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Review Article

Internet of Things (IoT) Towards Specialty-Specific Internet of Orthopaedic Things (IOT): The Evolution and Applications of Internet of Medical Things (IoMT)

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Abstract

The increasing use of IoT in the medical field necessitates the adoption of specialized terminology, such as the "Internet of Orthopedic Things (IOT)" to accurately describe and distinguish this specific area of application. The IOT is a rapidly growing field that combines orthopedic devices with internet connectivity and data analytics. This review paper provides an overview of the IOT, including its definition, components, and applications in orthopedic healthcare with special focus on its classification. The IOT has the potential to revolutionize the way orthopedic healthcare is delivered by providing real-time monitoring, personalized treatment, and remote care. Different IOT devices, including smart implants, wearable sensors, and mobile applications, and their use in orthopedic diagnosis, treatment, and rehabilitation have been discussed. It aims to serve as a valuable resource for healthcare professionals, researchers, and policymakers seeking to gain insight into the IOT and its potential impact on orthopedic healthcare.

Keywords: *Internet of Things; Internet of Medical Things; The Internet of Health Things; Internet of Orthopaedic Things; Technology in Health*

Abbreviations

IoT: Internet of Things; IoMT: Internet of Medical Things; IoHT: Internet of Health Things; IOT: Internet of Orthopaedic Things; CPS: Cyber-Physical System; M2M: Machine to Machine; CIM: Computer-Integrated Manufacturing; IoMD: Internet of Medical Devices; IoRT: Internet of Robotic Things

Introduction

The Industrial Revolution had a significant impact on orthopedic healthcare. Advancements in manufacturing led to the development of new materials and technologies for orthopedic devices including internet of orthopedic things (IOT). New surgical techniques were also developed, such as joint replacements, along with medical tools like X-rays, which improved diagnosis and treatment. Everything from pre-operative templating to joint replacement implant and surgical techniques are based on sensors, navigation and different apps. We reviewed the literature to define industrial revolutions, different terminologies of internet of things (IoT) in medical field with specific focus in orthopedics, their classification and potential applications.

Industrial revolutions: The technological revolution is a historical period characterized by rapid advancements in technology and innovation, resulting in significant changes in society, culture, and the economy [1]. Simply this is an era in which one or more technologies are replaced by another technology in a short period [2]. We already have witnessed four technological revolutions which rapidly replaced one set of technologies by another through process called the creative destruction [3]. The first industrial revolution (IR 1.0), starting in the late 18th century, brought about the mechanization of production through water and steam power. The second industrial revolution (IR 2.0), between the late 19th and early 20th centuries, saw the introduction of mass production techniques using electricity. The third industrial revolution (IR 3.0), starting in the late 20th century, brought about automation and computerization. The ongoing fourth industrial revolution (IR 4.0), involves the integration of physical, digital, and biological systems through emerging technologies such as artificial intelligence, the Internet of Things, and biotechnology. During the world economic forum (2019) meeting in Davos, Japan promoted another round of advancements called Society 5.0 [4]. Currently the era of industrial 4.0 revolution of connectivity is in progress [5] but some researchers confirmed the dawn of fifth industrial revolution (IR 5.0), after COCID-19 pandemic [6]. As the IR 4.0, CPS and IoT are linked to each other, therefore more focus is given to these terms. The fourth industrial revolution (Industry 4.0) is characterized by the integration of digital technologies, such as the internet of things (IoT), artificial intelligence (AI), and robotics, into manufacturing [7].

IoT in industry: Industry 4.0 involves the integration of advanced technologies such as the internet of things (IoT), cyber-physical systems (CPS), artificial intelligence (AI), robotics, cloud computing, and big data analytics to create "smart factories" [8].

Internet of things (IoT): Refers to a network of interconnected physical devices [9]. The actual idea of connected devices is half century old and had been there at least since the 70s and called “embedded internet” or “pervasive computing” [10]. The current concept of IoT was originated from machine-to-machine (M2M) communication and was first coined by Kevin Ashton in 1999 [11]. The internet of everything (IoE) is a term commonly used by Cisco, while Intel initially referred to it as the "embedded internet". Other terms used for this type of communication include M2M, web of things, industry 4.0, industrial internet of things (IIoT), smart systems, pervasive computing, and intelligent systems [12]. The IoT is a vast network connecting people, things, and devices. For example, wearable devices in the workplace can collect data on an individual's activity and productivity and share it with other devices used during work. The IoT is the interconnection of physical devices, so it consists of many components which helps in communication between devices, generally it consists of two types of components namely hardware and software. Here hardware components are physical components that provide the connectivity and provide detailed surrounding information to the device and the software components are that which compute the information provided by the physical components and control them. The "internet of things" (IoT) is a concept that not only has the potential to impact how we live but also how we work [13]. Radio-frequency identification (RFID) sensors are one of the fundamental components of the internet of things that aims at connecting every physical object to the cloud for the exchange of information [14]. The IoT devices can be connected, including internet connectivity, mesh networks, gateways, and cloud-based services. IoT devices can communicate with each other directly, or through intermediaries, and can access additional processing power, storage, and analytics capabilities through cloud-based services. Nonetheless, these IoT solutions add security challenges due to their direct access to numerous personal information and their close integration into user activities [15]. There are three main components of IoT i.e. hardware, software and internet protocols [16].

Hardware (Sensors and standard devices)

Sensors are accelerometers, temperature sensors, magnetometers, proximity sensors, gyroscopes, image sensors, acoustic sensors, light sensors, pressure sensors, gas RFID sensors, humidity sensors, micro flow sensors whereas standard devices are desktop, tablets, and cellophanes.

Software’s: Software’s are used in IoT for different applications which are embedded in the system to help in network connection, controlling, data collection, real-time analysis, and integration.

Internet protocols: Internet protocols are the technologies and protocol of IoT based on RFID, low energy radio protocol, NFC, low energy bluetooth, Wi-Fi direct and LTE-A. These protocols allow IoT to networking functionalities in contrast to standard networks of common system.

Cyber-physical systems (CPS): Refers to the integration of physical and computational components, while IoT refers to a network of interconnected physical devices and term is coined to Helen Gill in 2006 of the US national science foundation [17]. The cyber-physical systems (CPS) are also defined as smart systems that include engineered interacting networks of physical and computational components [18]. Greer., *et al*. 2019 minutely evaluated the definitions of IoT and CPS but generally the definitions are overlapping with each other [19].

Computer-integrated manufacturing (CIM): CIM is a manufacturing process where the computers are being used to control whole production.

The difference between Industry 4.0 (IoT and CPS based) and computer integrated manufacturing (CIM) is that industry 4.0 has a significant role for human workers in production, while CIM is workerless [20].

Machine-to-machine (M2M): Refers to the interaction of billions of devices and machines that are connected to the internet and to each other [21].

IoT in medicine and health industry

The internet of the medical things (IoMT): IoMT can be viewed as an IoT network of medical devices, sensors, and applications that link health-care cyber and physical resources. The first use of the term "Internet of Medical Things (IoMT)" is difficult to trace. However, the development of IoMT can be traced back to the early days of telemedicine when medical devices and sensors were first used to monitor remotely and manage patients' health. According to a report by Grand View Research, the global IoMT market is expected to reach USD 534.5 billion by 2025, growing at a compound annual growth rate (CAGR) of 19.9% from 2020 to 2025 [22].

The internet of health things (IoHT): IoHT is the integration of the physical and digital worlds through objects with network connectivity in the healthcare industry. The IoHT is already delivering tangible cost savings, but continuous investment is essential [23]. In summary, while both the IoMT and IoHT are subsets of IoT that focus on the healthcare industry.

The internet of orthopaedic things (IOT): IOT is a subfield of the Internet of Medical Things (IoMT) that specifically focuses on the development and deployment of digital technologies for orthopaedics. The IoT and CPS are getting popularity among orthopaedic surgeons and it is better to create a new speciality-based branch termed as Internet of Orthopaedic Things (IOT) to avoid confusion. The IoMT encompasses a wide range of medical fields, including cardiology, neurology, ophthalmology, and orthopaedics. Internet of Orthopedic Things (IOT), on the other hand, is a subset of the IoMT that specifically focuses on the network of connected medical devices, wearables, and other health-related sensors and systems in the field of orthopaedics. The IOT includes devices such as smart implants, sensors for gait analysis, remote monitoring systems, and rehabilitation devices. ChatGPT-3 unable to find the first time its use in literature and replied I'm not aware of who first used the term "Internet of Orthopedic Things (IOT)" [1].

The internet of medical devices (IoMD): The internet of medical things, also referred to as the Internet of Medical Devices (IoMD), is the network of medical devices and applications that connect to healthcare IT systems through the internet [24]

The internet of musculoskeletal devices (IoMD): IoMD is a newer term that refers to a similar subset of connected devices and systems in the field of orthopaedics, but with a greater emphasis on the integration of artificial intelligence and machine learning to enhance the performance and capabilities of these devices. Sensors hidden in orthopaedic implants can monitor internal temperature. The IoMD provides opportunities for advancement in treatment, surgery, education, research, and development. Medical sensors detect various signals to estimate a person's health status and collect environmental and logistics data. The use of IoT in orthopaedics can lead to better communication between doctors and patients, accurate treatment, and proper medication. Technologies used in IoMD include big data, cloud computing, smart sensors, artificial intelligence, actuators, and virtual reality or augmented reality [1]. Interestingly this content is the extracted by ChatGPT-3 and despite hectic search, information's could not be verified.

The internet of robotic things (IoRT): Refers to the merging of IoT and robotic applications [25].

IOT classification based on physical system

An imaginary patients Samantha's hip replacement hidden sensors may send the note that a local Staph infection is brewing to alarm the physicians [26]. Similarly other uses of IoMT in Health Sciences have been categorised i.e. innovative surgical interventions, ingenious diagnosis and imaging, drug delivery and patient monitoring and assistive care and therapy services [27].

In orthopaedics first ever classification by Misic., *et al*. (2018) described four types of IOT based external fixation devices [28]. Type 1 tagging system to resolve logistics problems, type 2 sensing system to collect physiological or environmental data, type 3 an intelligent system that can make sense of combined data from different sources, and type 4 is a closed-loop system that senses, makes intelligent decisions, and drives an actuator accordingly [28].

The desktops, laptops, tablets, smartphones, traditional mobile phones, TVs, DVD, MP3 players and game consoles are not considered as IoT [29]. There are advocates who believe that smart phones are IoT due to sensors presence in them [30]. An effective IoT device needs to have sensors, actuators, and a Radio Frequency (RF) module that allows it to transmit and receive data or signals via the internet [30]. Smartphones are arguably the most versatile IoT devices. We believe that by using build-in sensor or any other physical parts of these gadgets for new function than it may be considered as build-in IoT. Owing to the relatively large physical size of many orthopaedic implants, the bulk provides an opportunity for symbiosis between implant and sensing technology [31]. Large implants can integrate sensors and telemetry, with strain gage-based sensing being the primary technology. Smart orthopaedic implants measure physical parameters and have applications in various procedures. Ortho-Sensor provides components for off-the-shelf implants, and new wireless, battery-less, and telemetry-less sensors require no electrical connections [32]. The small, simple sensors are inexpensive to fabricate. We tried to classify IOT based on their location.

Based in relation to implants

In relation to implant
Build-in IOT
Build-out IOT
Add-on IOT
In relation to body
Internal IOT (Nanobots and Neuralink)
External IOT
Hybrid IOT
In relation to environment
Local IOT & Exoskeletons
Regional IOT
Complexed/Remote IOT

Figure

Build-in IOT

Phones as IoT: Sensors are the pen and paper of the next wave of data acquisition in medical field including orthopaedic [33]. IoT is a network of uniquely identifiable 'endpoints' or 'things' which communicate without human interaction using IP connectivity but still believes in "some" human interaction [34].

All smartphones are different and they may be used as Build-in IOT as discussed earlier due to fully loaded with different sensors in it. Ordinary objects that embed such sensors are considered as IoT than why not today's phone consisting of bluetooth, wifi, 2G/3G/4G, and such sensors should be considered as IoT too. If we use an CPR Apps based on build-in sensors in smartphones, then it may be labelled as build in IOT despite controversy.

Orthopedic implant's sensors: Are wearable devices that are integrated into orthopedic implants such as joint replacements, spinal implants, and fractures fixation devices [35]. These sensors can provide real-time data about the performance and function of the implant, allowing for better monitoring and management of orthopedic conditions. Some examples of orthopedic implant sensors are given:

1. **Joint replacement sensors:** These are sensors that can be integrated into joint replacements such as knee and hip replacements. They can provide information about the range of motion, torque, and stability of the joint, allowing for early detection of problems and improved patient outcomes. For an orthopedic surgeon, technical knowledge about the sensors is important for the success of sensor-assisted Total Knee Arthroplasty [36]. Persona IQ, the smart TKR loaded with a smart sensor to measure steps taken, walking speed, range of motion and other knee function following surgery [37,38].
2. **Spinal implant sensors:** These are sensors that can be integrated into spinal implants to monitor the health and stability of the spine. They can provide information about the load on the spine, the angle of the vertebrae, and any movements or changes in the spinal cord. Potential developments for spinal implants depend in the future on Micro-electromechanical systems (MEMS) and use of accelerometers [39]. The eDisc is the first artificial spinal disc to incorporate microelectronics to empower surgeon to monitor their patient remotely [40]. Theken Disc was designed with an integrated microelectronics module to reduce post operative complications and speedy outcome [41].
3. **Fracture fixation sensors:** These are sensors that can be integrated into fractures fixation devices such as casts and braces. They can provide information about the patient's movements, the position and orientation of the limb, and the progression of healing. Bluetooth pressure sensor kit that can measure skin-cast contact surface pressure (SCCSP) under a cast, monitor limb swelling, and notify the user with a mobile application [42].

Build-out IOT

The Loadpro, Intraoperative Rod Strain Sensor is a digital health device that can measure the mechanical strain on rods in a pedicle screw system [43]. Loadpro helps balance strains during surgery, while Accuvista tracks rod strains after spinal fusion. Both devices measure rod strain and communicate asymmetry to an external reader during surgical maneuvers [44]. Loadpro is applied externally on the rods (implants).

Add-on IOT

Take a regular car that is maybe a few years old, without internet connection. You can plug in an IoT adapter into its OBD port and remotely monitor many aspects of the car's operation. In this case the car is a 'thing', and the IoT device is a separate add-on. Ortho-tags are attached to orthopedic implants either prior to packaging and sterilization or during surgery by the surgeon. They are not built-in, but rather affixed to the implants [45]. Ortho-Sensor has aligned itself with multiple implant manufacturers to provide smart components that can be used with off-the shelf implants by surgeons who want the additional data intraoperatively [32]. Orthopedic implant tags are small, passive radio-frequency identification (RFID) tags that are attached to orthopedic implants such as joint replacements, spinal implants, and fractures fixation devices. These tags contain a unique identifier that can be used to track the implant throughout its lifespan and provide valuable information such as the manufacturer, model, and batch number.

The utilization of orthopedic implant tags can offer different advantages:

1. **Enhanced patient safety:** With a distinct identifier for each implant, medical professionals can swiftly access relevant information regarding the implant, such as its manufacturer and batch number, to detect any possible safety or recall concerns.
2. **Improved patient care:** Orthopedic implant tags can equip healthcare providers with crucial details about a patient's medical history and prior surgeries, enabling them to make more informed decisions regarding future treatments.
3. **Streamlined tracking and traceability:** Orthopedic implant tags can assist in monitoring the movement and whereabouts of implants, simplifying inventory management, and ensuring appropriate implant usage.
4. **Better data gathering:** Orthopedic implant tags can supply significant data for research and analysis, providing a deeper comprehension of the performance and longevity of different implant varieties.

In relation to body

Internal IOT

Sensor based IOT lies within the human body e.g. Internal fixation device (DCP, Arthroplasties). A tag is embedded within fixation device, storing the detailed manufacturers (material, component-specific, type and dimensions), internal logistics (storage location, handling history), patient-specific (anonymized) general data, and others. In this sense, the fixation device is self and patient aware. Tag is an active unit, capable to register itself to the central system at regular intervals, allowing access to external devices for data manipulation. Thus, it has communication, but not sensing capabilities. Strain gages are mounted onto the surface of implants such as the cervical spinal interbody cage shown and require lead wires connecting them to signal conditioning electronics. Nanobots and Neuralink can be discussed in this group too.

Nanobots

A nanorobot, also known as nanobot, nanomachines or nanomites, can be made from different mechanical components [46]. According to Bisset (2019), researchers have developed a method for creating highly reconfigurable swarms of millions of magnetic nanoparticles, which could be used for surgical purposes like navigating hard-to-reach spaces and for targeted drug delivery, cancer therapies, and eye surgeries [47]. The technology may also provide a new opportunity for treating stroke by recanalization of occlusion in vascular systems in the future. Stems cells and nanorobots (nano drones) to heal fractures and fight infections have been trialled [48].

Neuralink

Spine surgeon Kornelis Poelstra has expressed that the Neuralink technology could offer significant benefits in spinal surgery for patients with a range of neurological conditions [49].

External IOT

Outside body but directly in contact with human body. Two in five users of wearables say they feel naked when not wearing their device, with a quarter even sleeping with it on [50]. Examples of external IOT is given below.

MY01 TM continuous compartment syndrome monitoring sensor; The MY01 is intended for real-time monitoring and can be used as an aid in the diagnosis of compartment syndrome [51,52].

Hybrid IOT

Partly within and outside body but directly in contact with the body e.g. Sensing external fixation device. Conductivity and temperature sensors are within the body whereas force and inertial sensors are mounted outside the body on external fixator.

In relation to environment

Local IOT: (Smart wearable devices)

No physical contact with the human body but connected to human body indirectly through shoes, walking frame, watch, infusion or else. A Smart Walker that reduces falls and injuries [53]. Smart wearable orthopedic devices are high-tech, wearable devices that are designed to help people manage and monitor various orthopedic conditions such as joint pain, arthritis, osteoporosis, and musculoskeletal injuries. These devices can also provide real-time data and feedback to help people track their progress, monitor their health, and improve their overall physical health.

Smart knee braces: These are knee braces equipped with sensors that can monitor and track various parameters such as knee position, pressure distribution and joint movements. Such orthosis includes pressure sensor, shape memory actuator, and smart linkage [54].

Smart insoles: These are wearable insoles that can track your gait, pressure distribution and step count. Researchers have designed a real-time pressure mapping smart insole system based on a controllable vertical pore dielectric layer [55,56].

Smart spinal braces: These are wearable braces that can monitor and track the posture of the user and provide feedback to improve it. Nine of the best back (spinal) braces were reviewed in terms of benefits, risks, and options and recommend braces for short-term use because prolonged use may lead to dependence on the device, resulting in muscle weakness and atrophy [57].

Smart arm braces: These are wearable devices that can help manage conditions such as arthritis, repetitive stress injury and carpal tunnel syndrome. By the incorporation of these sensors and demonstrated that it is possible to detect complications in the treatment of injuries using immobilization smart splints to monitor different parameters during the treatment process [58].

Virtual walking stick: Mobile application to assist visually impaired people to walking safely [59,60]. The Smartcane alerts your family in case of a fall [61].

Inbed: This is a highly specialized system for bed-exit-detection and fall prevention to monitor patients and elderly peoples [62].

Infusion control system based: This paper studies the application of the infusion control system based on the IoT technology in joint orthopedics nursing work [63].

Nanogenerator based wearable devices: As a positive energy conversion device which can convert the biomechanical energy generated by daily activities into electricity [64].

IoT based monitoring of foot pressure using FSR sensor: A smart shoe is designed with four sensors placed at different positions to analyze pressure distribution. The signals from the sensors are sent to a microcontroller which is then processed and sent to a mobile device via a Bluetooth module. The system uses IoT to notify the patient and the doctor/physiotherapist when the signal goes beyond a certain limit. This proposed system can help monitor and receive condition feedback for patients using smart shoe technology [65].

Regional IOT

Remotely present but within the same locality where the patient is physically present but no direct physical contact with his body e.g. monitoring of in-door patients body temperature through thermal sensors (thermal mapping device mounted on wall). System has been designed to monitor indoor condition through MEMS based IoT-Alert System for COVID-19 patients in quarantine to protect medical staff [66]. A recent patent was granted for an RFID system to track and monitor implants and instruments to The Pantheon Surgical, LLC [67]. Recently Summate Scan Ready™ proposed the solution to the inventory management challenges of the orthopedic device to make the sets smart, not the parts [68].

Complexed/remote/distant IOT

The situation where IOT not only mounted on the patient, but other part is away from patient and give the feedback to patient through internet. OrthoLogIQ technologies will have the capabilities to monitor the patient's journey pre-operatively, intra-operatively and post-operatively, empowering surgeons and patients with comprehensive data-driven solutions [69]. With the developed mobile application, the person can instantly see the angle of movement and the application can instantly send information to doctor or trainer [70]. According to Chahal and Kharb (2019) by incorporating machine learning techniques with IoT, who tried to find a solution that can significantly help orthopedist to diagnose the pathologies of Vertebral Column [71]. IoMT-based Cyber Training Framework for Orthopaedics Surgery using Next Generation Internet Technologies such as OrthoLogIQ and MotionSense allows for data collection and reporting. OrthoLogIQ is a cloud-based platform and mobile application that collects data throughout the continuum of care and displays meaningful information on dashboards for healthcare providers. The combined technologies by Dr. Lee Berger enable wireless in-body communication, real-time data exchange/storage, diagnostics, and *in vivo* drug administrative capabilities of smart medical implants [72].

Applications of internet of orthopaedic things (IOT)

The following areas are advancing in orthopaedics and practical examples are discussed below.

Three-D printed surgical planning models and instruments

Metal 3D printing has potential in orthopaedic practice for creating customized implants or devices. While these printers are currently expensive and not widely available, they may become more affordable in the future. It is important to ensure that the biomechanical proportions of the printed devices are acceptable before implantation. Bioprinting is also a promising area of research in healthcare. Three-dimensional printing technology can revolutionize surgical practice, particularly in prosthetic and traumatological surgery. Medical 4.0 implementation involves 3D printing and the Internet of Things (IoT) as a solution to various challenges in the medical industry, including material requirements [73,74]. Similarly, 3D-printed patient specific instruments for corrective osteotomies of the lower extremity have been trialed [75].

Artificial intelligence and classification

Neural networks, also known as deep learning, have seen a resurgence in recent times and are a significant technological trend. AI's use in interpreting radiographs has enormous potential, as noted by Olczak., *et al*. (2017) [76]. Chung., *et al*. (2018) demonstrated the capability of neural networks in classifying humerus fractures, which can address the issue of low classification reproducibility as reported by Audigé., *et al*. (2004) [77,78]. Shehovych., *et al*. (2016) suggests that it could make classifications more clinically relevant [79]. Furthermore, Tiulpin., *et al*. (2018) have made considerable progress in classifying knee osteoarthritis and made their dataset available for experimentation as open data [80].

Augmented reality assisted surgeries

Gregory., *et al*. (2018) discussed the potential of mixed reality technology, which overlays computer-generated images onto the real world, for use in surgical procedures [81]. While augmented reality technology has been studied for medical applications since the mid-1990s [82].

Real-time patient monitoring systems

Continuous monitoring of vital signs, such as pulse oximetry, respiration rate, temperature, heart rate, heart rate variability, arterial blood pressure, skin temperature, skin conductance, and blood alcohol concentration, can detect clinical emergencies at an early stage [83]. Various sensors are used in healthcare for this purpose, including thermometers, blood pressure and glucose monitors, electrocardiograms, photo-plethysmograms, electroencephalography, imaging sensors, accelerometers, gyroscopes, and Global Positioning System devices.

Intelligent (Smart) implants

Smart knee implants with embedded sensors can enhance post-operative recovery, lower implant failure rates, and boost patient satisfaction, amid a global rise in knee replacement surgeries [84].

Rehabilitation

As the population ages, the importance of Personalized preventative health coaches, also known as Digital Health Advisors, will increase. These healthcare workers will utilize health data to assist clients in avoiding chronic and diet-related illnesses, improving cognitive function, and achieving overall better lifestyles [85].

Embedded and implantable sensors

Medical sensors not only transmit and process data but also trigger interventions, such as brain-controlled prosthetics and insulin pumps. Actuators like alarms and pacemakers can be integrated with the sensor nodes or function as independent units. The technology for controlling a robotic limb using the mind is also being developed [86].

Aware, sensing, smart and active (ASSA) external fixation device

Smart solutions to reduce complications have been designed for external fixation devices. The proposed solution incorporates aware, sensing, smart, and active paradigms to allow for real-time monitoring of bone fracture healing, addressing issues related to patient behavior, environmental factors, and data monitoring [29]. The potential benefits of this approach are demonstrated through an example of classifying patient compliance to postoperative treatment.

IoMT based training for residents in orthopaedic surgery

The article explores the potential of an Internet of Medical Things framework for surgical training, which incorporates Virtual Reality simulations and haptic-based interfaces [87]. The framework was developed using Global Environment for Network Innovations principles and has the potential to transform medical education [88].

3-D insoles

SOLS is a startup that provides orthopedic insoles through two business models, either by self-scan or consultation with an orthopedist followed by sending 3D-printed soles directly to the customer [89]. Similarly, Feetz and 3DShoes.com offer personalized sport shoes, allowing customers to scan their feet using a smartphone camera and select their desired shoe design, colors, and materials. Adidas and Nike are already evaluating this service in their stores. Your next pair of shoes could come from a 3-D printer, The New York Time article [90].

Smart robotics for smart healthcare

IoT-based technology and robotics have transformed human life into smart living, just like creating smart environments, homes, and cities. In healthcare, robotics with IoT have opened various areas such as surgical and interventional robotics, rehabilitative robotics, and support for clinical workforce, elderly, and disabled people. Orthopaedic surgeries have also benefited from robotics e.g. shaping the femur to fit prosthetic hip joint replacements with greater accuracy. OTOROB is an IOT based telerobotic consultation system [91,92].

The design and modification of orthopaedic plates based on features

Computer-aided orthopaedic surgery is an emerging field that has garnered increasing attention worldwide. In particular, the study and application of computer-aided orthopaedic implant design has received significant attention. Researchers have even developed intelligent solutions for designing plates [93].

Smart implants in orthopaedic surgery

Smart orthopaedic implants are devices that offer both diagnostic and therapeutic benefits, with potential applications for knee and hip arthroplasty, spine fusion, and fracture fixation [32]. These devices can measure physical parameters such as pressure, force, and temperature within the body. However, the integration of sensor technology requires extensive modification to the implants.

A cyber training framework for orthopaedic surgery

The use of virtual reality (VR)-based environments for surgical training has increased in recent years. Cecil., *et al*. (2017) developed a cyber training framework using VR simulators for an orthopaedic surgical process called Less Invasive Stabilization System (LISS) plating surgery [88]. The study found that this training significantly improved residents' understanding of the procedure, with most participants demonstrating significant enhancements in their LISS plating skills through the simulation.

Monitoring fracture healing with bone plates

Electrical impedance spectroscopy (EIS) can be integrated into fracture management modalities such as bone plating to monitor real-time healing [61].

IOT for joint ventures

Ospitek Inc. partnered with Spine Center Atlanta to implement IoT and AI enabled patient pathway and facility management tools to advance research [94]. Our previous work recommended the use of IOT for internet of orthopedic things and IoT for internet of things and same terminologies are being used in this paper too [95].

Conclusion

The field of IoT is rapidly evolving, with discipline-specific applications such as IoMT and IoHT leading to the development of specialty-based IOT for orthopedics. These advancements have opened various potential applications in the field of medicine, particularly in surgical fields like orthopedics. However, there is still a significant amount of research needed to effectively classify the knowledge in this area for better understanding and practical implementation.

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