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Review Article

Internet of things in medicine and dentistry

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ABSTRACT

The internet of Things (IoT) in medical arena, also known as internet of medical things (IoMT) is the collection of medical devices and application connecting healthcare Information Technology (IT) system by means of online computer networks. It enables virtually any medical devices as well as non digitalized things (like pills and beds) to connect process and communicate data via web. IoMT allows medical devices and health-care items to exchange data on the spot, online with anyone who has a genuine need for it. The aura of IoMT includes wireless communication technologies, cloud computing, wearable technologies, messaging protocols, security methods, development boards, microcontrollers, mobile/IoT operating systems, and programming languages, built upon numerous technologies including advanced sensors, IoT connectivity and artificial intelligence (AI). IoMT can improve healthcare quality and reduce costs too in hospitals and clinics. In places where distance is the limiting factor, Telemedicine plays a vital role in remote patient monitoring. Major applications include biomedical equipment remote monitoring, remote patient monitoring biosensors and radio frequency identification. IoT in Dentistry aims to streamline oral health care by enhancing oral health while reducing costs, promoting workflow, relieving dentists and dental workers of tedious and time-consuming activities, and igniting interest in personalized oral health care.

1. Introduction

Internet of things is a brief overview of network of physical objects; it connects huge numbers of devices that are linked to internet around the globe and facilitates collection and apportion of data between them. The internet of things pertaining to healthcare system, is known as Internet of Medical things (IoMT). The health care sector, with its ever emerging need of meeting patient demands and understanding technical aspects of devices used in diagnosis, prophylaxis and mitigation of ailments, requires a well-established system of database that would serve as a portal of perception.

Wireless networking technologies, cloud computing, wearable technology, messaging protocols, security methods, microcontrollers, mobile/IoT operating systems, development boards, and programming languages are all part of the Internet of Things (IoMT). They are executed by implementing IoMT, built upon various technology including advanced sensors and IoT connectivity.

Few of the major constraints concerned with the existent strategies in health care include the price of the treatments, non-availability of adequate details at the right time

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junctures and increased incidence of chronic illnesses; all of which cause an overload on healthcare infrastructure. However, with the apt use of IoT, these limitations can be overcome with ease.

Internet of things goes hand in hand with the revolutionizing field of Artificial intelligence (AI). AI is the emulation of human intelligence by computers, particularly computer systems, with learning, reasoning, and self-correction as major domains. Applications based on AI systems are realising its potential that can be found in the present scenario of life. To enhance human convenience, initiatives are already taken to construct AI-controlled robots. AI's current claims in healthcare sector are mainly focussed on Medical decision-making processes; enabling even the non-specialists to obtain expert level information.

The Internet of Medical things plays a crucial part in increasing the accuracy, credibility and productiveness of electronic devices. It also plays a significant role in the establishment of remote medical surveillance systems based upon mobile internet services.[1] Several research studies are in progress to assess and streamline the application of IoT in the sphere of medicine. As a result, the Internet of Medical Things entails a collection of medical equipment and apps that connect to healthcare IT systems via online computer networks. It allows almost any medical gadget, as well as non-digital goods (such as hospital beds and medications), to connect to the internet, analyse data, and send it across the internet.

The key architecture of IoT in healthcare intrinsically is constituted by the following three layers – Perception, Network layer, and Application layer.[2] The perception layer predominantly involves the identification technologies like sensors, GPS, cameras that allows comprehension through recognition of objects and converting the information into digital signals which makes it easier for communication through network transmission; The network layer comprises of the wired and wireless networks that aid in data communication and retention of data in a centralized system or in local storage system; The application layer incorporates the interpretation of data and accountable for application specific service purpose to the beneficiary.

The possible implications of IoMT range from remote monitoring of patient physiological conditions,[3] smart medical health bands,[4] construction of medical and dental decision making expert systems, telemedicine, and much more. The elements of IoT go in cohesion with the P9 concept of healthcare proposed by Ramesh Jain, University of California, Irvine, which is basically an expansion of the P4 medicine concept spearheaded by Leroy Hood.[5] The P9 concept involves i) Personalized or custom-made medicine, ii) Predictive medicine which helps in the determination of susceptibility of an individual to particular diseases, iii) Preventive medicine techniques through machine learning and decision analytical tools, iv) Participatory process which signifies the active taking part of the patient in the diagnosis and management of their medical condition, v) Pervasive concept of medicine wherein provisions for healthcare should be made available at all time and locations, vi) Precision medicine, vii) Privacy preservation, viii) Protection from any harm that can be induced by computer systems and ix) Price reasonability. IoT markedly improves the real-time life quality of a patient thereby facilitating the ultimate goals of healthier and longer lives.[1]

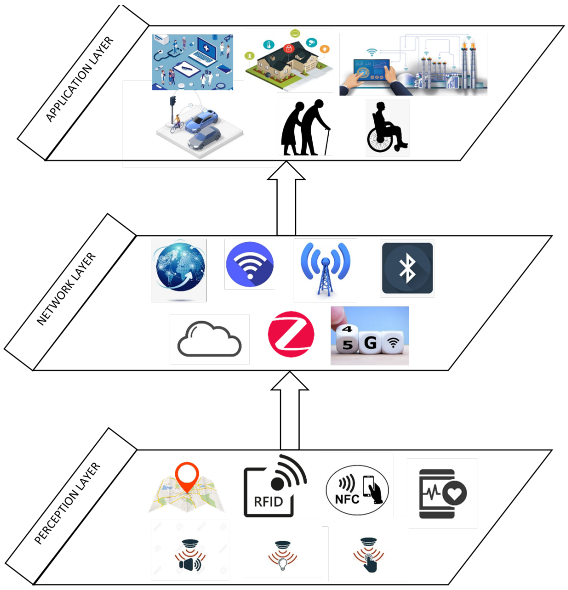

Fig. 1: IoT architecture

2. Biomedical Equipment Remote Monitoring

The steady and sustained advancements in modern medicine in the recent times are primarily due to the advent of a number of medical equipment. In the past, most of the diagnosis was feasible only after a thorough physical examination at a medical centre or hospital.[6] With breakthroughs in the information interpretation sector and high technological devices in healthcare, these medical devices play a major role in the prophylaxis, detection, management and prediction of prognosis of diseases.[7] Therefore there has been a paradigm shift from hospital centric approach to patient centric approach of healthcare.[8] IoMT has resulted in accessibility to healthcare for patients located at remote locations too. The so called smart systems or intelligence systems powered by cloud or other such cybernetics have brought the devices to the fingertips literally at one's own will. These newer medical devices constructed for use at home has been designed in a way that minimal assistance from healthcare professional is required.

An overview of the application process of the IoT in medical devices:

1. The smart systems embedded in the phones, watches, etc., vigilantly monitor the user's health data.
2. The smart systems send the collected data to the portal of data center from where qualified healthcare personnel analyses the measurements.
3. The data center analyses the data obtained.
4. The user gains insights about health information from the data center. Generates alerts in case of emergencies.

The assortment of utilization of IoT in healthcare sector is very diverse; a few of which are enlisted below:

2.1. *ECG monitoring*

An electrocardiogram is a medical test that diagnoses different cardiac conditions or abnormalities by recording and measuring the electrical activity that is generated by the heart due to depolarization and repolarization of atria and ventricles. Many studies have been done to study the application of IoT in ECG monitoring.[6] IoT integrated devices are implanted with sensors that monitor the impulses set off from the heart and collects the data which help in the early detection of the cardiac abnormalities.

2.2. *Blood pressure & blood glucose monitoring*

The pressure of the circulating blood against the blood vessels is known as blood pressure. IoT has been highly beneficial in keeping track of the systolic and diastolic values at fingertips by non-invasive methods. In patients who require continuous monitoring of BP due to high susceptibility of developing potential heart conditions or due to other reasons, IoT aids in provision of pre-emptive care and observation of other life style parameters in a precise manner; this lets the patients continue with their routine day to day activities without requirement of having to visit the health centres for check-ups often. Same goes for Blood glucose monitoring by IoT for diabetic patients.[9]

2.3. *Temperature & oxygen saturation monitoring*

One of the most important biomarkers for fever, tiredness, metabolic functionality, and other conditions is the core body temperature. Traditional worn sensors based on skin temperature measurements differ significantly from core body temperature; however, emerging IoT processes use smart systems that precisely monitor real-time values through wearable devices.[10] The percentage of arterial haemoglobin that is saturated with oxygen is measured by blood oxygen saturation. Wearable devices keep track of physiological indicators and wireless systems process the data collected via commercially available pulse oximeters.[11]

2.4. *Medication management*

In many patients non-compliance to the proposed prescription dosage and duration is one of the major constraints. IoT uses a distinct system of intelligence that makes it easier and comfortable for patients by means of smart medication boxes.[12]

2.5. *Other applications*

Asthma monitoring, mood monitoring, wheelchair management, rehabilitation systems.[13]

The functionalities of healthcare IoT are not just restricted to the above mentioned uses. Research is being undertaken to incorporate IoT in devices used in haemoglobin detection cancer treatment, remote surgeries, etc.[6]

3. Remote Patient Monitoring

Remote patient monitoring is an applied aspect of IoT that facilitates monitoring of patients outside of the traditional clinical set-ups. The WHO defines digital health as 'the application of digital, mobile, and wireless technology to aid in the attainment of health goals'. The concept of telemedicine also comes under the auspices of remote patient monitoring system.

This technology is highly promising for application in remote areas where adequate health care facilities or qualified medical professionals are not available, thereby increasing the accessibility to apt medical care and is cost-effectiveness. Applications are specially intended to be designed for patient groups with chronic ailments, with physical or mental disabilities and mobility issues, paediatric and geriatric population.

There are several challenges that exist while designing a schema for a remote patient monitoring system. The basic facets of a remote monitoring system include data acquisition, data processing, end terminal and the communication network system.[14] When developing a monitoring system, the decision to employ a contact or contactless technique, the type of sensors, the processing algorithm, and the communication network of choice are all important factors to consider.

Conventionally, keeping check of the normal physiological parameters requires usage of a contact based sensor; nonetheless these contact based systems impede with the routine day to day activities and functions of the individual, which may impose challenges in implementation of such a design. Therefore, the present day approach is mostly based on the core concept of trying to develop a contactless technique for monitoring the physiological parameters.

Remote patient technologies have been applied to monitor different parameters or ailments involving different organ systems of the human body. Majority of the studies are focussed on the most commonly incident diseases like diabetes, brain and neurological issues, cardiovascular and respiratory diseases, and a few other ailments too.

3.1. Diabetes

Diabetes is one of the most prevalent diseases worldwide, having an alarming rate of incidence in the near past. The most opted approach of management of diabetes is measurement and monitoring of blood glucose level at frequent intervals along with lifestyle modifications. However, the conventional technique of quantizing blood glucose levels involves use of finger stick systems which is an invasive method, therefore afflicts pain to the patient. Therefore, development of non-invasive means for self-management of the disease is required. Reverse iontophoresis, Bioimpedance, Thermal emission spectroscopy, Absorbance spectroscopy, Fluorescence, Polarimetry, Ultrasound, electromagnetic sensing, and other techniques used for non-invasive glucose monitoring can all be classified as electrode based, light based, or sound based approaches. Some of the commercially available devices that employ these techniques are GlucoWatch® G2 biographer, Pendra®, GlucoTrackTM, Or Sense NBM-200G, SpectRx Inc., Symphony®.[15]

3.2. Brain and neurological issues

The origin of neurological issues can be congenital or pathological or may be due to injuries. Mental disorders can also be considered as a concomitant aspect of brain and neurological disorders. The development of a monitoring system for these disorders is quite a challenge since these diseases have a close relatedness to other ailments and requires a complex design when compared with other such disease monitoring systems.[14] Studies have been conducted to assess the performance of IoT in cases of Parkinson's, Multiple sclerosis, Dementia, traumatic brain injuries, etc. The practicability of using remote monitoring technique and telemedicine in depression, chronic headaches and stroke have been found to yield more or less similar results as obtained in the clinic based approaches.

3.3. Cardiovascular & respiratory system disorders

Because of their wide range of applications and capacity to diagnose a few hidden illnesses, cardiac monitoring systems are the most popular remote systems intended for use in patients. The common illnesses included under this category are cardiac arrhythmia, stroke, blood clots, heart failure, hypertension, etc.,[14] Actual ECG monitoring or textile based contact systems are some of the technologies used for collection of data from the patient. One of the studies that has been conducted regarding this discipline have pointed out the applications of hardware and software devices that run on android platforms to monitor heart related illnesses by a telemonitoring system (Szydlo, Koneiczny et al 2015). Similarly, utilization of IoT technologies is useful for monitoring of respiratory rate also. However, some of the challenges posed with the usage of IoMT in these disorders include the difficulty for accessibility by rural population, practical usability of the device by elderly patients who tend to have lesser technical knowledge and infirm physical and cognitive ability to use the technology.

3.4. Other applications

Few of the notable implementations of IoMT have been listed below. These are a compilation of results from various studies that have been conducted.[14]

1. Smart phone or tablet assistance in routine surgical scenarios, eye care, etc.
2. Image based analysis of joints, ENT surgeries monitoring systems.
3. Baby incubator monitoring systems.
4. Provision of pre-hospital assistance for victims of Road traffic accidents or injuries and so on.

4. Biosensors

Biosensors are analytical devices that turn a biological response into an electrical signal, as termed by 'Cammann.' They should be very specific, independent of physical conditions such as pH and temperature, and reusable in the best case scenario.[16] In general sensors are categorized as physical, chemical and biological based upon the scenario of application. As per the definition of International Union of Pure and Applied Chemistry (IUPAC), a biosensor is a self-contained integrated device that uses a biological recognition element in direct spatial contact with a transduction element to provide specific quantitative or semi-quantitative analytical information. (1996).The classification of biosensors based upon the traditional perspective is mainly based on the type of transducer units, identification and recognition elements.

The technology of biosensors has entered into a stage of providing the individuals with insights into their own physical dynamic with the implementation of IoT in healthcare. A typical biosensor embodies an analytical system which has a bio-recognition element, a transducer element, a signal transmission system and an amplifier element.[17]

One of the key mechanisms of a biosensor involves the detection and recognition of the biomaterial or biomarker which is a structure, substance or activity in the body that influences or predicts the occurrence or outcome of disease like enzymes, antibodies, cells, tissue sheets, nucleic acids, micro-organisms, etc., Nanomaterial based biosensor technologies are also emerging up as a significant field of research in the recent times.

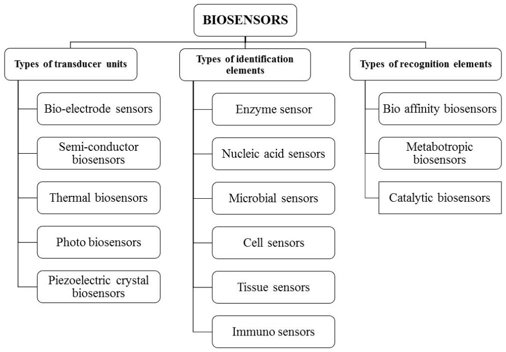

Fig. 2: Biosensors

4.1. Wearable biosensor systems

Due to the rising awareness among people regarding desire for health and fitness, advancements in material technologies and advent of smart phones & high speed internet, wearable biosensors have come into spotlight due to their minimal invasiveness, ability to monitor relentlessly and ease of carrying and operation. These include the wearable tear, interstitial fluid, saliva, sound, implantable blood sensors. Epidermal wearable biosensors provide tight contact with the skin by transferring sensors directly onto the skin surface or incorporating them into wristbands, watches, or textiles; they bank upon the optical, electrochemical or mechanical transduction modes in coherence with bio catalytic and ion-recognition receptors.[18] Ocular wearable biosensors monitor physiological factors such as glucose, pH, protein, and others through tears; most typically, IoTs are integrated into contact lenses for the detection of biomarker levels since they are comfortable to wear and come into direct contact with the basal tears.[19] Oral cavity wearable biomarkers involve the monitoring of the saliva fluid as it is one of the best possible alternatives of choice for blood analysis in detection of biomarkers. It can be used to monitor levels of glucose, alcohol, cortisol, etc., Few of the other wearable biosensors involves monitoring of vital parameters like heart rate, blood pressure, core body temperature, ECG and so on.

Data mining algorithms are applied to comprehend the data obtained through the wearable sensor devices and they can predict patterns in connection to the desired application of the device. The collected data are interpreted and verified and used for follow-up clinical action.

Cost, user experience, energy efficiency, data protocol support, security, privacy, reliability, mobility, interoperability, and platform agnostics are among factors considered while evaluating IoMT sensor systems.[16]

Limitations: The wearable biosensors faces challenges related to its scope or aim of usage, data validation techniques, stability of the device to endure physiological stresses in addition to security and privacy issues.

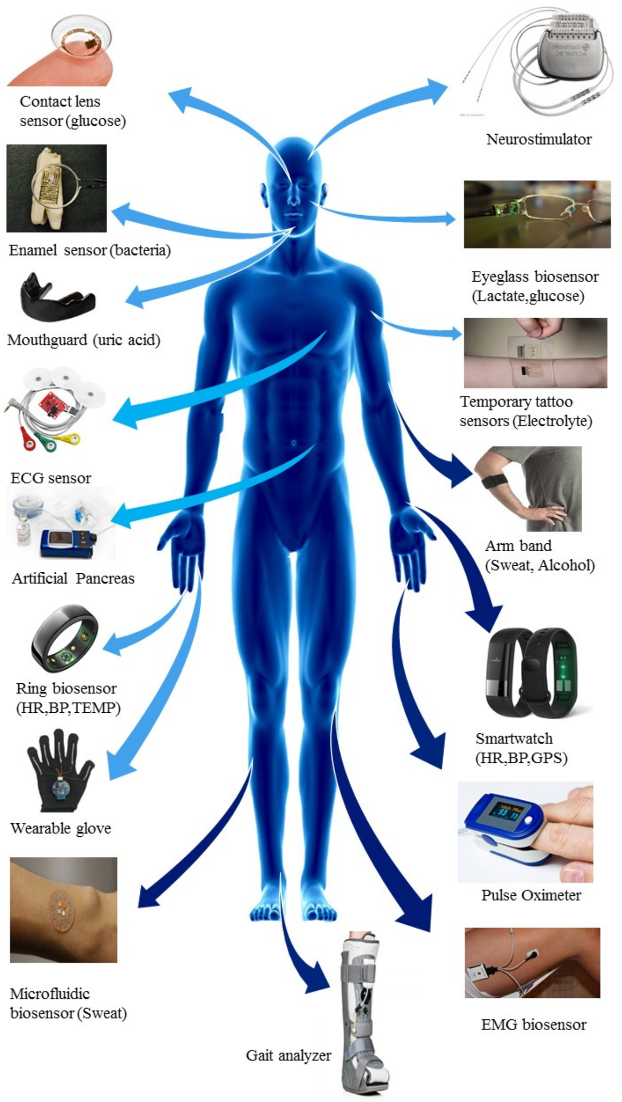

Fig. 3: Applications of IoMT

5. Radio Frequency Identification

RFID is a form of wireless communication, an innovative technology that is considered as the latest wave in the IT revolution. Basically an RFID uses radio waves for data collection and transfer. In the world of Marketing, RFID makes it easier to locate the stock, deliver timely shipments and cut down on costly data errors. Off late its utility has been explored in health sector too. RFID has the capacity to capture data without human intervention.

This system encompasses a transponder (tag) that is attached to a person or object which emits a signal that is received by a reader thereby identifying the information through the software application. The Transponders are

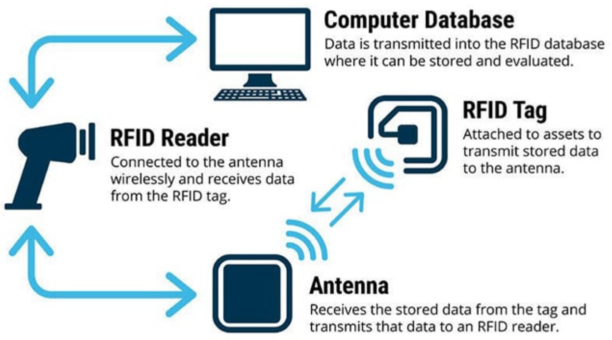

Fig. 4: Basic RFID system

either active (having their own energy source) or passive (using the energy source from the reader).[19,20] The common RFID applications being deployed in hospitals include: people, equipment, medicine/drugs and others.

5.1. Patient/staff tracking

Around a lakh patients die due to medical errors. Hospital Information System (HIS) is available only in few hospitals and a majority use only bar code technology for ensuring right treatment to the patients. The fatality rate can be drastically decreased by providing the patients to wear the RFID wrist band which keep track of the entire patient details, which are accessed by the authorized doctors and nurses. This also helps in monitoring the patients on a real – time basis. A real time location system (RTLS) is also very useful in tracking the new born babies for preventing child abduction. Also the physicians and staff nurses when needed to be present at the patient side are traced by the RTLS.[21,22]

5.2. Equipment

Include mainly medical instruments and surgical tools. RTLS helps in asset tracking for monitoring the exact place of availability of these costly equipments within the hospital premises. On metal RFID tags on surgical equipment keeps a track on their inventory as well as about the disinfection process they underwent. RFID inlays offer a cost-effective inventory solution for single-use items such as gauze, disposable exam paper, glove boxes, and plastic vials, which can be housed in RFID-enabled inventory rooms, shelving units, and vending machines.[23]

5.3. Drugs/medicines

RFID helps in combating the growth of counterfeit drug, Reverse logistics and recall management, Prescription adherence and drug testing.

5.4. Others

The other areas in health sector which finds the application of RFID is in hospital waste management, laundry and security systems. In some countries medical waste are stolen and sold during transportation leading to environmental pollution and disease transmission affecting people's health. RFID technology model was applied and promising results were found.[24]

6. Internet of Dental Things (IoDT)

Dentistry is a significant part of medicine that has embraced the digital revolution.[25] The internet of medical things, artificial intelligence, augmented and virtual reality, big data, and analytical algorithms, among other technologies, have all aided the advancement of digital dentistry. These multitude of technological applications in dentistry not only aid in streamlining the delivery of oral healthcare to patients but also helps in maximizing oral care at current costs; also alleviates the dentists and the support staff from various laborious tasks.

6.1. Mechanism of neural networking

The human intellect has the ability to synthesise sensory input gathered through the application of predetermined categories. Learning, reasoning, and self-correction are all part of this process. This is the ability to analyse data collected from a specific recognition sensor or input tool using a specified problem-solving and learning algorithm in preparation for an artificial neural network. The major application domains include Medical decision-making processes which help build an expert system, diagnostics, prognostics, data mining and machine learning.

6.2. Augmented & virtual reality

With improvements in these technologies it is now possible to develop an interactive and communicative system in dental education. Instead of the traditional pre-clinical set up laboratory system, students can have an enhanced practical skill session by implementation of virtual reality technologies, thereby drastically improving the hand-eye coordination, ergonomics and also preventing the harm in a real life patient. These are also highly beneficial in the departments of prosthodontics and maxillofacial surgery since they allow the practitioners to have a clear perspective of the oral condition of the patient through accurate simulations.[26]

6.3. Digital oral health records

With the advent of smart phones, internet revolution, and systems that have unlimited storage capacity, the data obtained through routine dental screening can be stored indefinitely and can be used as a guide for disease prediction and prognostic modelling; These data can also be used for framing population specific prevention programs, clinical support systems or expert systems, identification of associating and confounding factors, etc., therefore contributing to an enhanced oral care delivery system. These population based retrieval of personalized oral health records serve as a great platform of interconnection between the dentists and their support staff to cohesively deliver an optimum level of oral health care for their patients.[27]

6.4. *Digital oral scanner*

The conventional method of taking a physical impression, using it as a mould to pour casts have been used in to make prosthesis; however most of the times these are sometimes inaccurate upto an extent due to the properties of the material, hence failing to replicate accurate oral anatomy. Consequently, introduction of CAD-CAM (Computer aided design & manufacturing) technologies in dentistry has brought the field of prosthodontics into a new frontier, thereby enabling obtainment of a digital impression with an intra-oral scanner and direct fabrication systems.[28]

6.5. *Tele-dentistry & remote monitoring*

Tele-dentistry is defined as the provision of dental care, advice, or treatment via information technology portals rather than direct personal interaction with patients. It utilizes the electronic health records, referral systems, digital imaging systems and aims to increase provision of efficient health care, increase access of dental treatment in remote places, improving the quality of care and reduced oral disease burden.[29]

6.6. *Artificial intelligence*

The simulation of human intelligence processes by machines, particularly computer systems, is known as artificial intelligence. Artificial neural networking systems have a plethora of applications in dentistry including:

1. Clinical decision support systems
2. Tooth ache prediction models
3. Determine who is at risk for oral cancer and who is in the early stages of the disease
4. Diagnosis of Proximal Dental caries
5. Locating minor apical foramen
6. Vertical root fracture estimation
7. Chemical resistance of dental ceramics estimation
8. To differentiate the internal derangements of TMJ subgroups
9. Clinical approach to impacted maxillary canines
10. Necessity of extraction before orthodontic treatment
11. Based on 3D scan data, classification of certain aspects of a tooth
12. Periodontitis risk assessment
13. Symptom & Risk factor based diagnosis of gum disease and so on.[30,31]

Limitations: The main challenges of enforcing Internet of things in dentistry is mostly the inability of perception of large numerical data and lack of infinite storage capacity which are now being overcome by cloud and parallel computational methods.

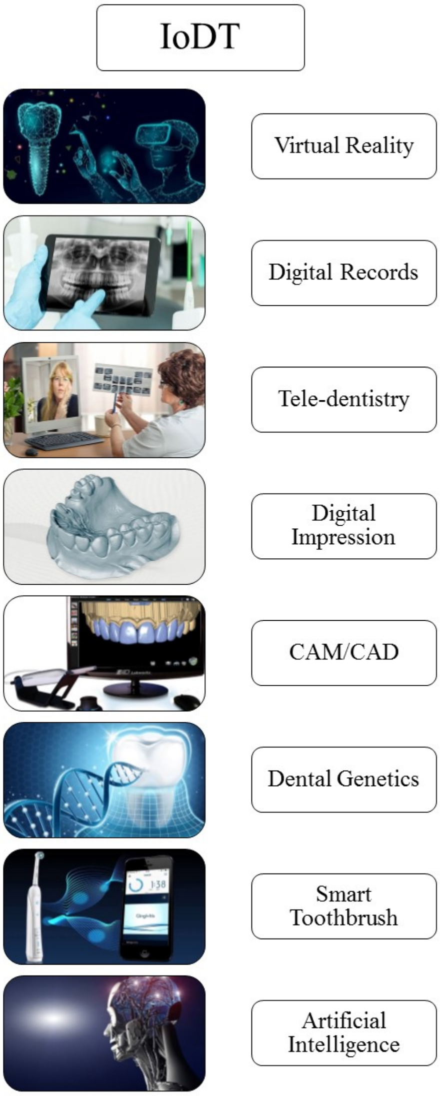

Fig. 5: Applications of IoDT

7. Conclusion

Traditional health care is undergoing a paradigm shift as digital transformation places technologically advanced goods in customers' possessions and improves access to health care services for patients and physicians even in the remote areas. The Internet of Things has walked the walk in the recent past and well integrated in various sectors, including healthcare, increasing productivity and data analysis. It can improve patient safety by a faster disease diagnosis with improved and proactive treatment. It is also pivotal in managing medical equipments and medications, thereby reducing the errors by efficient data generation saving cost & time, beneficial for patients, physicians and hospitals.

8. Ethical Approval

This review article does not contain any studies with human participants or animals performed by any of the authors.

9. Source of Funding

Not Applicable.

10. Conflict of Interest

The authors declare no conflict of interest.

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