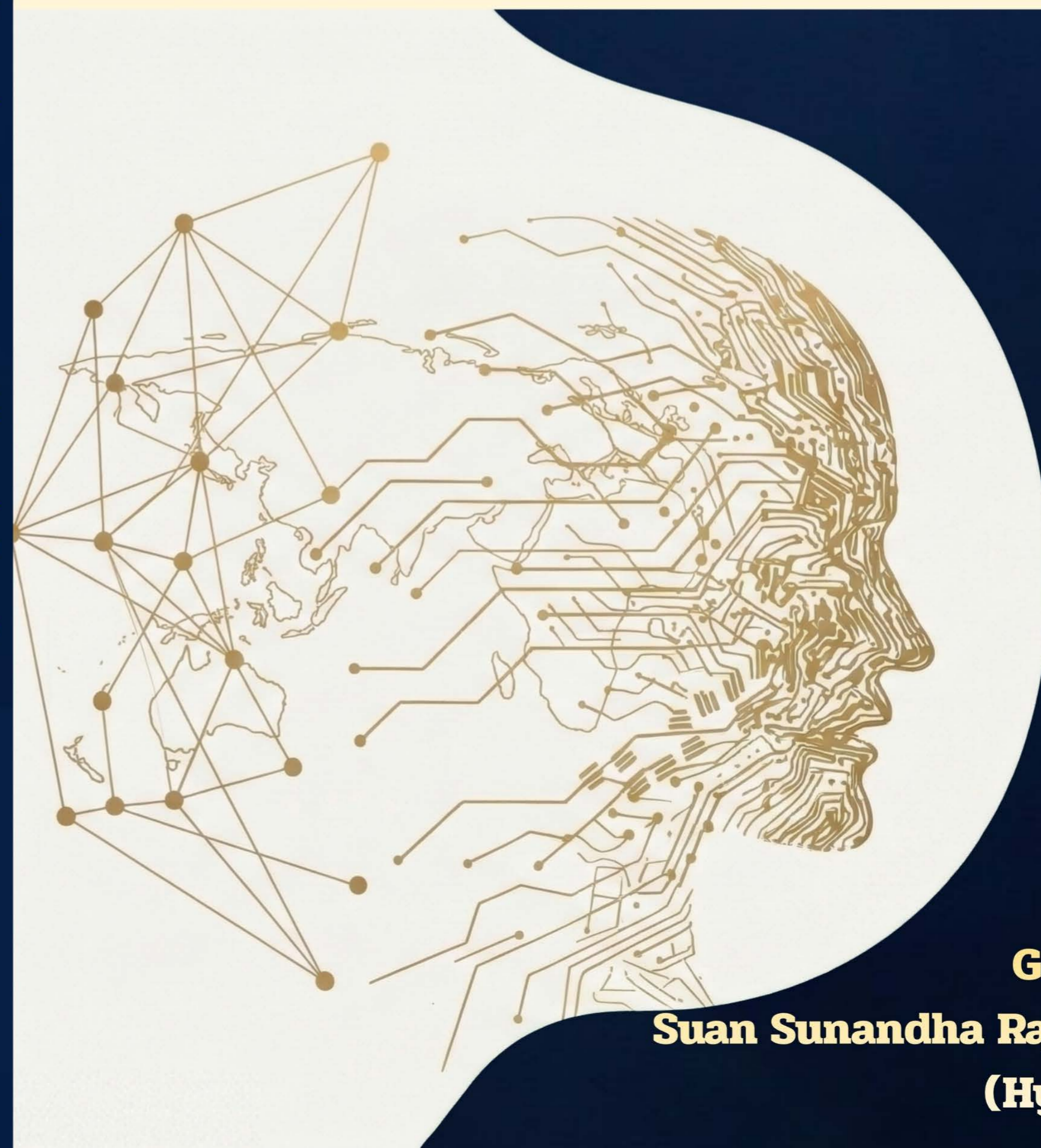
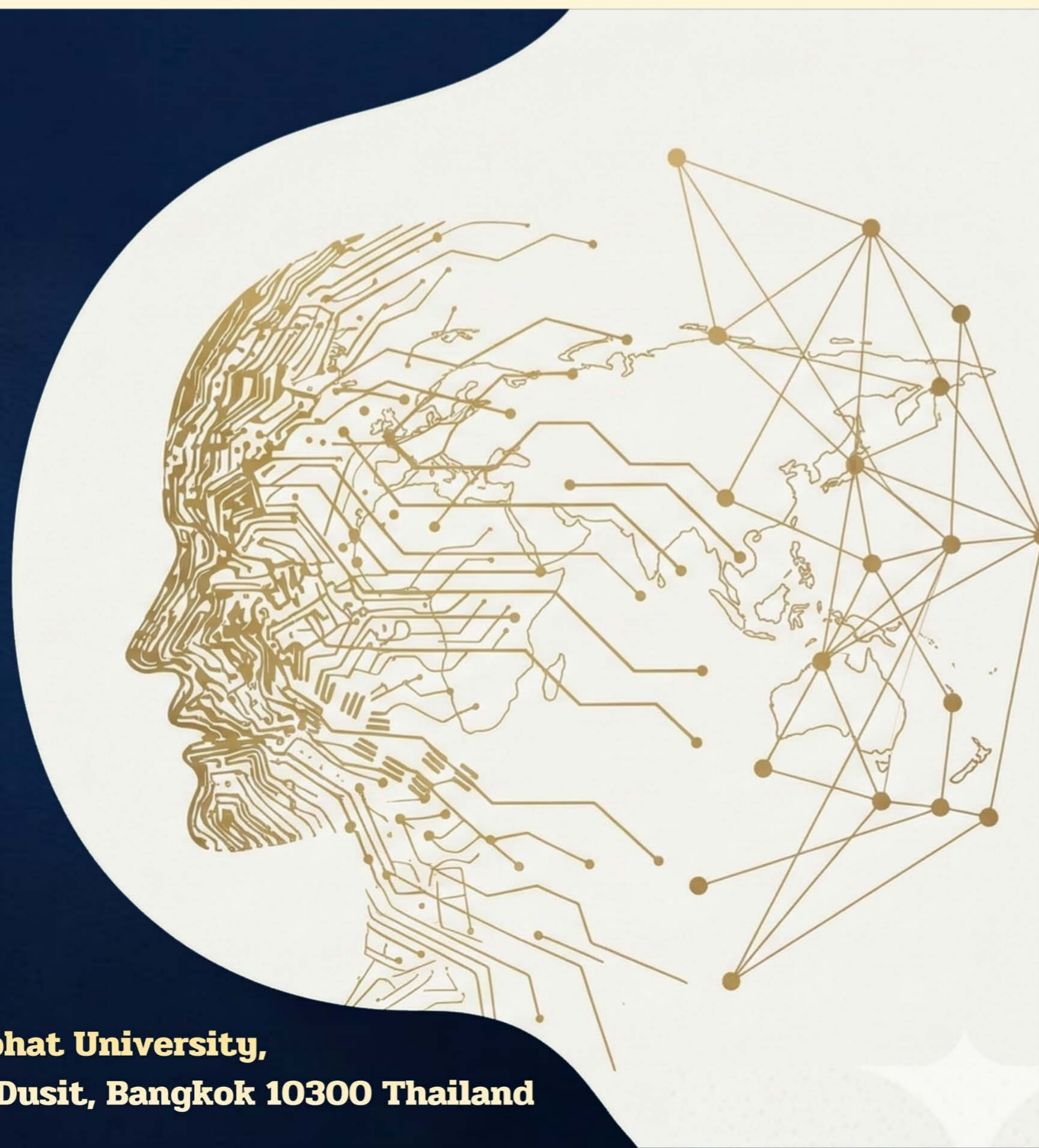


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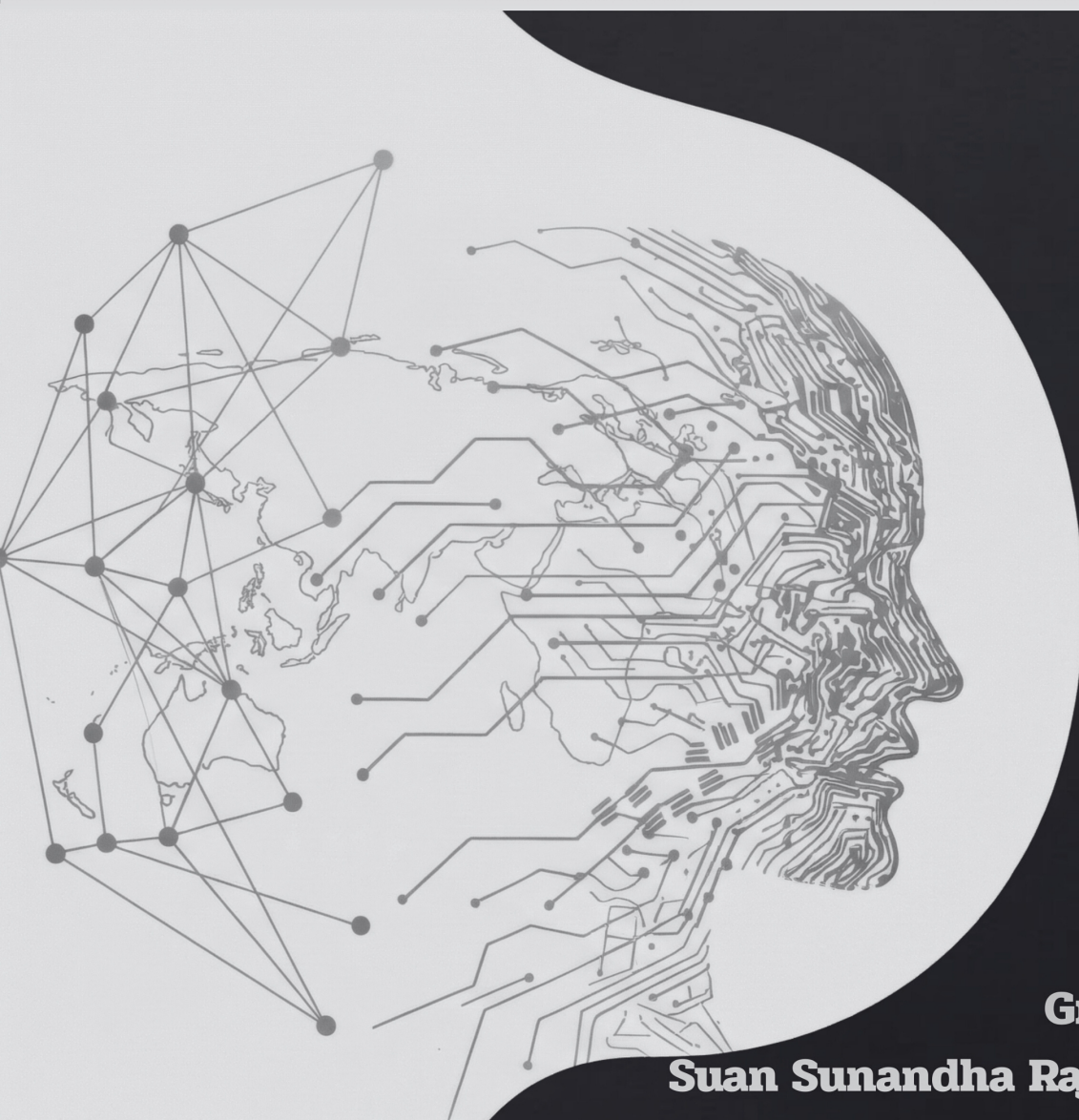
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DIABETIC RETINOPATHY RECOGNITION USING IMAGE PROCESSING AND MACHINE LEARNING MODELS ON FUNDUS IMAGES

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Abstract

This research develops a machine learning classification framework that integrates multiple image processing techniques and canonical image alignment to enhance diabetic retinopathy recognition from fundus photographs. Color fundus images from the Ocular Disease Intelligent Recognition (ODIR) dataset, collected by Shangong Medical Technology Co., Ltd. from different hospitals/medical centers in China, were preprocessed using ridge detection, Sobel edge detection, Canny edge detection, Robert edge detection, and color contrast enhancement. Canonical fundus images were constructed to standardize structural representation across samples, and an additional dataset was created by resizing and realigning the processed images, using image registration techniques, to match their corresponding canonical images. Six classification methods, Support Vector Machine (SVM), k-Nearest Neighbors (k-NN), Naïve Bayes, Decision Trees, Gradient Boosted Trees (GBT), and Wasserstein Distance Classification (WDC), were evaluated using training-testing splits of 70:30, 75:25, and 80:20. For left-eye fundus photographs, the best performance was obtained using GBT with a 75:25 training-testing split on canonical-aligned images. The model achieved an accuracy of 0.7715, a precision of 0.7637, a recall of 0.7715, and an F1-score of 0.7645. For right-eye photographs, the highest performance was also achieved by GBT, using a 70:30 training-testing split on canonical-aligned images, yielding an accuracy of 0.7196, a precision of 0.7125, a recall of 0.7196, and an F1-score of 0.7039. These findings indicate that aligning processed images to canonical fundus templates enhances structural consistency and improves the classifier's ability to detect diabetic-related abnormalities. Overall, the results demonstrate that combining multiple image processing techniques with canonical image alignment substantially improves diabetic retinopathy classification performance. The evidence supports the potential of machine-learning-based frameworks as effective screening tools for early detection of diabetic retinopathy.

Keywords: Diabetic retinopathy, Machine learning, Image classification, Image registration

Introduction

At present, diabetes has become increasingly prevalent among the Thai population. In the past, diabetes was found predominantly in older adults or individuals aged 50 years and above. However, recent reports indicate a rising incidence of diabetes among children and

adolescents, largely attributed to changes in dietary behaviors (Department of Disease Control, 2023). Diagnosing diabetes typically involves blood testing to measure glucose levels. If diabetes is left untreated and individuals continue consuming unhealthy foods and beverages, a range of complications may occur, including renal impairment, neuropathy, vascular occlusion, coronary artery disease, and ocular complications. Among these, ocular complications may develop into Diabetic Retinopathy (DR) if patients do not receive proper treatment or fail to control their dietary habits. Screening for diabetic retinopathy is usually performed by dilating the pupils of diabetic patients to obtain fundus images, which are then analyzed for diagnostic purposes. A major challenge, however, is that this diagnostic process requires specialized ophthalmologists, and there is currently a shortage of such professionals in Thailand. To address this issue, this study seeks to apply Artificial Intelligence (AI), specifically machine learning techniques, to detect signs of diabetic-related abnormalities from fundus photographs. Such an approach could support clinical diagnosis and help prevent future vision loss. Fundus images can be used to analyze a wide range of ocular disorders, such as retinal degeneration, macular edema, and macular tears. Nevertheless, direct comparison between images from healthy individuals and those with existing conditions may lead to diagnostic errors, as retinal images inherently vary among individuals. Therefore, this study aims to utilize canonical images, a concept introduced in the work of Qi et al. (2022). The approach involves applying machine learning techniques to perform image registration, aligning images to a common orientation. A canonical image is then constructed by averaging selected fundus images from a group of normal eyes. Subsequently, machine learning techniques combined with digital image processing are employed to analyze fundus photographs exhibiting diabetic abnormalities.

This research ultimately aims to develop an effective tool capable of accurately classifying fundus images that exhibit diabetic abnormalities.

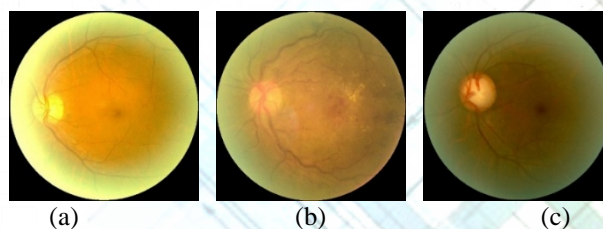
Research Objective

To develop and evaluate an effective tool for accurately classifying fundus images with diabetic-related abnormalities.

Preliminary Knowledge

- **Fundus Photography**

Fundus photography is a diagnostic imaging technique used to capture high-resolution images of the retina and key posterior structures, including the optic disc and retinal vasculature, using a specialized fundus camera. It is essential for screening ocular diseases that may be asymptomatic in early stages, particularly diabetic retinopathy, macular degeneration, and glaucoma. (Sriwichai, Tanthanuch, & Yimmuang, 2023)



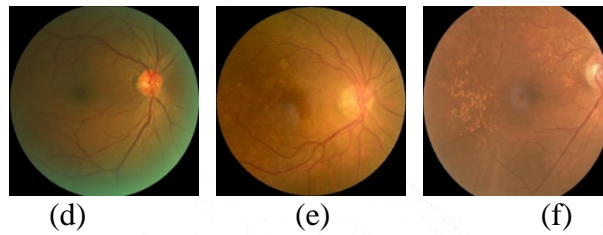


Figure 1. Examples of Fundus Images

(a) Normal left eye; (b) Diabetic left eye; (c) Glaucomatous left eye; (d) Normal right eye; (e) Right eye with diabetes and macular degeneration; (f) Right eye with hypertensive retinopathy.

Source: <https://www.kaggle.com/datasets/andrewmvd/ocular-disease-recognition-odir5k>

- **Image Processing**

This section presents the image processing techniques using in this research. (Gonzalez & Woods, 1992)

- **Ridge detection:** Ridge detection is used to identify elongated, vessel-like structures in images. In fundus analysis, this technique enhances the visibility of retinal blood vessels, allowing for better assessment of vessel narrowing, dilation, tortuosity, and microvascular abnormalities, which are key indicators of early diabetic retinopathy.
- **Sobel edge detection:** Sobel filters detect edges by computing intensity gradients in horizontal and vertical directions. In fundus images, Sobel detection helps highlight major vascular boundaries, optic disc contours, and lesion edges, which supports feature extraction in machine learning models.
- **Canny edge detection:** Canny is a multi-stage edge detector that produces thin, well-defined edges with low noise. It is widely used in fundus imaging to detect microaneurysms, hard exudates, hemorrhages, and vessel structures with high accuracy, making it one of the most effective methods for diabetic retinopathy related lesion extraction.
- **Robert edge detection:** Roberts is an early-gradient method that computes edges using diagonal differences. It is suitable for detecting fine structural changes, especially in high-contrast regions of fundus images. Although simpler than Sobel and Canny, it helps detect small bright lesions such as exudates.
- **Color contrast enhancement:** Color contrast enhancement adjusts intensity and channel differences to improve the visibility of important retinal features. This technique enhances the appearance of vascular patterns, microaneurysms, hemorrhages, drusen, and macular abnormalities, facilitating more accurate classification by the model. In this study, the technique used involves enhancing the original image by multiplying the color value of each pixel by 6 and then subtracting the result from a Gaussian-blurred version of the original image.
- **Image registration:** Image registration aligns multiple images into the same coordinate system, correcting variations due to eye movement, camera angle, or patient positioning. For diabetic retinopathy recognition, registration ensures consistent comparison across patients and enables the construction of canonical fundus images, improving lesion localization and algorithm robustness.

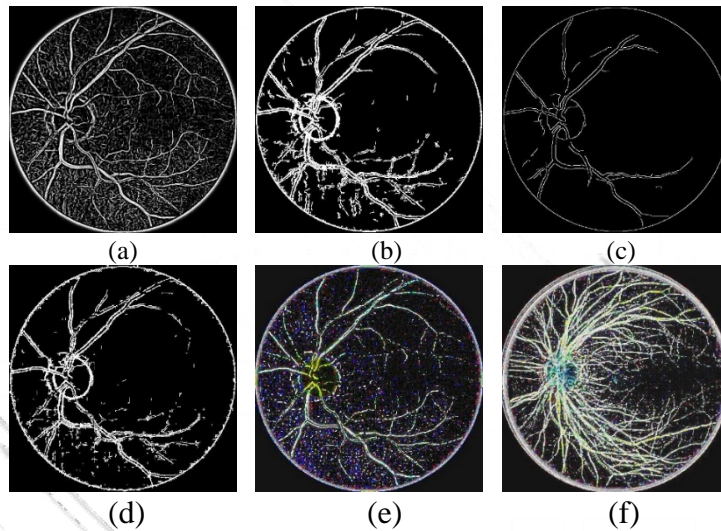


Figure 2. Examples of Fundus Images Processed Using Image Processing Techniques
 (a) Using Ridge Detection; (b) Using Sobel Edge Detection; (c) Using Canny Edge Detection;
 (d) Using Robert Edge Detection; (e) Using Color Contrast Enhancement;
 (f) Using Image Registration for the Construction of Canonical Fundus Image.

- **Wasserstein Distance Metric**

In this study, the Wasserstein distance was employed to enhance the classification performance of diabetic retinopathy recognition. The Wasserstein distance, also known as the Earth Mover's Distance (EMD), is a metric that quantifies the dissimilarity between two probability distributions. It is based on the concept of determining the minimum transportation cost required to transform one distribution into another, considering both the amount of probability mass to be moved and the distance over which it is transported.

Let μ and ν be two probability distributions defined on the metric space (X, d) . The p -th order Wasserstein distance (or p -Wasserstein distance) between μ and ν is defined as:

$$W_p(\mu, \nu) = \left(\inf_{\gamma \in \Gamma(\mu, \nu)} \int_{X \times X} d(x, y)^p d\gamma(x, y) \right)^{1/p}$$

where $\Gamma(\mu, \nu)$ denotes the set of all joint distributions (or couplings) on $X \times X$ whose marginals are μ and ν , respectively, and $d(x, y)$ represents the metric distance between points x and y (Panaretos & Zemel, 2019).

In this research, an appropriate Wasserstein metric is utilized to improve the discrimination of fundus images exhibiting diabetic abnormalities, thereby contributing to a more robust and accurate classification framework.

- **Classification Techniques**

The classification techniques employed in this study are presented as follows.

- **Support Vector Machine (SVM):** SVM identifies an optimal separating boundary between classes and is effective for medical images with high-dimensional features, making it suitable for normal–abnormal fundus classification.

- **Nearest Neighbors (k-NN):** k-NN classifies an image based on the labels of its closest samples in the feature space. Its simplicity and intuitive nature make it useful for datasets where similar images cluster together.
- **Naïve Bayes:** A probabilistic classifier based on Bayes' theorem, assuming feature independence. It is computationally efficient and performs well with simple feature sets extracted from medical images.
- **Decision Trees:** Decision Trees classify images through a sequence of feature-based splits. They are interpretable models that highlight which image features contribute most to the final decision.
- **Gradient Boosted Trees (GBT):** GBT combines multiple weak decision trees to create a strong ensemble model. It offers high accuracy and handles complex patterns commonly found in medical imaging data.
- **Wasserstein Distance Classification (WDC):** The Wasserstein distance measures the dissimilarity between image-derived distributions. It is particularly useful for detecting structural deviations in fundus images, facilitating sensitive identification of diabetic abnormalities.

Scope of the Research

- **Fundus Image Dataset**

The fundus image dataset consists of publicly available color images obtained from: <https://www.kaggle.com/datasets/andrewmvd/ocular-disease-recognition-odir5k>. The images are in JPG format with a resolution 512×512 pixels (96 dpi). The dataset was compiled from multiple hospitals and medical centers across China by Shanggong Medical Technology Co., Ltd., using various brands of fundus cameras, such as Canon, Zeiss, and Kowa. This ophthalmic dataset contains information from 5,000 patients, including age, color fundus photographs of the left and right eyes, and physician diagnoses provided in the form of keyword labels: Normal (N), Diabetes (D), Glaucoma (G), Cataract (C), Age-related Macular Degeneration (A), Hypertension (H), Pathological Myopia (M), and Other diseases/abnormalities (O).

- **Hardware and Software**

The computer and primary software used in this research are as follows: an AMD Ryzen 5 5600H processor with 16 GB RAM with Microsoft Windows 11 OS, and Python 3.12.7 executed within Jupyter Notebook 7.2.2.

Research Methodology

The procedures used in this research are outlined as follows. An overview of the workflow is presented in Figure 3.

1. **Image grouping:** The fundus images were separated into left-eye and right-eye sets and further categorized into normal and diabetic retinopathy groups.
2. **Image preprocessing:** Each image was processed using the selected techniques—ridge detection, Sobel edge detection, Canny edge detection, Robert edge detection, and color contrast enhancement.
3. **Canonical image construction:** In this step, images with complete and appropriate dimensions, together with high-quality details after image processing—such as retinal blood vessels, major vascular boundaries, microvascular structures, optic disc contours, or lesion edges—were selected to serve as the canonical images.

4. **Canonical-aligned image preparation:** Additional processed images were resized and realigned to match their corresponding canonical images.
5. **Dataset splitting:** The dataset was partitioned into training and testing sets using three ratios: 70:30, 75:25, and 80:20.
6. **Classification:** Six classification techniques—SVM, k-NN, Naïve Bayes, Decision Trees, GBT, and WDC—were applied to perform image classification.
7. **Performance evaluation:** The classification results were assessed using standard performance metrics.

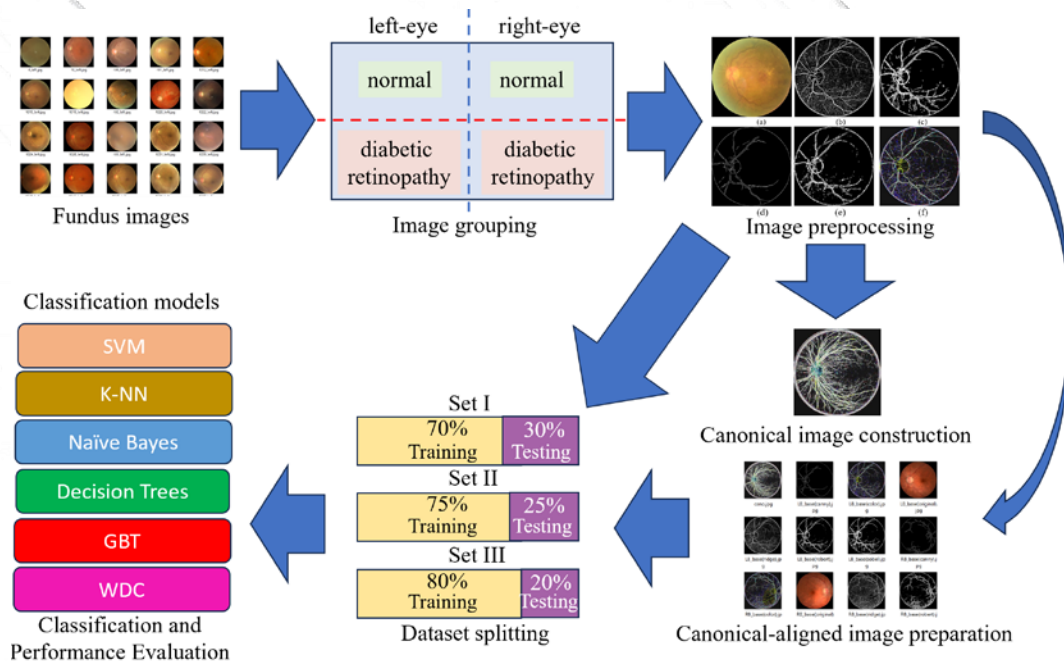


Figure 3. An overview of the workflow

Research Results

The precision performance of the classification models is presented in graphical form, as shown in Table 1 and 2.

Table 1. Accuracy Performance of Each Classification Model in left eye

Ratio	Canonical Image Adjusted	Feature	SVM	k-NN	Naïve Bayes	Decision Trees	GBT	WDC
70:30	Not Adjusted	Original	0.7045	0.6667	0.6059	0.6208	0.7301	0.5897
		Ridge	0.6653	0.6518	0.5371	0.6100	0.6883	0.5924
		Robert	0.6613	0.6424	0.5695	0.6127	0.6734	0.6140
		Sobel	0.6802	0.6127	0.5735	0.5547	0.6910	0.5965
		Canny	0.6748	0.6410	0.5749	0.6032	0.6707	0.5924
		Color	0.6896	0.6626	0.5560	0.6221	0.7072	0.5830
		All	0.6815	0.6896	0.5776	0.6370	0.7274	0.6329
	Adjusted	Original	0.7085	0.6518	0.5951	0.6073	0.7206	0.5709
		Ridge	0.7018	0.6302	0.5614	0.5992	0.6964	0.5897

Ratio	Canonical Image Adjusted	Feature	SVM	k-NN	Naïve Bayes	Decision Trees	GBT	WDC
		Robert	0.6680	0.6329	0.5682	0.5924	0.6788	0.5709
		Sobel	0.6653	0.6140	0.5587	0.5479	0.6788	0.5479
		Canny	0.6721	0.6208	0.5830	0.5803	0.6910	0.6005
		Color	0.6910	0.6437	0.5493	0.5695	0.6964	0.5965
		All	0.6748	0.6599	0.5628	0.6181	0.7247	0.6032
75:25	Not Adjusted	Original	0.7520	0.6710	0.5721	0.6499	0.7488	0.6191
		Ridge	0.7407	0.6775	0.5267	0.6094	0.7277	0.5770
		Robert	0.7196	0.6483	0.5446	0.5851	0.7342	0.6337
		Sobel	0.6969	0.6305	0.5462	0.5883	0.7147	0.6078
		Canny	0.7066	0.6580	0.5721	0.5997	0.7083	0.6386
		Color	0.7180	0.6840	0.5186	0.6078	0.7553	0.6207
		All	0.6759	0.6856	0.5511	0.6159	0.7715	0.6062
	Adjusted	Original	0.7455	0.7002	0.5673	0.6143	0.7601	0.5883
		Ridge	0.7099	0.6613	0.5267	0.5948	0.7277	0.5770
		Robert	0.6921	0.6661	0.5673	0.6029	0.7147	0.5900
		Sobel	0.7034	0.6353	0.5413	0.6013	0.7164	0.6207
		Canny	0.6921	0.6240	0.5737	0.5867	0.7066	0.6207
		Color	0.7131	0.6953	0.5154	0.6224	0.7455	0.6126
		All	0.6969	0.6921	0.5478	0.5997	0.7715	0.5916
80:20	Not Adjusted	Original	0.7328	0.6619	0.6174	0.6275	0.7206	0.6012
		Ridge	0.6923	0.6377	0.5547	0.6154	0.6943	0.5709
		Robert	0.6721	0.6397	0.5911	0.5445	0.6700	0.6093
		Sobel	0.6700	0.6559	0.5729	0.5648	0.6903	0.6215
		Canny	0.6903	0.6356	0.5709	0.5506	0.6660	0.5870
		Color	0.7105	0.6640	0.5607	0.6174	0.7045	0.6255
		All	0.6822	0.6680	0.5688	0.6356	0.7126	0.5972
	Adjusted	Original	0.7126	0.6559	0.5931	0.6296	0.7247	0.5425
		Ridge	0.7085	0.5992	0.5567	0.5810	0.7065	0.5769
		Robert	0.6984	0.6275	0.5648	0.5445	0.6457	0.5992
		Sobel	0.7004	0.5931	0.5607	0.5810	0.6923	0.5668
		Canny	0.6964	0.6093	0.5789	0.5607	0.6680	0.5729
		Color	0.6943	0.6680	0.5466	0.6053	0.6964	0.5951
		All	0.6802	0.6518	0.5688	0.6093	0.7146	0.5870

Table 2. Accuracy Performance of Each Classification Model in right eye

Ratio	Canonical Image Adjusted	Feature	SVM	k-NN	Naïve Bayes	Decision Trees	GBT	WDC
70:30	Not Adjusted	Original	0.7018	0.6320	0.5732	0.6170	0.6922	0.5923
		Ridge	0.6484	0.6170	0.5212	0.5978	0.6375	0.5869
		Robert	0.6402	0.6088	0.5308	0.5746	0.6580	0.5800
		Sobel	0.6430	0.6334	0.5458	0.5595	0.6703	0.5746
		Canny	0.6936	0.5937	0.5759	0.5923	0.6512	0.5746
		Color	0.6949	0.6498	0.5294	0.6156	0.6908	0.6005
		All	0.6717	0.6375	0.5568	0.6101	0.7031	0.5814
	Adjusted	Original	0.7031	0.6471	0.5568	0.6142	0.6867	0.5609
		Ridge	0.6621	0.6416	0.5212	0.5705	0.6512	0.5937
		Robert	0.6566	0.5896	0.5363	0.5759	0.6539	0.6115
		Sobel	0.6772	0.6088	0.5404	0.5855	0.6416	0.5677
		Canny	0.6566	0.6293	0.5663	0.5636	0.6498	0.5869
		Color	0.6758	0.6347	0.5253	0.5978	0.6977	0.5581
		All	0.6525	0.6443	0.5486	0.6005	0.7196	0.6033
75:25	Not Adjusted	Original	0.7028	0.6535	0.5599	0.5829	0.6929	0.5714
		Ridge	0.6798	0.6338	0.5238	0.6026	0.6601	0.5813
		Robert	0.6470	0.6158	0.5287	0.5665	0.6732	0.5878
		Sobel	0.6420	0.6256	0.5435	0.5468	0.6749	0.6141
		Canny	0.6732	0.6338	0.5698	0.5862	0.6667	0.6207
		Color	0.6913	0.6634	0.5123	0.6158	0.6979	0.6420
		All	0.6617	0.6798	0.5304	0.6125	0.7126	0.6076
	Adjusted	Original	0.7291	0.6273	0.5484	0.5862	0.6995	0.6125
		Ridge	0.6667	0.6338	0.5238	0.5878	0.6913	0.5665
		Robert	0.6683	0.6322	0.5304	0.5698	0.6700	0.6108
		Sobel	0.6634	0.6141	0.5386	0.5796	0.6913	0.5599
		Canny	0.6798	0.6125	0.5862	0.5369	0.6535	0.6338
		Color	0.6847	0.6535	0.5172	0.6158	0.6913	0.5583
		All	0.6634	0.6716	0.5402	0.5796	0.6979	0.6190
80:20	Not Adjusted	Original	0.7043	0.6653	0.6222	0.6119	0.6961	0.6140
		Ridge	0.6489	0.6181	0.5688	0.5585	0.6201	0.6016
		Robert	0.6550	0.5811	0.5893	0.5708	0.6982	0.5708
		Sobel	0.6591	0.6263	0.6057	0.5708	0.6797	0.5606
		Canny	0.6612	0.6242	0.6119	0.5626	0.6468	0.5852
		Color	0.6817	0.6715	0.5955	0.5914	0.7064	0.6263
		All	0.6591	0.6591	0.6037	0.5975	0.6982	0.5811
	Adjusted	Original	0.7105	0.6345	0.6140	0.6222	0.6961	0.6078
		Ridge	0.6797	0.6653	0.5647	0.5585	0.6612	0.5708
		Robert	0.6674	0.6283	0.5873	0.5503	0.6838	0.6263
		Sobel	0.6694	0.6345	0.5914	0.5914	0.6776	0.5996
		Canny	0.6530	0.6304	0.6078	0.5729	0.6448	0.5893
		Color	0.6653	0.6694	0.5791	0.6078	0.6776	0.5873
		All	0.6530	0.6612	0.6037	0.6366	0.6797	0.5996

Conclusion

This study developed a machine learning framework for classifying diabetic abnormalities in fundus images through the integration of multiple image processing techniques and canonical image alignment. The experimental results clearly show that preprocessing methods such as ridge detection, Sobel edge detection, Canny edge detection, Robert edge detection, and color contrast enhancement, together with image registration for canonical alignment, improve classification performance compared with using unprocessed images.

Across all models evaluated, GBT produced the most consistent and superior results. For the left-eye dataset, the highest accuracy was achieved using a 75:25 training testing split with canonical-aligned images, yielding an accuracy of 0.7715, a precision of 0.7637, a recall of 0.7715, and an F1-score of 0.7645. For the right-eye dataset, the best performance was obtained using a 70:30 split with canonical-aligned images, achieving an accuracy of 0.7196, a precision of 0.7125, a recall of 0.7196, and an F1-score of 0.7039. These outcomes emphasize the value of aligning images to canonical templates, as this approach enhances structural consistency and strengthens the classifier's ability to detect diabetic-related abnormalities.

Overall, the findings confirm that the integration of diverse image processing techniques, canonical image construction, and advanced machine learning models provides an effective approach for automated diabetic retinopathy screening. This framework has the potential to support clinical decision-making, particularly in healthcare environments where ophthalmology specialists are not readily available.

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