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A Deep Learning-Based Segmentation Technique for Automatic Detection of Conjunctivitis from Conjunctival Eye Images

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Abstract: ***Eye diseases are becoming common in day-to-day life and affecting all age groups of people. The ratio of ophthalmologists to patients suggests the need for an automated technique to detect eye diseases. Conjunctivitis is of many types, including adenoviral conjunctivitis, ocular drug toxic conjunctivitis, pollen-allergic conjunctivitis, bacterial conjunctivitis, and many others. Conjunctivitis can be automatically detected using conventional image processing techniques, but with lower accuracy and precision, and more computational time is required compared to deep learning and AI techniques. This paper presents a novel deep-learning-assisted segmentation technique for the automatic detection of conjunctivitis that overcomes the limitations of conventional methods. The proposed method uses Attention-U-Net++ with Transformer Encoder (Global Context), Swin / ViT CNN +, Transformer Monte-Carlo Dropout Layer Enabled at inference time, Uncertainty-aware and Segmentation Mask + Uncertainty Map, which provides better results with Accuracy= 90.3%, sensitivity= 0.87, specificity= 0.93, precision=0.88, recall=0.87, F1-Score= 0.89, ROC-Auc=0.96.***

Keywords: Pollen Allergic Conjunctivitis, Ocular Drug Toxicity, U-Net++, swin/ViT, CNN, ROC

Nomenclature:
CNN: Convolutional Neural Network

I. INTRODUCTION

The human immune system's response to the allergy [1] caused by pollen is an antibody called immunoglobulin E (IgE), also known as pollen allergic conjunctivitis, which is characterised by conjunctival hyperemia, papillary reaction, chemosis, and redness [2,3]. The pollen-allergic conjunctiva appears similar to that of viral and dry-eye conjunctivitis, with diffuse, nonlocalized inflammation. Pollen conjunctivitis is also called seasonal allergic conjunctivitis or hay fever eyes, caused by pollen from trees or flowers, grasses, or weeds, or by an allergic reaction to airborne pollen, which irritates the conjunctiva [4], a membrane lining the inside of the eyelids covering the white part of the eye. The conjunctivitis causes inflammation, itching, redness and watery eyes [5] Conjunctivitis also occurs due to prolonged medication, drug exposure, chemotherapy and hypersensitivity or cumulative epithelial toxicity called ocular drug- toxic conjunctivitis [2]. This type of conjunctivitis is characterised by patchy hyperemia, a rough surface, epithelial damage, vascular dilation, chemosis, and patterns such as punctate staining. Ocular drug-toxic conjunctivitis detection is made difficult by its similar appearance to allergic and viral conjunctivitis, subtle texture changes, specular reflections, and illumination artefacts [9].



[Fig.1: Conjunctiva Images of Various Degrees of Conjunctivitis [10]]

The drug's toxicity affects various parts of the eye, including the optic nerve, cornea, and retina. Drug-induced toxic conjunctivitis is a superficial reaction called retinopathy or optic neuropathy [7], visible in the conjunctiva image; some are also visible in the fundus image. The symptoms are visible on the anterior part of the eye, which results in itching or burning sensations, excessive tearing discharge, swelling, blurred vision, papillary reactions and redness [8]



[Fig.2: Severe Drug Toxicity Visible in Fundus Images [9]]

I0 gives the conjunctiva RGB image. $\varepsilon\ \mathbb{R}^{H \times W \times 3}$ 1.1

Intensity thres-holding provides the specular regions given by $M_x(x,y) = \{1, I_{RGB}(x,y) > \tau_s, 0,$
Ow I_1 = Inpaint (I_{RGB}, Ms) 1.2

Removes high-intensity highlights caused by tear film reflection. Prevents false-positive lesion detection.

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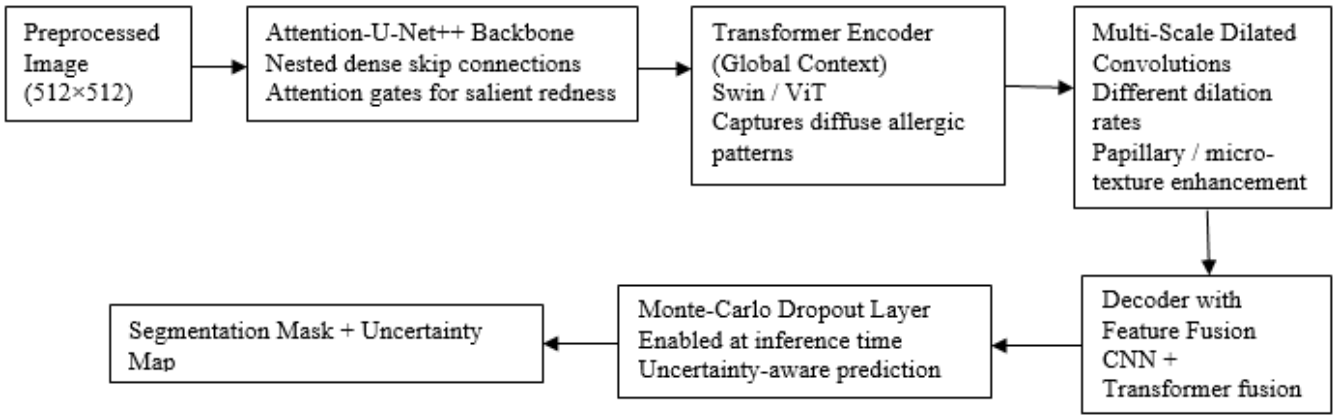
II. PROPOSED METHODOLOGY



[Fig.3: Block Diagram of the Proposed Method]

Colour normalisation will be performed to reduce inter-device and illumination colour variation [8], by converting RGB colour to LAB colour model, which is given by

$I_{LAB} = C_{RGB\rightarrow LAB}(I)$ $I_2 = \sigma t (I_{L9AB} - \mu s)/ \sigma s + \mu t$ 1.3

Where - μs, σs are source mean & std and σt, μt are target mean & std. Homomorphic filtering or illumination correction is applied to separate illumination and reflectance components by log transform, providing highlight to the redness $L(x,y)= \log I_2 (x,y)$ 1.4

The frequency domain expression is given by

$I_3 = F^{-1} = [H(u,v)F(L(x,y))]$ 1.5

by multiplying a high-pass filter. The Region of interest (ROI) mask, which removes eyelids, iris, sclera boundaries and focuses [6] on the conjunctiva, is given by

$M_{ROI} = f_{seg}(I_3)$ 1.6

$I4 = I3 \Theta MROI$ gives the extracted region 1.7

For better lesion visibility, vascular congestion patterns are amplified using enhanced contrast normalization given by $R^I = R- (G+B/2)$ $I_5 = CLAHE (R^I)$ 1.8

Then the image is resized to 512x512 1.9

The hybrid segmentation [9] the model is given by

$Ip \in \mathbb{R}^{512x512x3}$ 2.0

Attention is applied in U-net++ for dense skip connections, suppressing irrelevant tissue features. Given by

$F_c = AUNet++ (I_p)$ 2.1

Attention gating $= F_a = \alpha \Theta F_c$ Where $\alpha = \sigma(W^T [F_C, g])$ 2.2

For capturing diffuse allergic patterns and long-range spatial dependencies [7], the transfer encoder swin/ViT are used, which is given by patch enabling and self-attention.

$Z_0 = patch (I_p)+PosEnc$ 2.3

$Z_l = MSA(LN(Z_{l-1}))+ Z_{l-1}$ 2.4

For capturing papillary texture at multiple receptive fields, the multi-scale dilated convolution is used, $F_d = conv D_k (F_c)$, where D_k 2.6

is the dilation rate [5]

The Monte Carlo Dropout uses stochastic forward passes and a final prediction given by the expression.

$S_t = f_0^{(t)}(I_P)$, $\hat{S} = \frac{1}{T}\sum_{t=1}^{T} st$ 2.7

$U = \frac{1}{T}\sum_{t=1}^{T}(st - s^I)^2$ 2.8

III. OUTPUT PARAMETER METRICS

The output of the proposed methodology provides the following attributes after applying the method to the conjunctiva image data set [10]. The Allergic Area Percentage indicates the percentage of the conjunctiva area affected, given by

$AAP = (\sum Mlesion(x,y) / \sum Mroi(x,y)))X\ 100$ 2.9

The normalized red component is given by

$RI = \frac{R(x,y)}{R(x,y)+G(x,y)+B(x,y)}$ 3.0

$Mean = \frac{1}{N}\sum_{ROI}\frac{R}{R+G+B}$ 3.2

If this value is higher, it indicates increased hyperemia. The GLCM - Grey-Level Co-occurrence Matrix is given by

$PTS = \alpha \cdot Contrast + \beta \cdot Entropy + \gamma \cdot Homogeneity$ 3.3

Where $Contrast = \sum_{i,j}(i-j)^2 p(I,j)$ 3.4

$Entropy = -\sum_{i,j} \log(i,j)\ (I,j)$ 3.5

The vessel density index indicates the vascular congestion given by

$VDI = \frac{\sum Mvessel(x,y)}{\sum Mroi(x,y)}$ 3.6

For RGB to CIE conversion, to highlight the redness in the eye, is given by

$LAB_A^{Mean} = \frac{1}{N}\sum_{ROI} A(x,y)$ 3.7

A binary output gives the classification output of pollen allergic conjunctivitis [9]

$C = \{1$, present. 0, absent 3.8

For automated segmentation, the following parameters are considered

Dic coefficient $Dice = \frac{2TP}{(2TP+FP+FN)}$ 3.9

IoU (Jaccard index) $= \frac{TP}{(TP+FP+FN)}$ 4.0

Recall (Sensitivity) $= \frac{TP}{TP+FN}$ 4.1

Pixel Accuracy $= \frac{TP+TN}{TP+TN+FP+FN}$ 4.2

Specificity $= \frac{TN}{TN+FP}$ 4.3

Precision $= \frac{TP}{TP+FP}$ 4.4

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$$\text{F1-Score} = \frac{2.Precision.Recall}{Precision+Recall} \quad 4.5$$

$$\text{ROC-AUC} = \int_0^1 TPR(FPR)d(FPR)$$ Where TPR=Sensitivity, FPR= 1- specificity [6] 4.6

$$\text{Confidence score (\%)} = \text{Max}\ (P_{Model}) \times 100 \quad 4.7$$

IV. RESULTS

Table I: Results Obtained in Various Papers and the Proposed Method

Author	Method	Images	Model	Result
HitoshiTabuchi et.al [1]	Deep learning model and training the model	872	VGG-16,	AUC of 0.957
Michiko Yonehara. et al. [2]	deep learning algorithm	4942 slit-lamp images from 10 ophthalmological institutions	pretrained Mask R-CNN R50-FPN	The area under the curve (AUC) was 0.959 for AC,0.905 for normal subjects, 0.847 for GPC, 0.829 for VKC, and 0.790 for AKC.
Wei et al [3]	Conjunctiva injection grading	Colour anterior-segment images	Multi-class redness grade	Acc= 88%, sensitivity= 0.89, specificity= 0.91, precision=0.87, recall=0.86, F1-Score= 0.87, ROC-Auc=0.93
Yonehara et al [4]	Segmentation + Classification	Slit-lamp conjunctiva images	Multi-label clinical findings	Acc= 86.2%, sensitivity= 0.88, specificity= 0.90, Dice Coefficient=0.85, IoU=0.75
Rampat et al [5]	Segmentation + Classification	conjunctiva images	AI Methods	Acc= 95%, sensitivity= 0.95, specificity= 0.96, Dice Coefficient=0.85, IoU=0.80 ROC-Auc=0.97, recall=0.93
Yoo et al [6]	Detection / Segmentation (small lesions)	conjunctiva images	AI & ML	Acc= 88%, sensitivity= 0.86, specificity= 0.90, Dice Coefficient=0.80, IoU=0.70
Proposed method	Identification of conjunctivities	1022 Conjunctiva images and 542 Fundus images	Swin / ViT and CNN Transform	Acc= 90.3%, sensitivity= 0.87, specificity= 0.93, precision=0.88, recall=0.87, F1-Score= 0.89, ROC-Auc=0.96

V. CONCLUSION AND FUTURE SCOPE

The proposed method uses images from the Keggle database of 1000 fundus images and Attention-U-Net++ with Transformer Encoder (Global Context), Swin / ViT CNN +, Transformer Monte-Carlo Dropout Layer Enabled at inference time, Uncertainty-aware and Segmentation Mask + Uncertainty Map, Acc= 90.3%, sensitivity = 0.87, specificity = 0.93, precision=0.88, recall=0.87, F1-Score = 0.89, ROC-Auc=0.96. Executed on an Intel i5 Processor with 8 GB RAM with a 2.30 GHz processor on the Python platform. The method can also be applied to detect major conjunctivitis based on the disease's characteristics.

DECLARATION STATEMENT

As the article's author, I must verify the accuracy of the following information after aggregating input from all authors.

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