

INTISARI

SISTEM FOTOAKUSTIK *NEAR-INFRARED* DENGAN SEGMENTASI VOLUMETRIK BERBASIS UNET3D UNTUK PENCITRAAN 3D *HIDDEN* *CARIES*

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Telah dilakukan penelitian mengenai deteksi dini karies dan *hidden caries* (karies tersembunyi) yang sulit dideteksi secara visual. Kebaruan utama dalam penelitian ini adalah pengembangan sistem pencitraan fotoakustik berbasis laser diode *Near-Infrared* (NIR) 808 nm, yang dikombinasikan dengan rekonstruksi citra 3D menggunakan model UNet3D. Pendekatan ini memungkinkan deteksi dan visualisasi kedalaman karies dan *hidden caries* pada sampel *ex vivo*. Sebagai pembandingan, citra fotoakustik berbasis laser diode 532 nm digunakan untuk mengevaluasi efektivitas panjang gelombang 808 nm. Penelitian ini mencakup karakterisasi sistem PAI dan evaluasi performa segmentasi volumetrik dengan metrik *Dice Score* dan *Precision*. Hasil karakterisasi menunjukkan akurasi mikrofon yang tinggi ($R^2 = 1$), perpindahan motor *stepper* presisi ($p\text{-value} > 0,05$), serta stabilitas daya laser ($CV < 1\%$). Perbedaan signifikan intensitas akustik rata-rata antara citra PAI 808 nm dan 532 nm menunjukkan efektivitas 808 nm dalam mendeteksi karies, *hidden caries*, dan gigi normal ($p\text{-value} < 0,05$). Model UNet3D yang dilatih dengan *dataset* citra PAI 808 nm menghasilkan citra 3D dengan performa terbaik pada Sampel 1 (*Dice Score* 97%; *Precision* 98%), diikuti Sampel 3 (*Dice Score* 79%; *Precision* 99%) dan Sampel 2 (*Dice Score* 77%; *Precision* 100%). Hasil penelitian menunjukkan bahwa sistem fotoakustik berbasis NIR 808 nm mampu mendeteksi *hidden caries* pada citra 2D, merekonstruksi citra 3D, dan memvisualisasikan kedalaman karies dengan akurasi tinggi, serta berpotensi menjadi terobosan dalam aplikasi klinis deteksi karies secara non-invasif.

Kata kunci: Pencitraan fotoakustik, laser diode, deteksi karies, rekonstruksi citra 3D, model UNet3D.

ABSTRACT

NEAR-INFRARED PHOTOACOUSTIC SYSTEM WITH UNET3D-BASED VOLUMETRIC SEGMENTATION FOR 3D IMAGING OF HIDDEN CARIES

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A study has been conducted on the early detection of caries and hidden caries, which are difficult to detect visually. The main novelty of this research is the development of a photoacoustic imaging (PAI) system based on a Near-Infrared (NIR) 808 nm laser diode, combined with 3D image reconstruction using the UNet3D model. This approach allows for the detection and visualization of caries and hidden caries depth on ex vivo samples. For comparison, photoacoustic images based on a 532 nm laser diode were used to evaluate the effectiveness of the 808 nm wavelength. The research includes system characterization of the PAI and performance evaluation of volumetric segmentation using Dice Score and Precision metrics. The characterization results show high microphone accuracy ($R^2 = 1$), precise stepper motor displacement (p-value > 0.05), and laser power stability (CV < 1%). Significant differences in the average acoustic intensity between PAI images of 808 nm and 532 nm demonstrate the effectiveness of 808 nm in detecting caries, hidden caries, and normal teeth (p-value < 0.05). The UNet3D model trained with the 808 nm PAI image dataset produced 3D images with the best performance on Sample 1 (Dice Score 97%; Precision 98%), followed by Sample 3 (Dice Score 79%; Precision 99%) and Sample 2 (Dice Score 77%; Precision 100%). The results show that the NIR 808 nm-based photoacoustic system can detect hidden caries in 2D images, reconstructing 3D images, and visualizing caries depth with high accuracy, and has the potential to be a breakthrough in clinical non-invasive caries detection.

Keywords: Photoacoustic imaging, diode laser, caries detection, 3D image reconstruction, UNet3D Model.