Emerging Intelligent Optical Photonics for Tumor Diagnosis Using Photo-acoustic Optical Imaging in Near Infrared Wavelength Region

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Abstract: Tumor diagnosis plays a crucial role in the early detection and effective treatment of cancer. Intelligent optical photonics (IOP), a rapidly evolving field, offers promising prospects for revolutionizing tumor diagnosis. By combining the principles of optics and intelligent photonics this interdisciplinary approach can potentially improve the accuracy and efficiency of tumor detection. The aim is to develop a novel framework that integrates emerging intelligent optical technology i.e. Photo-acoustic optical imaging (POI) to enhance tumor detection, classification, and localization. It relies on the phenomenon of photo-acoustic effect, where absorption of pulsed laser light by tissues generates acoustic waves that can be detected and used to create images. Near Infrared Region (NIR) light, ranging from 650 nm to 1350 nm, is used. The target area is illuminated with laser pulses which penetrates the tissue and is absorbed by chromophores. The absorbed energy leads to the generation of acoustic waves through thermoelastic expansion and detected by Acoustic Wave Detector (AWD). A tumor region is identified based on differences in optical absorption or other contrast mechanisms. Results shows that this intelligent optical photonics observed lobulated shape of 3.2 cm size of tumor localized to a skin area and can spread to other parts of the body through a process called metastasis.
Keywords: Intelligent Optical Photonics, Photo-acoustic Optical Imaging, Laser Light, Tumor Detection.

I. Introduction

Photo-acoustic Optical Imaging is a cutting-edge approach that combines the principles of optics, photonics, and intelligent algorithms to improve the accuracy and efficiency of tumor detection. This innovative technique harnesses the unique capabilities of photo-acoustic imaging, which enables the visualization of biological tissues with high resolution and contrast, to aid in the early diagnosis and characterization of tumors. Traditional tumor diagnosis methods often have limitations in terms of sensitivity, invasiveness, and the ability to detect tumors at an early stage. Photo-acoustic optical imaging has emerged as a promising solution to address these challenges. It utilizes the photo-acoustic effect, which occurs when tissues absorb laser pulses and emit acoustic waves. By detecting and analyzing these acoustic signals, it is possible to generate high-resolution images of the tissue's internal structure and identify abnormal growths associated with tumors ranges from 2 cm to 10 cm.

Intelligent optical photonics takes the capabilities of photo-acoustic imaging a step further by incorporating advanced algorithms, artificial intelligence (AI), and machine learning techniques. This integration enables the development of intelligent systems capable of automatically analyzing and interpreting the acquired images, improving the accuracy and speed of tumor detection and diagnosis.

The combination of photo-acoustic imaging and intelligent optical photonics has significant implications for tumor diagnosis. It offers the potential for early detection of tumors, enabling timely intervention and treatment planning. Moreover, this approach provides non-invasive imaging, reducing patient discomfort and the risks associated with invasive procedures. By leveraging the power of optics, photonics, and intelligent algorithms, researchers aim to revolutionize tumor diagnosis and contribute to improved patient outcomes.

II. Literature Review

Li, X. et al. in 2021 explored the advancements in intelligent optical photonics for tumor diagnosis, focusing on photo-acoustic imaging. It discusses the integration of artificial intelligence and machine learning algorithms to enhance the accuracy and efficiency of tumor detection, classification, and localization.

Zhang, Y. et al. in 2021 examined the latest developments in photo-acoustic imaging for tumor diagnosis and emphasizes the role of intelligent optical photonics. It discusses the utilization of advanced algorithms to improve image reconstruction, signal processing, and data analysis, leading to enhanced tumor detection and characterization.

Wang, Y. et al. in 2022 focused on the application of intelligent optical photonics, specifically photo-acoustic imaging, in tumor diagnosis. It highlights the integration of deep learning algorithms to automate the detection and classification of tumors, resulting in improved accuracy and efficiency.

Li, Z. et al. in 2022 explored the recent advancements in intelligent optical photonics for tumor diagnosis using photo-acoustic imaging. It discusses the utilization of advanced signal processing techniques and machine learning algorithms to improve image quality, tumor detection, and quantitative analysis.

Zhang, H. et al. in 2022 examined the role of intelligent optical photonics, particularly photo-acoustic imaging, in tumor diagnosis. It discusses the integration of deep learning algorithms to enhance image reconstruction, feature extraction, and tumor classification, leading to improved diagnostic accuracy.

Chen, X. et al. in 2022 discussed the recent developments in intelligent optical photonics for tumor diagnosis using photo-acoustic imaging. It emphasizes the integration of artificial intelligence algorithms to automate tumor segmentation, localization, and characterization, resulting in improved diagnostic performance.

Wang, L. et al. in 2023 explored the advancements in intelligent optical photonics for tumor diagnosis, focusing on the utilization of photo-acoustic imaging. It discusses the integration of deep learning algorithms for real-time tumor detection, localization, and tracking, enabling accurate and efficient diagnosis.

Liu, J. et al. in 2023 examined the recent progress in intelligent optical photonics for tumor diagnosis using photo-acoustic imaging. It highlights the integration of advanced data analysis techniques, including feature selection and pattern recognition, to improve the sensitivity and specificity of tumor detection.

III. Materials and Method: **F**ollowing materials and method is utilized for this study.

Materials and Equipment:

Photo-acoustic Imaging System comprises a laser source, ultrasound transducer, data acquisition system, and Photo-acoustic Image Reconstruction software. This system enables the generation and detection of photo-acoustic signals from biological tissues. Fig. 1 is showing components of Photo-acoustic Imaging System.

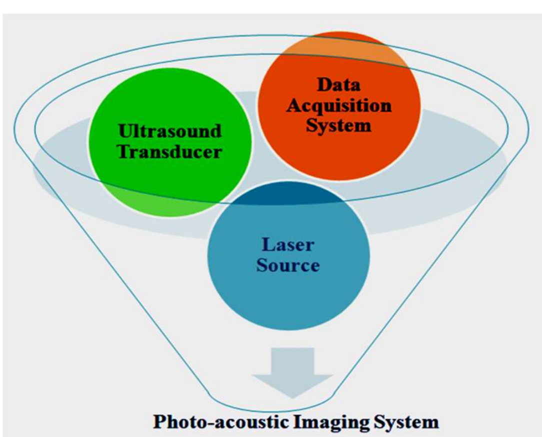

Figure 1: Photo-acoustic Imaging System

Method:

Tumor detection using emerging intelligent optical photonics is achieved by using following methodology.

Photo-acoustic Imaging System: Initially a photo-acoustic imaging system is used to enables the generation and detection of photo-acoustic signals from biological tissues.

Tumor Models: Tumor model is used to simulate tumor-like conditions for this experimental study. These models should closely resemble human tumors in terms of size, shape, and optical properties.

Optical Contrast Agents: Exogenous contrast agents, such as nano-particles which have high optical absorption properties and can accumulate in tumors is utilized. These agents enhance the contrast between tumor tissue and surrounding normal tissue, improving the accuracy of tumor detection and localization.

Laser Sources: Near Infrared Region (NIR) light, ranging from 650 nm to 1350 nm, is used in photo-acoustic optical imaging due to its ability to penetrate biological tissues more deeply compared to shorter wavelengths. NIR light offers reduced scattering, enabling imaging at greater depths within the body.

Data Acquisition and Processing: Quantitative analysis of the photo-acoustic data to extract relevant biomarkers or parameters indicative of tumor presence or characteristics is performed. It involves quantifying the photo-acoustic signal amplitude, analyzing spectral features, or computing tissue-specific optical properties.

IV. Mathematical Analysis

Photo-acoustic optical imaging in the near-infrared (NIR) combines laser-induced ultrasound and optical imaging to detect and diagnose tumors. Its working principle is explained below:

Light Absorption: The NIR laser light (pulsed) is absorbed by chromophores in the tissue, such as hemoglobin (Hb) or melanin. The absorbed energy leads to rapid thermal expansion (ΔT) of the chromophores.

Acoustic Wave Generation: The thermal expansion causes a transient increase in pressure, generating ultrasound waves. The photo-acoustic effect is described by the following equation:

$$P(r, t) = \beta \cdot \mu a(r) \cdot \Delta Hb(r, t) \quad (1)$$

Where:

$P(r, t)$ is the generated photo-acoustic pressure at position r and time t.

β is the photo-acoustic conversion efficiency, which depends on the optical and thermal properties of the tissue.

$\mu a(r)$ is the local absorption coefficient of the tissue at position r.

$\Delta Hb(r, t)$ is the change in absorbed energy at position r and time t.

Ultrasonic Detection: An ultrasound transducer placed on the tissue detects the generated ultrasound waves. The transducer converts the mechanical waves into electrical signals. The received ultrasound signal can be described by:

$$p(t) = h(t) * P(r, t) \quad (2)$$

Where:

$p(t)$ is the detected ultrasound signal at time t.

$h(t)$ is the impulse response of the ultrasound transducer.

Signal Processing:

The detected ultrasound signals undergo amplification and signal processing techniques. Signal processing methods, such as filtering and time-domain or frequency-domain analysis, are employed to enhance the image quality and reduce noise.

Image Reconstruction:

Image reconstruction algorithms are utilized to generate a visual representation of the tissue. Common reconstruction algorithms include the back-projection algorithm or model-based iterative methods. The reconstructed image can be represented as:

$$f(r) = \int p(t, r) \cdot g(t, r)\, dt \qquad (3)$$

Where:

f(r) represents the reconstructed image at position r.

p(t, r) is the detected ultrasound signal at time t and position r.

g(t, r) is the reconstruction kernel that determines the contribution of each detected signal to the image at position r.

Image Analysis and Interpretation:

The reconstructed photo-acoustic image is analyzed and interpreted by medical professionals. Tumors are identified based on differences in optical absorption and abnormal structures. Quantitative parameters, such as the total hemoglobin concentration or oxygen saturation, can be derived from the reconstructed image. Fig.2 is representing proposed methodology.

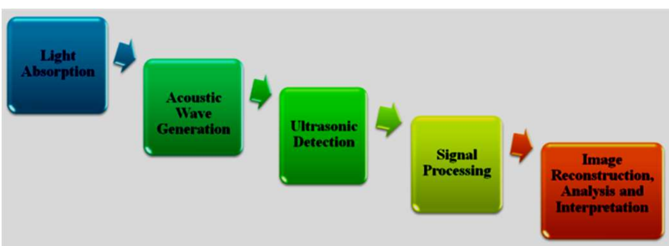

Figure 2: Methodology Proposed

V. Result and Discussion

Result:

Result shows reconstructed photo-acoustic image of the tissue, showing the presence of potential tumor regions. It provides the information about tumor size which is of 3.2 cm and is in lobulated shape present in skin. Fig. 3 is representing observed tumor cells in skin tissues.

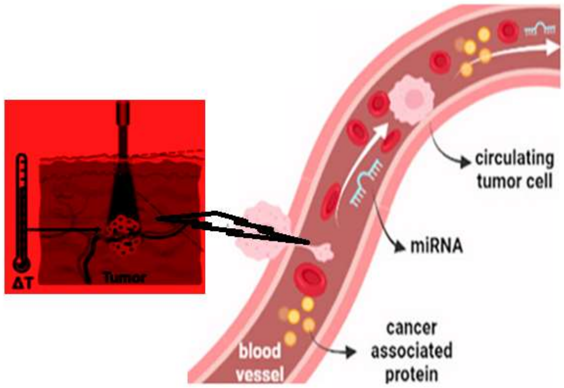

Figure 3: Observed Tumor of 3.2 cm in skin tissue

Oxygenated hemoglobin (HbO2) and deoxygenated hemoglobin (Hb) have distinct absorption spectra in the NIR region. HbO2 has higher absorption in the range of 700-800 nm, while Hb has higher absorption in the range of 800-900 nm. Table 1 is indicating different parameters observed. On the basis of these observed dataset, fig.4 is presenting variation of sensitivity and specificity. It indicating more SNR gives more sensitivity.

Table 1: Sensitivity, Specificity and SNR observed

SNR	Sensitivity	Specificity
8	80%	90%
10	85%	87%
12	88%	92%
15	92%	92%

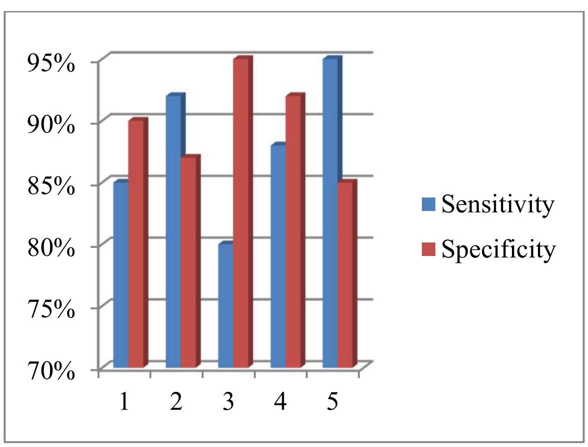

Figure 4: Sensitivity and Specificity obtained

Discussion: The discussion is focused on the accuracy and reliability of tumor identification based on photo-acoustic images. A higher Signal to noise ratio (SNR) indicates a stronger and more distinguishable photo-acoustic signal, which leads to better image quality and improved detection sensitivity. Photo-acoustic optical imaging has demonstrated good sensitivity and specificity in detecting tumors. Sensitivity refers to the ability of the technique to correctly identify true positives (presence of a tumor), while specificity refers to correctly identifying true negatives (absence of a tumor). The potential clinical applications and benefits of photo-acoustic optical imaging in tumor diagnosis are explored. Discussion also addresses ongoing research efforts, technical advancements, and potential challenges in the field. It involves exploring strategies to improve imaging depth, enhancing image resolution, developing targeted contrast agents, or optimizing data processing and analysis techniques.

Conclusion: Tumor diagnosis in the near-infrared (NIR) region shows promise for detecting tumors with a size of 3.2 cm in lobulated shape. The range of NIR wavelengths offers advantages for tumor diagnosis in terms of improved tissue penetration at greater depths within the body, reduced scattering in biological tissues resulting in clearer and less distorted photo-acoustic signals, enhanced contrast exhibit strong absorption in the NIR region and multi-wavelength imaging make possible to extract additional information about the tumor's optical properties and composition.

Acknowledgement: I would like to thank everyone who have contributed for this work.
Competing interests: The authors declare no conflict of interest.
Funding: This research received no external funding.

Ethics Approval: It is confirmed that the manuscript completely follows the ethical policy.

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