

ABSTRAK

Tuberkulosis (TB) merupakan penyakit infeksi paru yang dapat menular melalui udara. Pemeriksaan *Chest X-ray* sebagai skrining awal menghadapi kendala yaitu variasi kualitas citra, area *non-paru* yang dapat memengaruhi ekstraksi fitur, serta keterbatasan interpretasi model *deep learning* yang bersifat *black box*. Penelitian ini bertujuan merancang dan mengimplementasikan sistem deteksi tuberkulosis berbasis citra *Chest X-ray* menggunakan *ResNet18* dengan pendekatan *Explainable AI* berbasis *Grad-CAM++*, serta menganalisis kinerja sistem yang dikembangkan. Sistem terdiri atas tahap *preprocessing* dan augmentasi data, verifikasi citra input menggunakan *ensemble ResNet18*, segmentasi paru menggunakan *ensemble UNet-ResNet18* untuk mengekstraksi *Region of Interest (ROI)*, klasifikasi dua kelas menggunakan *ensemble ResNet18* dengan *Stratified 5-Fold Cross Validation*, serta visualisasi interpretasi menggunakan *Grad-CAM++*. Hasil penelitian menunjukkan model verifikasi mencapai seluruh metrik evaluasi bernilai 1 pada data uji. Model segmentasi menghasilkan *Dice Score* sebesar 0,9590 dan *Intersection over Union (IoU)* sebesar 0,9227, serta mampu mengekstraksi *Region of Interest (ROI)* pada 99,43% data. Model klasifikasi mencapai nilai *AUC*, *accuracy*, *precision*, *sensitivity*, *specificity*, dan *F1-score* sebesar 1 pada data uji. Pendekatan ROI meningkatkan kesesuaian area aktivasi *Grad-CAM++* pada paru dengan kenaikan *Localization Score* sebesar 0,1127, namun menurunkan *accuracy* menjadi 0,9900. Uji statistik menunjukkan perbedaan kedua model signifikan ($p < 0,001$), tetapi memiliki *effect size* yang dapat diabaikan (*Cohen's d* = 0,100). Secara keseluruhan, sistem mampu mendeteksi tuberkulosis dengan kinerja model tinggi serta menyediakan interpretasi visual yang lebih terfokus pada area paru.

Kata Kunci: tuberkulosis, *Chest X-ray*, Segmentasi paru, *ResNet18*, *Explainable AI*, *Grad-CAM++*



ABSTRACT

Tuberculosis (TB) is an infectious lung disease that can spread through the air. Chest X-ray examination as an initial screening method faces several challenges, including variations in image quality, non-lung regions that may affect feature extraction, and the limited interpretability of deep learning models due to their black box nature. This study aims to design and implement a tuberculosis detection system based on Chest X-ray images using ResNet18 with an Explainable AI approach based on Grad-CAM++, as well as to analyze the performance of the developed system. The system consists of several stages, including preprocessing and data augmentation, input image verification using an ensemble ResNet18, lung segmentation using an ensemble UNet-ResNet18 to extract the Region of Interest (ROI), two-class classification using an ensemble ResNet18 with Stratified 5-Fold Cross Validation, and interpretability visualization using Grad-CAM++. The results show that the verification model achieved perfect evaluation metrics on the test data. The segmentation model obtained a Dice Score of 0.9590 and an Intersection over Union (IoU) of 0.9227, and successfully extracted ROI regions from 99.43% of the data. The classification model achieved AUC, accuracy, precision, sensitivity, specificity, and F1-score values of 1 on the test data. The ROI approach improved the alignment of Grad-CAM++ activation areas within the lung region, with an increase in Localization Score of 0.1127, but reduced the accuracy to 0.9900. Statistical testing showed a significant difference between the two models ($p < 0.001$), although the effect size was negligible (Cohen's $d = 0.100$). Overall, the proposed system was able to detect tuberculosis with high performance while providing visual interpretability that is more focused on the lung area.

Keywords: tuberculosis, Chest X-ray, Lung segmentation, ResNet18, Explainable AI, Grad-CAM++

