

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions drawn from the complete research process, encompassing the design, implementation, and evaluation of retinal blood vessel segmentation models using the CAS-UNet architecture with CFCA and CA modules. The conclusions summarize the analytical findings regarding the performance of both models across the various testing scenarios conducted, providing a comprehensive overview of the effectiveness of the proposed methods. This chapter also presents recommendations for future research directions.

5.1 Conclusions

Based on the results of this research; spanning model design, implementation, and evaluation of retinal vessel segmentation, the following conclusions are drawn in accordance with the formulated research questions and objectives:

1. This study successfully developed and evaluated retinal blood vessel segmentation models using the CAS-UNet architecture integrated with two attention mechanisms, CFCA and CA, on the combined DRIVE and CHASE_DB1 dataset. The research process encompassed image preprocessing, patch extraction using balanced random sampling, model training, and systematic hyperparameter scenario testing. The results demonstrate that both models achieve stable segmentation performance across datasets with diverse image characteristics. The integration of attention mechanisms into the CAS-UNet architecture also supports the preservation of thin and branching retinal vascular structures, reinforcing the role of segmentation as a fundamental step in medical image analysis and early ocular disease detection.
2. Based on the performance evaluation results, CAS-UNet with the CFCA module achieves a sensitivity of 82.45%, higher than CAS-UNet with CA at 80.20%. Sensitivity reflects the model's ability to detect retinal vessel regions; this result therefore confirms that CFCA is more effective at

preserving fine and branching vessel detail. On the F1-score metric, CFCA achieves 82.11%, marginally higher than CA at 81.79%, indicating a more favorable balance between precision and recall during segmentation. Furthermore, the IoU of CFCA at 69.65% is higher than that of CA at 69.18%, demonstrating that CFCA segmentation outputs exhibit greater spatial agreement with the ground truth. Conversely, CAS-UNet with the CA module achieves an accuracy of 97.12%, marginally higher than CFCA at 97.10%. Accuracy reflects overall pixel classification capability, while CA's specificity of 98.60% higher than CFCA's 98.39% indicates superior performance in recognizing background regions and reducing misclassification of non-vessel pixels. Although the performance differences between the two models are relatively modest, the findings confirm that the two attention mechanisms confer distinct segmentation characteristics: CFCA excels in preserving vascular detail, while CA demonstrates superior background classification performance.

Overall, this study demonstrates that CAS-UNet with the CFCA module achieves higher sensitivity, F1-score, and IoU indicating stronger capability in detecting retinal vessel regions and producing segmentation outputs that more closely approximate the ground truth. Meanwhile, the CA module achieves marginally higher accuracy and specificity, reflecting its capacity to accurately classify background regions and maintain overall pixel-level classification precision. The developed models not only exhibit high segmentation performance but also demonstrate stability across diverse testing scenarios, establishing their potential for further development as assistive instruments for early ocular disease detection in clinical settings.

5.2 Recommendations

Based on the results of this research, the following recommendations are proposed for future investigation:

1. The developed models are recommended for evaluation using real clinical data obtained from healthcare institutions. This validation step is essential for assessing the extent to which the model can be applied in genuine

clinical environments and constitutes a necessary prerequisite toward the development of artificial intelligence-based diagnostic support systems.

2. Architectural enhancement may be pursued through the use of deeper backbone networks or transformer-based approaches. Systematic exploration of alternative or hybrid attention module combinations may also be conducted to further improve the model's capacity for extracting diagnostically relevant features.
3. The implemented web-based system can be enhanced by incorporating additional interactive features that increase usability and the practical value of the developed platform.