Review on Terahertz Technology in Head and neck diseases: Advancement & Challenges

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Received 20.09.2023 **received in revised form** 01.10.2023, **accepted** 16.10.2023
DOI: 10.47904/IJSKIT.13.2.2023.30-33

Abstract- **Terahertz radiation situated between infrared and milimeter waves on the electromagnetic spectrum has concentrated considerable attention on its remarkable potential in medical diagnosis and biomedical applications over the last three decades. The exploration of terahertz interaction with biological systems has given rise to an exciting field in the life sciences. Terahertz radiation demonstrated its ability to diagnose various diseases like brain cancer, thyroid nodules, and eye conditions. This comprehensive review delves into the biological attributes of THz waves and their clinical applications, with a primary focus on the remarkable progress made in utilising THz technology for head and neck diseases. We examine the current state of research, offering insights into the promising role of THz technology in enhancing diagnosis and treatment for these specific conditions.**

Keywords– **QCLS, CT, THz, OTIT**

1. INTRODUCTION

Terahertz (THz) radiation, situated within the electromagnetic spectrum between infrared and microwaves, with frequencies ranging from 0.1 to 10 THz, was once a vast, unexplored frontier known as the terahertz gap. This gap persisted due to the absence of effective generators and detection techniques for an extended period. However, due to the quick development of ultrafast laser technology and advancements in semiconductor materials science, recent decades have seen a remarkable transformation. These developments have given rise to stable and reliable THz laser sources, igniting a renaissance in THz radiation applications, particularly in spectroscopy and imaging technology. The unique attributes of THz radiation have paved the way for its widespread application in the diagnosis and treatment of head and neck diseases. We provide a succinct overview of the unique biological attributes of THz radiation, with a specific focus on the research advancements concerning the biological effects of THz waves in head and neck diseases. Comparative summary presented various reported literatures with the state-of-the-art biomedical applications particularly. R. Madhavan (2023) demonstrated the effectiveness of Terahertz imaging in enhancing tissue contrast for head and neck tumors the cancer cell detection.[1] In a related work by John et. al, [2][3], the applications of the biological efects of THz in biomedicine and the characterization techniques of THz in detection of cancer, protein, amino acids & polypeptides, DNA etc. were reported. THz technology – THz imaging and THz spectroscopy was introduced in another study, a short overview of THz technology advances and its application for cancer diagnosis was highlighted. Being located between microwave & infrared region, THz waves are strongly sensitive to and attenuated by water through strong absorption. The characteristic properties of THz radiation such as low photon energy implying nonionizing hazard on biological tissue cause the technology to be interesting for biological applications. Son et al. (2021) explored the potential of Terahertz-based therapeutics, showing promise in treating laryngeal carcinomas. Peng Y. (2020) introduced the concept of intraoperative Terahertz imaging for real-time surgical guidance in tumor resections.

2. BIOLOGICAL CHARACTERISTICS OF TERAHERTZ TECHNOLOGY

The biological characteristics of terahertz (THz) technology refer to the potential effects of THz radiation on living organisms, including humans. THz technology operates in the electromagnetic spectrum range between microwave and infrared frequencies, typically from 0.1 to 10 THz. While THz radiation has promising applications in various fields, such as imaging, sensing, and communication, there is ongoing research and debate regarding its biological effects like tissue Interaction, Skin Penetration,Biological Imaging The biological characteristics of THz radiation are multifaceted and encompass its sensitivity to molecular vibrations, interaction with water molecules, ability to provide unique spectral signatures, non-ionising nature high resolution, and penetration capabilities, as well as its influence on refraction and absorption. These attributes collectively empower THz technology to revolutionise the field of biomedical research and diagnostics, offering innovative solutions for the detection and identification of bio-organic molecules and tissues. Son et al.[4] have reviewed the biomedical THz state-of-the-art techniques, methodologies and applicable potential techniques that could revolutionize healthcare. They surveyed some techniques for wet tissue penetration depth enhancement where they discussed methods for reaching internal organs like endoscopy and otoscopy. Further, explained the principles of operation of some THz based sensors with diabetes, breathing conditions and blood disorders sensing examples. Many of the THz biomedical applications were reported to be in cancer imaging including in detection of oral, skin, gastric, brain and breast cancers. Moreover, the potential of cancer treatment through demethylation of malignant DNA by the use of a specifc high-power frequency of THz radiation are also reported with its potential as a cancer biomarker. In a similar work by Danciu [5][6]. In another study, the potential biomedical application of THz technology; imaging and spectroscopy specifcally for cancer, based on the features exhibited by THz radiation including low ionization energy and ability to identify biomolecules using their spectral fngerprints was reviewed [7].

3. TERAHERTZ IMAGING

The journey of terahertz (THz) imaging commenced with the groundbreaking work of Hartwick et al., who reported the first THz image using an optically pumped molecular THz laser. However, the true turning point arrived in 1995, when Hu and Nuss unveiled optoelectronic THz imaging technology, leveraging femtosecond laser-based sources. This pivotal development ignited a surge of enthusiasm and research activity in the burgeoning field of THz science and technology [8]. The evolution of THz imaging techniques, encompassing both optoelectronic and all-electronic methods, has ushered in a new era of scientific exploration and practical applications. These advancements continue to expand the horizons of the THz imaging technology shown in Figure 1, enabling a diverse range of fields to benefit from its unique capabilities [9].

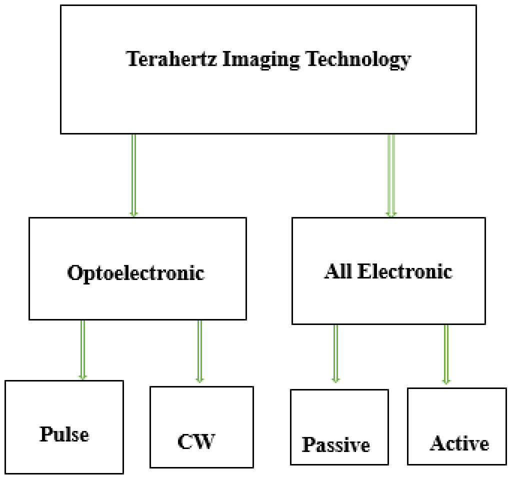

Figure 1: Terahertz Imaging Technology

3.1 Optoelectronics Terahertz Imaging Technology

Optoelectronic terahertz (THz) imaging technology is a subset of THz imaging that relies on optoelectronic components for the generation and detection of THz radiation. This technology combines principles from optics and electronics to create THz images of objects or materials and key components, as well as the principles of optoelectronic THz imaging: Thz Source, Thz Manipulation, Terahertz Detection, Control, and Synchronization. This technology is particularly useful for applications that require high sensitivity and spectral information in the THz range. It finds applications in fields such as material characterization, pharmaceuticals, security screening, and non-destructive testing. The ability to capture both amplitude and phase information in the THz spectrum makes it valuable for studying a wide range of materials and biological samples.

3.2 All Electronics Terahertz Imaging

It represents an innovative approach to capturing and visualising THz radiation without the need for traditional optical components like lasers and optics. Instead, these systems rely on specialised electronic devices and detectors that operate at THz frequencies. In all-electronic THz imaging, high-frequency electronic circuits are used to both generate and detect THz radiation, making the systems more compact and potentially more cost-effective than optoelectronic counter parts. Key components often include THz quantum cascade lasers (QCLs) for emission and THz detectors based on semiconductor materials or superconducting devices. This approach allows for the creation of THz images with high spatial resolution and sensitivity, making it suitable for various applications such as security screening, medical imaging, and materials research. As technology in this field continues to advance, all-electronic THz imaging holds the promise of enabling new and exciting capabilities in THz sensing and imaging.

Table 1: Applications of terahertz in head and neck diseases

Brain Tumor	IT can help visualize the boundaries of tumors, aiding surgeons in tumor removal procedures and treatment planning.
Eye Diseases	THz imaging can potentially detect early-stage cataracts by assessing changes in the transparency and water content of the eye's lens. Early detection can lead to timely intervention and better treatment outcomes.
Oral Cancer	This can aid in achieving complete tumor resection while minimizing damage to healthy tissues, reducing the risk of recurrence.
Thyroid Nodule	It distinguishes types of thyroid nodules

4.TERAHERTZ COMPUTED TOMOGRAPHY

Terahertz computed tomography (THz CT) is an imaging technique that uses terahertz radiation to create detailed cross-sectional images of objects and materials. Terahertz radiation falls in the electromagnetic spectrum between microwave and infrared radiation, typically ranging from 0.1 to 10 terahertz (THz). This technology has several applications in various fields, including medical imaging, security screening, and materials science. How Teraheterahertz is shown by a block diagram.

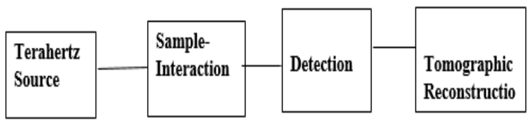

Figure 2: Block Diagram of Terahertz

Here, terahertz radiation is generated using various methods, such as terahertz time domain spectroscopy. In detection, terahertz is directed towards the object or material being scanned. In interaction, terahertz waves interact with the material, and these waves can penetrate many non-metallic and non-planar materials, making them useful for imaging a wide range of samples. Here, the system detects the terahertz waves that are either transmitted through the sample or reflected from its surface. In data collection, multiple data points are collected as the terahertz waves pass through or interact with the object. These data points were acquired from different angles to create a three-dimensional data set. In reconstruction, computational algorithms are used to process the acquired data and reconstruct the 3D image of the object or material. Some applications are medical imaging, material science, security screening, the semiconductor industry, and non-destructive testing. Whileterahertz CT has significant potential, it also hassome limitations, such as limited penetration depthin certain materials and the need for specialized equipment. Researchers continue to work on improving technology and expanding its range of applications. Applications of terahertz in head and neck diseases [10].

5. FUTURE CHALLENGES

1. Clinical Validation: One of the primary challenges is conducting extensive clinical validation studies to establish the reliability and effectiveness of THz technology in diagnosing and monitoring head and neck diseases. This involves large-scale clinical trials and comparisons with established diagnostic methods to demonstrate its clinical utility.
2. Standardisation: Developing standardised protocols and methodologies for THz measurements in head and neck diseases is crucial. Standardisation efforts are necessary to ensure consistent and reproducible results across different research groups and healthcare institutions.
3. Patient Safety: Ensuring the safety of patients during THz examinations is paramount. Thorough investigation into the potential biological effects of THz radiation on the head and neck region is needed to establish safety guidelines and protocols for THz-based procedures.
4. Data Interpretation: THz data can be complex, and effective data interpretation is essential for deriving clinically relevant information. Developing user-friendly and robust data analysis tools and algorithms specific to head and neck disease applications is a challenge. [11]

6. CONCLUSION-

In conclusion, the review of Terahertz (THz) technology in the context of head and neck diseases reveals a field of immense promise and significant hurdles. THz technology's unique photoelectric properties make it a frontier in scientific research, offering the potential for early disease detection and in-depth insights into biomacromolecules' interactions. The complex relationship between THz waves and biological systems has sparked a surge of interest in life sciences. Moreover, THz radiation technology's progress in emission sources and detection methods positions it as a valuable tool in the medical field. However, challenges such as limited clinical adoption, concerns about safety, and the need for more extensive validation studies must be addressed to harness the full potential of THz technology in improving head and neck disease diagnosis and treatment. As we move forward, the integration of THz technology with cutting-edge innovations like big data analysis and artificial intelligence holds the promise of enhancing precision medicine and providing personalized, patient-centric healthcare solutions.

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