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学位論文題目	Fundus Images Registration with Bifurcation Detection and Entropy Evaluation （分岐点検出とエントロピー評価を用いた眼底画像のレジストレーション）
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論文内容の要旨

This thesis addresses the challenge of improving fundus image registration accuracy through innovative techniques such as bifurcation detection and entropy evaluation. Accurate fundus image registration is crucial for tracking retinal changes over time, diagnosing and monitoring diseases, and ensuring consistent treatment planning. Despite its importance, existing methods often lack validation due to the absence of suitable datasets for quantitative evaluation and comparison.

Several challenges hinder the clinical implementation of fundus image registration, including the lack of standardized validation and the impracticality of many algorithms due to their long execution times. To enhance both accuracy and speed, this study employs a comprehensive feature-based registration pipeline. It proposes detecting bifurcation points in fundus images as landmarks, utilizing methods such as traditional pixel-wise segmentation, Frangi filter-based detection, and deep learning for region-of-interest delineation and feature extraction. Restrictions are introduced to mitigate localization errors, and a new metric is proposed for evaluating feature extraction quality.

The study leverages the FIVES dataset to train a U-Net deep learning model, enhancing blood vessel segmentation and bifurcation detection. U-Net is used to produce a probability map for bifurcations, creating a pseudo-ground-truth using the FIVES dataset. Experimental evaluations with the FIRE dataset, which provides ground truth for assessment, show that integrating deep learning into the registration pipeline significantly improves accuracy and efficiency. The inclusion of U-Net for bifurcation probability mapping not only enhances registration accuracy but also accelerates the process.

Results indicate that bifurcation points effectively register fundus images, performing

comparably to more complex methodologies. The research also finds that simpler transformation models can be equally effective, challenging the assumption that complexity yields better results.

Key findings include achieving an Intersection Over Union of 0.7559 for blood vessel segmentation and an Area Under the Curve of 0.626 on the FIRE dataset, with a notable 0.720 in the Longitudinal Study subset. This research advances medical imaging by providing robust, accurate, and efficient methodologies for fundus image registration, contributing valuable insights for clinical decision support systems and enhancing diagnostic precision in ophthalmology.

論文審査の結果の要旨

精度の高い眼底画像のレジストレーションは，時間の経過による網膜の変化を把握でき，診断及び疾患の観察に非常に重要である．しかし，従来の方法では，眼底画像のレジストレーションにかかる実行時間が長すぎるため，臨床での実用性ができない．

眼底画像のレジストレーションの精度及び速度を向上させるために，本研究では，眼底画像を適切に表現できる特徴量を用いた眼底画像のレジストレーション方法を提案する．眼底画像の分岐点をランドマークとし，伝統的な pixel-wise 分割法(1)，Frangi filter-based 検出法(2)，及び深層学習モデル(3)を用いて，Region of Interest (ROI)を特定し，特徴量を抽出する．Localization のエラーを低減するために，高品質な特徴量を評価する方法(1)を提案した．また，Intersection over Union (IoU)や，Area Under the Curve(AUC)等の評価法を用いて，提案法の有効性を確認した．

本学位論文は，いずれも申請者が著者に含まれる，レフェリー付きの学術雑誌論文 3 編及び国際会議プロシーディングス 2 編を元に作成された．このうちの 4 編全ての論文において申請者が筆頭著者である．

「学位論文の基礎となった論文」

(1)**A Straightforward Bifurcation Pattern-Based Fundus Image Registration Method,** Jesús Eduardo Ochoa-Astorga, Linni Wang, Weiwei Du and Yahui Peng, Sensors Vol. 23, No. 18: 7809, September 2023.

(2)**Fundus Image Registration with Binary Morphology Extraction of Feature Points,** Jesús Eduardo Ochoa Astorga, Weiwei Du, Yahui Peng and Linni Wang, The 6th International Symposium on Computer, Consumer and Control (IS3C), Page(s): 182-185, June 2023.

(3)**Enhanced Vascular Bifurcations Mapping: Refining Fundus Image Registration,** Jesús Eduardo Ochoa-Astorga, Linni Wang, Weiwei Du and Yahui Peng, Electronics Vol. 13, No. 9: 1736, May 2024.