Migration Letters

Volume: 19, No: S8 (2022), pp. 1654-1666

ISSN: 1741-8984 (Print) ISSN: 1741-8992 (Online)

www.migrationletters.com

Exploring The Internet Of Things In Dental Field-New Perspectives

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Abstract:

A revolutionary approach to oral healthcare is presented by the combination of wireless sensors with the Internet of Medical Things (IoMT) and the nascent Internet of Dental Things (IoDT). The applications of sensor technology in dentistry are examined in this study with an emphasis on disease management, prevention, and individualized care. The use of intraoral sensors for the early identification of oral cancer, the tracking of salivary biomarkers, and the monitoring of vital signs are important topics of discussion. The ability of non-invasive electrochemical sensors to monitor metabolites and electrolytes in bodily fluids is highlighted, as this can provide important information on general health and well-being. The monitoring of ailments like heart disease, sleep apnea, and Parkinson's disease is discussed in relation to wearable sensors, which allow for early symptom detection and individualized treatment plans. Furthermore, the application of edge computing technology is examined in light of its contribution to improving data security and processing efficiency. The study highlights how sensor technology has the potential to completely transform the way oral healthcare is delivered by providing patients and healthcare professionals with tailored treatment plans and actionable findings. Keywords: intraoral sensors, electrochemical sensors, wearable sensors, edge computing, oral healthcare, disease management, preventive, individualized treatment, wireless sensors, Internet of Medical Things (IoMT), and Internet of Dental Things (IoDT).

Key words: *wireless sensors, Internet of Medical Things (IoMT), Internet of Dental Things (IoDT), oral healthcare, disease management, prevention, personalized treatment, intraoral sensors.*

Introduction:

The Internet of Things (IoT) is an advanced internet-based architecture that has been incorporated into many different areas of science and technology. Its impact is especially noticeable in the market's growth in IoT-enabled digital gadgets, internet services, medical equipment, and smart home technology improvements [1, 2]. Smart entities, including wireless sensors and electronic gadgets, are incorporated into cloud networks inside this networked web-based architecture to enable various capabilities. As a result, procedures for gathering, exchanging, transferring, and storing data have been improved by IoT applications, increasing productivity, and saving time [1, 2]. Scientific researchers have given Internet of Things (IoT) a lot of attention, which has resulted in a recent boom in studies and technical developments based on IoT principles. The Internet of Things (IoT) is regarded as one of the most exciting and quickly developing aspects of web-based technology and has become a major force behind technical growth [3]. Additionally, the Internet of Things has sparked the creation of cutting-edge medical applications in the field of medicine that are meant to improve patient care and manage chronic illnesses. The "Internet of Medical Things (IoMT)," a specific subset of IoT, is a prime example of how IoT technology and medical procedures interact [4].

The foundational goal of the Internet of Medical Things (IoMT) in the medical domain is "prevention and management of chronic debilitating diseases." Patient healthcare data is continuously monitored in order to achieve this goal. To make monitoring tasks easier, mobile applications are seamlessly integrated with wireless sensors, electronic gadgets, and wearable health monitors. As a result, IoMT is crucial to contemporary medicine and produces large amounts of healthcare data for use in current healthcare systems [4]. Based on previous surveys aimed at assessing the market penetration of IoMT, it is anticipated that between 2022 and 2025, the Internet of Medical Things would have a market share of roughly $115 billion in the larger IoT applications space. Furthermore, it is projected that between 100 and 150 billion different tracking devices and sensors would be connected within cloud networks by the end of this decade [5]. The medical industry is changing as a result of this explosion in IoMT development, and "IoMT experts in medicine" are a new class of healthcare professionals that are emerging [4]. These specialist specialists will track patients' health states using IoMT wireless devices and sensors, facilitating early diagnosis and illness prevention. Additionally, they will be essential in supporting disease-free lifestyles and psychosomatic health among people of all ages, which will raise the standard of primary healthcare systems as a whole [4].

The last ten years have witnessed a substantial shift in clinical dentistry due to the development of digital technologies [6], the quick development of dental materials [7], improved clinical patient-management strategies, and the adoption of patient-centered preventive treatment methods. Modern clinical dentistry has greatly benefited from the digital revolution, and this trend is anticipated to continue in the years to come [8]. General well-being is closely linked to oral health. The World Health Organization (WHO) has released a survey that indicates that oral disorders are among the most common health problems in society. These conditions can lead to pain, discomfort, tooth loss, and in extreme situations, even death. Dental caries is the most common dental disease in the world, impacting almost 4 billion people, and periodontal disorders are the 11th most common disease globally. Moreover, oral malignancies are among the top three most common tumors worldwide, carrying a heavy burden. As such, oral cancer, periodontal disorders, and tooth caries are common problems affecting people all over the world. Dental procedures are frequently expensive and time-consuming, accounting for 5% of all healthcare spending worldwide. This amount increases to about 20% of the total healthcare spending in underdeveloped nations. The prevalence of dental problems in society is caused by a number of variables, such as the consumption of fermentable carbohydrates in contemporary diets, alcohol and tobacco use, poor oral hygiene habits, and insufficient fluoride exposure. Reducing the prevalence of oral cancer, periodontal disorders, and dental caries in communities requires addressing these issues.

Importance of IOT and Applications:

A cloud network-based technical innovation that has been effectively incorporated into the medical industry is the Internet of Medical Things (IoMT) [9]. IoT technology is used in medicine, specifically, for managing chronic diseases, preventing disease, and actively monitoring patients. Dentistry currently lacks an analogous Internet of Things infrastructure (IoT Dentistry). On the other hand, there is hope that the Internet of Dental Things (IoDT) would greatly improve oral health conditions such as periodontal disease, dental caries, and oral cancer detection and prevention. IoDT would also be essential to the monitoring and data collection processes in oral healthcare systems, giving dentists access to cutting-edge techniques for risk assessment.

Dental caries is a complicated illness caused by a mineral imbalance that dissolves enamel and destroys both organic and inorganic materials in the hard and soft tissues of teeth [10]. Reduced pH levels, frequent sugary food consumption, duration, decreased salivary secretions, cariogenic bacterial flora (e.g., Streptococcus mutans, Lactobacilli, etc.), and poor oral hygiene conditions are all factors that contribute to the development of caries [11]. Bacterial biofilm on the surface of teeth is the cause of periodontal disease, which is characterized by inflammation of the gingiva, adjacent alveolar bone, and periodontal ligament [12]. Periodontal infections and dental caries are long-term bacterial disorders that can lead to tooth loss. These illnesses continue to be common despite advances in medical research and higher living standards because of dietary and lifestyle modifications, behavioral changes, systemic disease side effects, and patients' lax oral hygiene practices [13].

Oral malignancies, the sixth most prevalent cancer in humans, present as invasive lesions within the oral cavity [14]. Early diagnosis and detection of oral cancer lesions is critical to successful cancer care. Regretfully, oral malignancies are frequently detected at a later stage, which results in dismal surgical outcomes and poor prognoses [15]. In order to detect and prevent oral malignancies in their early stages, dentists are essential [16]. As life expectancy rises and treatment technologies evolve, illness prevention will become the primary focus of dental care in the future. The motto of the future dental care paradigm will be "Prevention measures are as important as curative methods." New technologies, like IoDT, have the potential to help prevent dental caries and other oral disorders, as well as successfully manage them. In the future management of dental caries and other oral diseases, three key factors will form the foundation: prevention, early disease detection, and risk assessment. These preventive measures must be easily applicable to a large population, affordable to patients, and effectively utilized at the community level. The Internet of Dental Things (IoDT) holds significant promise for widespread adoption in various fields of dentistry due to its ease of application. IoDT facilitates the rapid collection, transfer, and analysis of patient data, serving as a technological bridge between patients and oral healthcare providers. In summary, IoT Dentistry presents a promising future and is poised to revolutionize the dental field.

This review paper primarily focuses on the effective implementation of IoDT in dentistry and is organized into six sections as follows:

1. Introduction: This section introduces IoMT technology and highlights the significance of IoT application—specifically, the Internet of Dental Things (IoDT)—in dentistry.
2. Study Protocol and Methodology: The second section outlines the study protocol and methodology employed in this review.
3. Overview of Digital Technologies in Dentistry: The third section provides an overview of various digital technologies currently used in dentistry, including advanced computer-based technologies widely utilized in daily dental practice.
4. Challenges and Monitoring Devices in IoDT Implementation: The fourth section discusses potential challenges in implementing IoDT in dentistry and explores monitoring devices and data collection tools used in IoDT.

5. IoDT Technology-Dependent Oral Health Care Model: In the fifth section, an IoDT technology-dependent oral healthcare model in dentistry is introduced.
6. Conclusions: The final section presents the conclusions drawn from this literature review study.

Digital Platforms in Dentistry:

Advanced computer-aided technology known as Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) is used to fabricate dental prostheses, which are frequently used in patient treatment procedures [19]. Three major computer programs are used in this technology: first, digital scanning is used to collect patient data; next, specialist software is used for design; and lastly, the final appliances are manufactured [20]. Online CAD/CAM systems can be used for additive technological manufacturing processes or subtractive manufacturing processes [20, 21]. An innovative computer-based technique used in many dental applications is 3-Dimensional (3-D) printing. It is employed in the creation of surgical guide planes, which are essential for implant installation. In addition, 3-D printing plays a key role in the production of night guards, orthodontic aligners, crowns in crown and bridge prosthetic dentistry, and restorative dentistry models for prosthodontic patients [22]. As a result, 3-D printing facilitates the procedures of treatment management and planning. Cone Beam Computed Tomography (CBCT) is a sophisticated radio-imaging method that uses a spinning detector and an X-ray beam with a conical form. The detector completes a full circle around the subject or object, gathering radiography data in order to produce a sequence of two-dimensional pictures. Then, using modified Feldkamp techniques, these images are transferred to computer programs and transformed into 3-D representations [23, 24]. In dental implantology, CBCT largely aids in diagnostic and therapy planning [25]. Several dental specialties have found use for it, including endodontics [26], maxillofacial surgery [27], orthodontics [28, 29], periodontics [30], and orthodontics for prognostics of conditions like cleft lip-cleft palate, skeletal malformations, tooth resorption, and detection of pathologies in synovial joints and alveolar bones.

CBCT is a crucial computer-based technique in modern dentistry because it produces precise 3-dimensional images of the surrounding skeletal structures as well as the soft and hard tissues of tooth [31]. Electronic Dental Records (EDR) systems are commonly employed in dental clinics to store patients' clinical data and information. The majority of dental practitioners manage patient information through software, making EDR an essential tool in modern dental offices [32]. A recent study indicates that approximately 70-75% of dental practitioners in the USA and 90-95% in Scandinavian countries utilize EDR systems to store clinical data in their practices [33]. These numbers are steadily increasing as more dentists adopt electronic data storage due to its ease of use, cost-effectiveness, time-saving benefits, and the utility of clinical data for dental research purposes [33]. Digital Radiography has revolutionized dental radiography with its 2-D and 3-D imaging techniques, offering superior radiographic contrast and quality while reducing radiation exposure [34]. Digital Impressions have become more common than conventional impression techniques for various dental procedures, including crowns, fixed prosthodontics, and implant-supported prostheses. Digital impressions offer greater precision, accuracy, speed, and dentist-friendly operation compared to traditional methods [36].

3-Dimensional Finite Element Analysis/Method (3D-FEA/FEM) is an emerging technology used for biomechanical analysis, particularly in evaluating complex structures and estimating their biomechanical properties. In oral implantology, it aids in assessing stress concentrations in implants and surrounding alveolar bone [37]. Virtual Reality (VR) technology creates immersive 3-dimensional environments that allow patients to interact as if they are physically present. VR is being researched for applications in dentistry, including surgical training and dental student education [39, 46,47,48]. Augmented Reality (AR) supplements real-world surroundings with computer-generated illustrations and information, enhancing diagnostic and treatment planning processes. AR is utilized in various dental procedures, including implant placement, orthognathic surgeries, orthodontics, endodontics, and restorative dentistry [49, 50]. Teledentistry combines dentistry and information technology, utilizing telecommunication for patient consultations, exchanging images, radiographs, and patient information to provide dental care remotely, particularly in inaccessible and remote geographic areas [51]. Teledentistry has proven beneficial in detecting dental disorders in elderly patients, evaluating oral prosthesis condition, enhancing oral health in rural areas, diagnosing third molar impactions, and detecting dental caries [52, 54, 55]. Teledentistry offers a convenient and effective approach to oral health screening, early disease detection, diagnosis, patient consultation, and disease management, making it a valuable tool in remote dental care [56].

Challenges of IoT Implementation in Dentistry:

The implementation of IoT in dentistry presents several challenges, primarily stemming from issues related to data size, security management, clinical integration, heterogeneity, and data collection efficiency. Heterogeneity poses a significant challenge in IoDT implementation, as there is variability in clinical systems among dental practices. Seamless connectivity between patient dental record systems and IoDT servers is crucial for efficient monitoring and analysis of patients' healthcare data. However, the current prevalence of conventional paper record systems in small-scale dental clinics exacerbates this challenge [57]. Data size is another major concern, as the clinical application of IoDT generates vast amounts of dental data. Managing big data in IoDT requires substantial resources, infrastructure, and services for data collection, monitoring, transfer, and analysis. Adapting IoDT to dentistry entails monitoring numerous clinical and nonclinical parameters, necessitating effective data storage and management systems [58]. The collection, storage, and analysis of big data pose significant challenges in IoDT implementation. With an expected 75-100 billion IoDT-associated devices by the end of the decade, storing and accessing data in the cloud, as well as ensuring its proper evaluation, become paramount. The storage and reuse of cloud data represent significant hurdles in future research and patient oral healthcare systems [59].

Facilitating easy, simple, and secure connections between devices and cloud servers is essential for IoDT. A robust IoDT system should feature a straightforward device management system and data encryption to ensure data security and manageability [60]. Efficient data collection is critical for IoDT success. Well-designed data collection devices, monitoring devices, and sensors are necessary to streamline data collection processes. Stronger connections between dental devices and the cloud are essential for extracting needed data quickly and easily. One of the most important parts of implementing IoDT is minimizing the risk of data loss and updating data security. Significant obstacles arise from system disruptions during data collection and transport, as well as the possibility of data loss afterwards. Larger memory capacity are required in order to handle this, as data can be temporarily stored in the data gathering devices/sensors themselves. Maintaining collected data security requires regular changes to cloud security [60, 61]. There's a chance that some computer devices will be less secure and private than other devices when the number of IoDT-related gadgets grows quickly. It is a difficult effort to ensure the security and privacy of these devices [62]. Reducing energy usage is essential to guarantee uninterrupted monitoring device operation in the event of power outages. Energy-efficient design and data encryption techniques can provide the continuous power sources that monitoring devices need for data transfer to occur. An essential component of IoDT technology success is the wearable, sensor, and monitoring devices' ease of use. These devices' wearability and design greatly aid in making the data collection procedure easier.

These devices must be small in size, light, portable, biocompatible with the surrounding tissue, and long-lasting. They should also be user-friendly for patients and simple to charge and run.

Devices for Monitoring IoT:

Devices for monitoring and data collection in IoDT play a critical role in continuous patient observation and disease detection. Intraoral wireless sensors, both invasive and noninvasive, are utilized for this purpose. These sensors are positioned in the oral cavity to enable uninterrupted monitoring of patient functions without causing discomfort or disruption [63]. Sensor placement within the oral cavity requires careful consideration to ensure continuous monitoring without inconveniencing the patient. Invasive sensors may be integrated with oral implants in the alveolar bone, while noninvasive sensors can be attached to the buccal or lingual surface of teeth or or oral devices. The future detection and data collection of diseases heavily rely on web-based sensor technology, which incorporates advanced communication technologies such as wireless e-communication, automation processes, the principles of the Internet of Things (IoT), and cloud computing [64]. IoT technology comprises sensor technology and cloud networks, both of which have undergone significant transformations in recent years. Sensor-associated devices communicate data to patients' personal cell phones or tablets, forming a Body Area Network (BAN). These sensor-embedded devices monitor, transfer, and integrate patient data into cloud networks for further analysis and diagnostics [65]. The future of disease detection and diagnosis will rely on advancements in sensor technology, cloud networks, and wireless communication devices. With the expected proliferation of IoT devices, the network will become increasingly complex and crowded, with patients at the center of this environment [66]. In several medical research, wireless sensors, and the Internet of Medical Things (IoMT) are used to control and prevent various diseases. These sensors are essential for monitoring vital signs and treating chronic disorders, as well as for identifying, diagnosing, treating, and avoiding diseases. Assessing a patient's physiological state and general health requires monitoring vital signs such blood pressure, pulse oxygenation, blood sugar, heart rate, and breathing rate. Effective health monitoring is now possible because to the successful implementation of flexible and stretchable sensors with silicone-based electronics for tracking vital signs, particularly for patient groups that are poor and live in distant places [67, 68]. IoMT and smart sensors are used in the treatment of diabetes mellitus (DM) to avoid problems like diabetic foot ulcers, which can result in gangrene and lower limb ischemia. IoMT devices save lives and avert complications by remotely monitoring patients' health [69].

The motor functions of persons with Parkinson's Disease (PD), a chronic neurological illness, are affected. Continuous activity monitoring and data collection for disease management are made possible by lightweight wearable sensors that are incorporated into the clothes of people with Parkinson's disease (PD) and linked to wireless communication devices [70, 71]. To improve safety and accuracy during surgical procedures, smart sensor technology is also used. IoMT improves surgical instrumentation and lowers the hazards associated with invasive operations by enabling the vision of instruments during surgeries in conjunction with sensors [72]. Capacitive sensors can be used to measure respiration rates and monitor symptoms of Chronic Obstructive Pulmonary Disease (COPD), which is characterized by airway blockage and breathing difficulties. Patients with COPD can have their respiratory functions continuously monitored thanks to these sensors and IoMT [73]. Wearable sensors and smart phones are employed to monitor the spread of infectious diseases such as Ebola among vast populations. Furthermore, musculoskeletal disorders are treated with wearable sensors linked to IoMT technology, highlighting the adaptability and efficacy of sensor-based technologies in healthcare [74, 75]. Wireless sensors play a significant role in the early diagnosis and prevention of oral diseases when integrated with IoMT technology, offering promising avenues for disease management. Here's how these sensors are utilized in various applications:

1. **Oral Cancer Detection**: Smart mobile fiber optic probe sensors are utilized in diagnosing oral and cervical cancers. These sensors enable early detection and diagnosis, crucial for improving prognosis and treatment outcomes [76].
2. **Saliva Biomarker Detection**: Silicone biosensors are employed to detect biomarkers present in saliva, particularly for diagnosing oral squamous cell carcinoma. These sensors offer a non-invasive method for early detection of oral cancer [77].
3. **Sleep Apnea and Stress Management**: Adherence sensors embedded in lower arch devices are used for managing disorders like sleep apnea and stress. These sensors aid in monitoring and treating such conditions effectively [78].
4. **Bite Force Measurement**: Intraoral sensors, such as Fiber Bragg Grating (FBG) sensors, are utilized to measure biting force accurately. These sensors, integrated into oral appliances, offer valuable insights into oral function and health [79].
5. **Non-Invasive Electrochemical Sensors**: Electrochemical sensors are used for tracking electrolytes and metabolites in body fluids like tears and saliva. These sensors find applications in healthcare monitoring, fitness tracking, and military use due to their efficiency and cost-effectiveness [80].
6. **Gait Disturbance Monitoring in Parkinson's Disease**: Wearable sensors are employed to assess gait disturbances and fall episodes in Parkinson's disease patients. These sensors facilitate continuous monitoring and management of motor symptoms [81].
7. **Heart Disease Monitoring**: Electrochemical sensors, integrated with IoMT technology, enable continuous monitoring of vital parameters such as heart rate, blood pressure, oxygen saturation, and body temperature. This monitoring system aids in the early detection and management of heart diseases [82].
8. **Salivary Metabolite Tracking**: Wearable mouthguard sensors are used to track salivary metabolites, offering a non-invasive method for monitoring oral health and collecting patient data [83, 84].
9. **Smart Toothbrushes**: Smart toothbrushes equipped with sensors and IoDT technology enable real-time monitoring of oral hygiene practices. These brushes collect data on brushing techniques, pressure applied, and plaque removal efficacy, facilitating personalized oral care management [85, 86].
10. **Edge Computing Technology**: Mounted chips with edge computing technology offer advantages such as better battery life, faster response times, energy efficiency, cost-effectiveness, and enhanced data security. These chips process data locally, reducing the burden on cloud networks and improving overall system performance [89, 90].

By leveraging wireless sensors integrated with IoMT technology, oral healthcare professionals can enhance disease management, promote preventive care, and improve patient outcomes through continuous monitoring and personalized interventions.

Conclusion:

In conclusion, a novel approach to oral healthcare is presented via the integration of wireless sensors with the Internet of Medical Things (IoMT), which offers a variety of applications for disease management, prevention, and customized therapy. Healthcare practitioners may now analyze salivary biomarkers with remarkable accuracy and efficiency, monitor vital signs, and identify early warning indications of diseases like oral cancer by using smart sensors implanted in intraoral devices like mouthguards and toothbrushes. These sensors offer non-invasive data collection techniques, allowing for real-time, ongoing patient monitoring of their dental health. Moreover, the use of non-invasive electrochemical sensors makes it easier to monitor metabolites and electrolytes in bodily fluids like saliva, providing information on general health and wellbeing. Wearable sensors are essential for tracking ailments including heart disease, sleep apnea, and Parkinson's disease since they allow for early symptom detection and individualized treatment plans. Moreover, edge computing technology improves data processing effectiveness, guaranteeing quicker reaction times, more energy efficiency, and better data security. The development of the Internet of Dental Things (IoDT) creates new opportunities for dental disease management and prevention. Dental professionals can access real-time patient data, identify trends, and decide on the best course of action by utilizing sensor technologies and cloud-based systems. IoDT provides a comprehensive solution for improving patient outcomes and raising the standard of oral healthcare delivery, from monitoring oral hygiene practices to identifying early indicators of tooth caries and periodontal disorders. In general, the combination of wireless sensors with IoMT and IoDT signifies a paradigm shift in oral healthcare by providing tailored treatment options and relevant insights to patients as well as healthcare providers. The possibilities for innovation in disease management and preventative care in dentistry are virtually endless as long as technology keeps developing. The dental business may move toward a future where oral disorders are identified early, efficiently prevented, and precisely managed, thereby enhancing the general health and well-being of people globally, by embracing these breakthroughs and utilizing the potential of sensor technology.

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