoT healthcare analytics solution. In: Proceedings of the First Workshop on IoT-Enabled Healthcare and Wellness Technologies and Systems [Internet]. New York, NY, USA: Association for Computing Machinery; 2016 [cited May 9, 2021]. p. 3-8 (IoT of Health '16). Available from: https://doi.org/10.1145/2933566.2933567.
40. Kumar PM, Devi Gandhi U. A novel three-tier Internet of Things architecture with machine learning algorithm for early detection of heart diseases. Comput Electr Eng 2018;65:222-35.
41. Divya Krishna K, Akkala V, Bharath R, Rajalakshmi P, Mohammed AM, Merchant SN, *et al*. Computer aided abnormality detection for kidney on FPGA based IoT enabled portable ultrasound imaging system. IRBM 2016;37:189-97.
42. Chiuchisan I, Geman O. An approach of a decision support and home monitoring system for patients with neurological disorders

using Internet of Things concepts. WSEAS Trans Syst 2014;13: 460-9.
43. Sundhara Kumar KB, Bairavi K. IoT based health monitoring system for autistic patients. In: Vijayakumar V, Neelanarayanan V, editors. Proceedings of the third International Symposium on Big Data and Cloud Computing Challenges (ISBCC – 16'), Smart Innovation, Systems and Technologies. Springer International Publishing, Cham; 2016. p. 371-6.
44. Jara AJ, Zamora MA, Skarmeta AFG. An Internet of Things-based personal device for diabetes therapy management in ambient assisted living (AAL). Pers Ubiquit Comput 2011;15:431-40.
45. Fan YJ, Yin YH, Xu LD, Zeng Y, Wu F. IoT-based smart rehabilitation system. IEEE Trans Industr Inform 2014;10:1568-77.
46. Kumar KMC. Internet of Fitness Things—A move towards quantified health: Concept, sensor-cloud network, protocols and a new methodology for OSA patients. In: 2015 IEEE Recent Advances in Intelligent Computational Systems (RAICS). 10–12 Dec 2015. p. 364-9.
47. Laranjo I, Macedo J, Santos A. Internet of Things for medication control: Service implementation and testing. Procedia Tech 2012;5:777-86.
48. Tun SYY, Madanian S, Parry D. Clinical perspective on Internet of Things applications for care of the elderly. Electronics 2020;9:1925.
49. Kraemer FA, Braten AE, Tamkittikhun N, Palma D. Fog computing in healthcare—A review and discussion. IEEE Access 2017;5:9206-22.
50. Jaleel A, Mahmood T, Hassan MA, Bano G, Khurshid SK. Towards medical data interoperability through collaboration of healthcare devices. IEEE Access 2020;8:132302-19.
51. Eken C, Eken H. Security Threats and Recommendation in IoT Healthcare. In 2018 [cited May 10, 2021]. p. 369-74. Available from: https://ep.liu.se/en/conference-article.aspx?series=ecp&issue=142&Article_No=54. [Last accessed on 2021 May 10].
52. Regulatory Yearly Wrap 2020: Medical Device in India [Internet]. The National Law Review [cited May 10, 2021]. Available from: https://www.natlawreview.com/article/regulatory-yearly-wrap-2020-medical-device-india. [Last accessed on 2021 May 10].
53. Ministry of Health and Family Welfare (Department of Health and Family Welfare). Chapter IIIA, Registration of Certain Medical Devices [Internet]. Ministry of Health and Family Welfare; 2020. Available from: https://cdsco.gov.in/opencms/opencms/system/modules/CDSCO.WEB/elements/download_file_division.jsp?num_id=NTU0OQ==. [Last accessed on 2021 May 10].
54. Cabinet Approves Promotion of the Domestic Manufacturing of Medical Devices in country [Internet] [cited May 10, 2021]. Available from: pib.gov.in/Pressreleaseshare.aspx?PRID=1607485. [Last accessed on 2021 May 10].
55. van den Heuvel R, Kapadia A, Stirling C, Zhou J. Medical devices 2030—Making a Power Play to Avoid the Commodity Trap Thriving on Disruption Series [Internet]. KPMG International Cooperative; 2018. Available from: https://advisory.kpmg.us/content/dam/institutes/en/healthcare-life-sciences/pdfs/2018/medical-devices-2030.pdf. [Last accessed on 2021 May 10].
56. Benny R, Anjit TA, Mythili P. An overview of microwave imaging for breast tumor detection. PIER B 2020;87:61-91.
57. Kwon S, Lee S. Recent advances in microwave imaging for breast cancer detection. Int J Biomed Imaging 2016;2016:5054912.
58. Jain S, Nehra M, Kumar R, Dilbaghi N, Hu T, Kumar S, *et al*. Internet of medical things (IoMT)-integrated biosensors for point-of-care testing of infectious diseases. Biosens Bioelectron 2021;179:113074.
59. Mao H, Yang L, Zhu H, Wu L, Ji P, Yang J, *et al*. Recent advances and challenges in materials for 3D bioprinting. Prog Natu Sci Mat Int 2020;30:618-34.
60. Andrews RJ, Mah RW. The NASA smart probe project for real-time multiple microsensor tissue recognition. Stereotact Funct Neurosurg 2003;80:114-9.
61. Liu S, Zhang R, Zheng Z, Zheng Y. Electromagnetic–acoustic sensing for biomedical applications. Sensors (Basel) 2018;18:3203.
62. Sarmah D, Saraf J, Kaur H, Pravalika K, Tekade RK, Borah A, *et al*. Stroke management: An emerging role of nanotechnology. Micromachines (Basel) 2017;8:262.
63. Malasinghe LP, Ramzan N, Dahal K. Remote patient monitoring: A comprehensive study. J Ambient Intell Humaniz Comput 2019;10:57-76.
64. Malkary G. Trends in Remote Patient Monitoring 2019 [Internet]. Spyglass-Consulting; 2019. Available from: https://www.spyglass-consulting.com/Abstracts/Spyglass_RPM2019_abstract.pdf. [Last accessed on 2021 May 10].

Downloaded from http://journals.lww.com/mjby by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC1y0abggQZXdtwnfKZBYtws= on 12/08/2024