Project ID: ROBO022

Non-invasive Autonomous Anemia Screening Using Conjunctival Images

Introduction

- Anemia affects about 25% of the world population.
- Standard practice for diagnosis of anemia requires blood analysis.
- Pre-screening for possible anemia remains a challenging task.

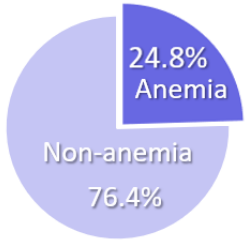


Table 1: Comparison of previous researches

Study	Sample size	Procedure	Tool	Accuracy	False Negative
Strobach et al. (1988)	50	(Physician eye check)		66.0%	60.7%
Collings et al. (2016)	101	Manual	Color palette	72.3%	43.5%
Tamir et al. (2017)	19	Manual	Fixed frame	78.9%	-
Park et al. (2020)	153	Manual	-	-	-

Fig. 1: Extraction of conjunctiva images were done manually. [1][4][7]

- **Objective:** Develop a non-invasive, autonomous and robust method for pre-screening of anemia from eye photos

Background

- WHO definition of anemia hemoglobin level
  - Female: less than 12.0 g/dl
  - Male: less than 13.0 g/dl
- Paleness of palpebral conjunctiva is commonly used for pre-screening of anemia.

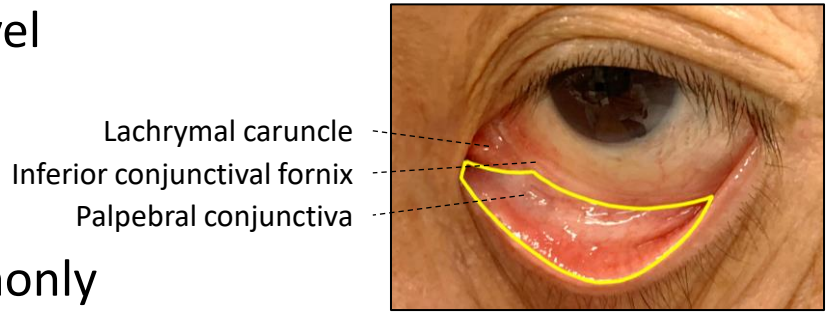


Fig. 2: Palpebral conjunctiva

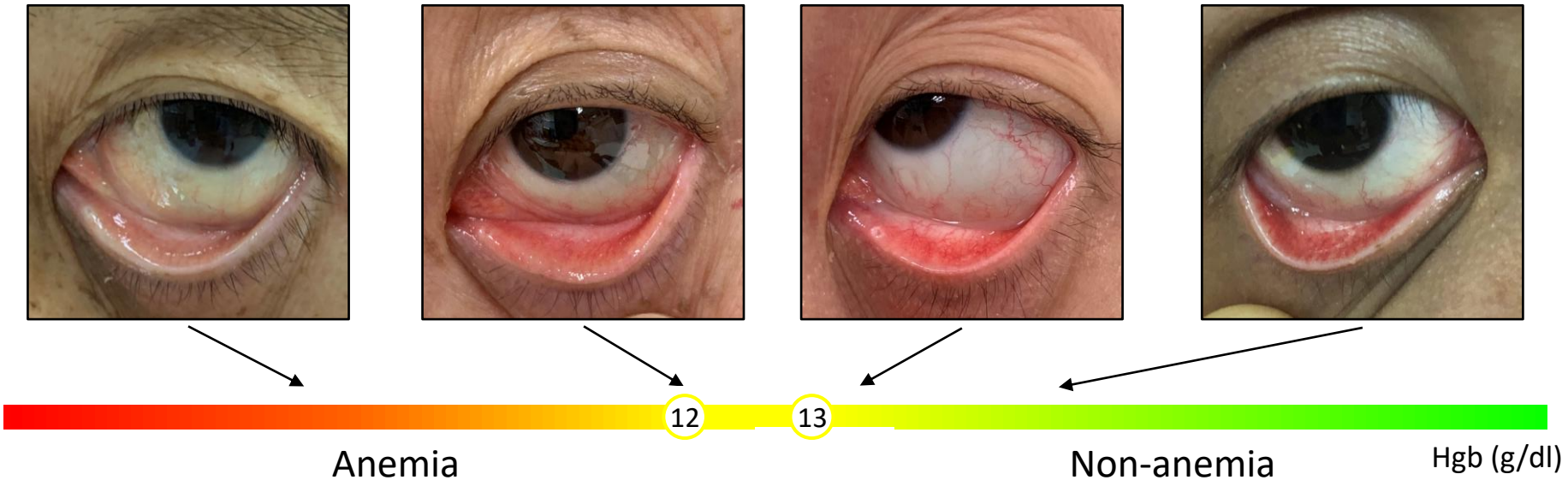


Fig. 3: Examples of palpebral conjunctiva image of anemia and non-anemia cases

Conjunctival Image Collection

- 55 subjects with 10 palpebral conjunctival images from each subject
  - blood analysis within three months before images were taken

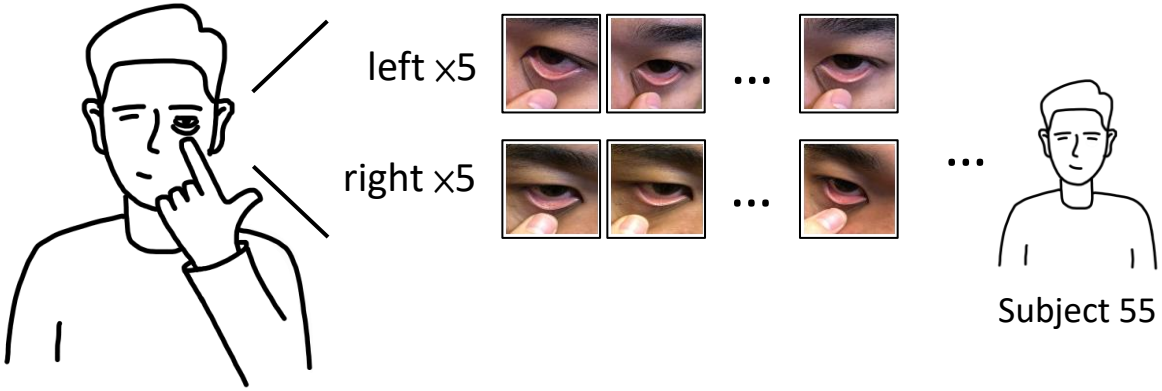


Fig. 4: 550 images from 55 subjects

Table 2: Sample size of anemia/ non-anemia vs. female/male

	Anemia	Non-anemia
Female	11	14
Male	15	15

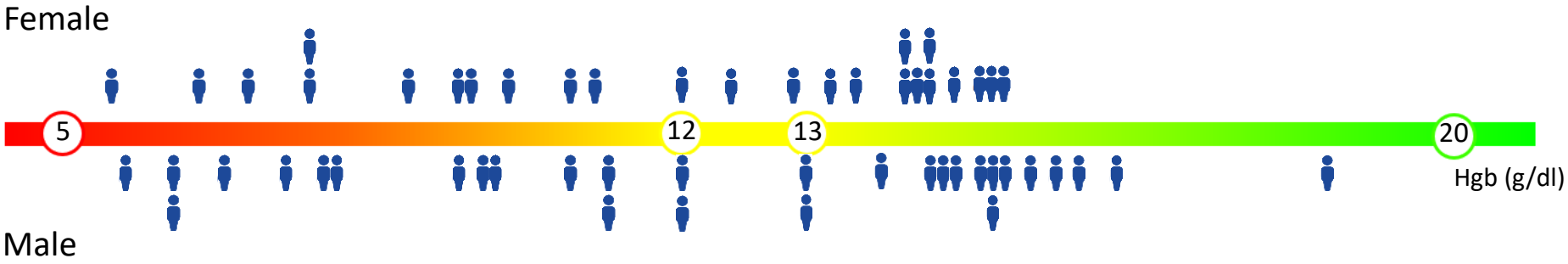
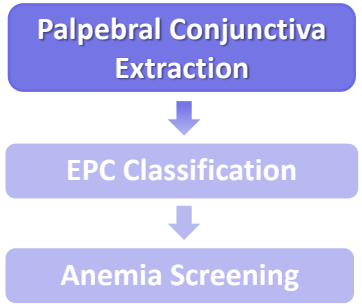


Fig. 5: Hemoglobin level of all 55 subjects

Extraction of Palpebral Conjunctiva

- Use TernausNet for palpebral conjunctiva extraction
  - UNet model with VGG11 encoder feature
  - Convolutional layers (filter size=3; stride=1, 2; padding=1)
  - Max pooling (size=2)



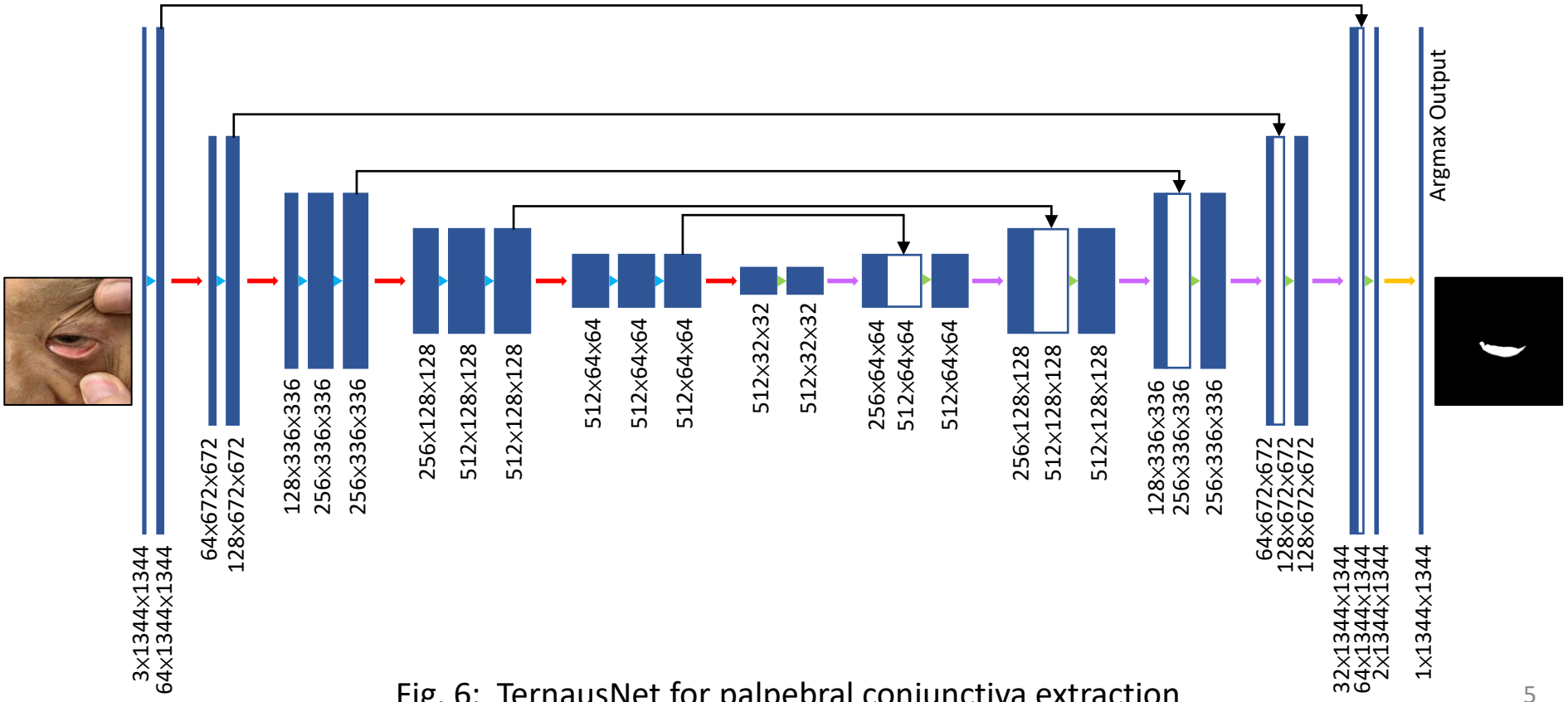


Fig. 6: TernausNet for palpebral conjunctiva extraction

Palpebral Conjunctiva Extraction Result

- Evaluation Metric: Intersection over Union (IoU)

$$\text{IoU} = \frac{\text{Area of Overlap}}{\text{Area of Union}} = \frac{\text{RoI} \cap \text{EPC}}{\text{RoI} \cup \text{EPC}}$$

  - Region of Interest (RoI) – Ground truth manually marked
  - Extracted Palpebral Conjunctiva (EPC) – Output of extraction model
- At epoch = 619, training/validation loss < 0.34, training/validation IoU > 0.87. (Fig. 7)
- Automatic Extraction Statistics (Fig. 8)
  - Best/Worst IoU = 0.973/0.676
  - Average IoU = 0.903, σ = 0.037
  - 92.7% of Images has IoU $\geq$ 0.850

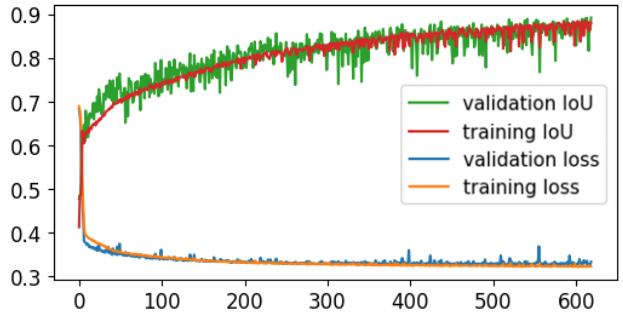


Fig. 7: Epoch vs. training loss and IoU

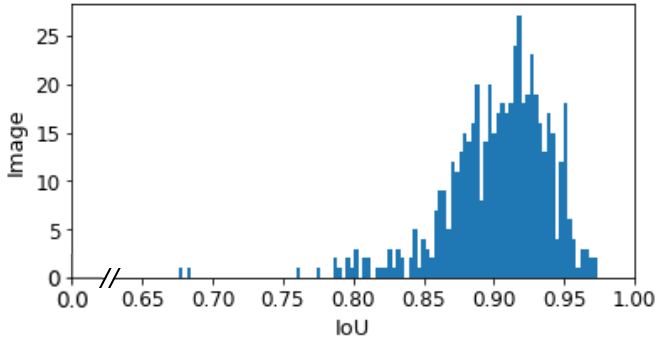


Fig. 8: IoU distribution of all EPCs

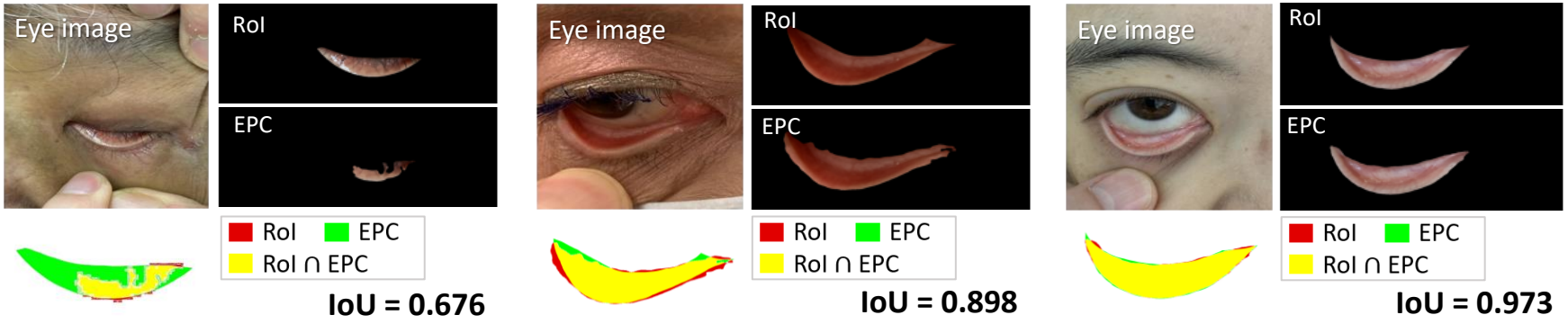
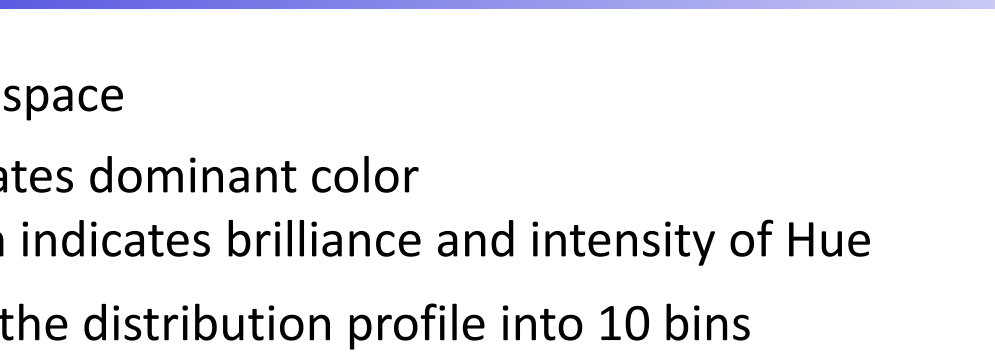


Fig. 9: Examples of palpebral conjunctiva extraction result

Feature for EPC Classification

- Use HSV color space
  - Hue indicates dominant color
  - Saturation indicates brilliance and intensity of Hue
- Equally divide the distribution profile into 10 bins
- Define 10 tuple feature as < $hs_1, hs_2, \ \dots\ , hs_{10}$ >



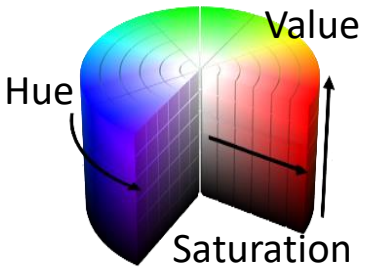
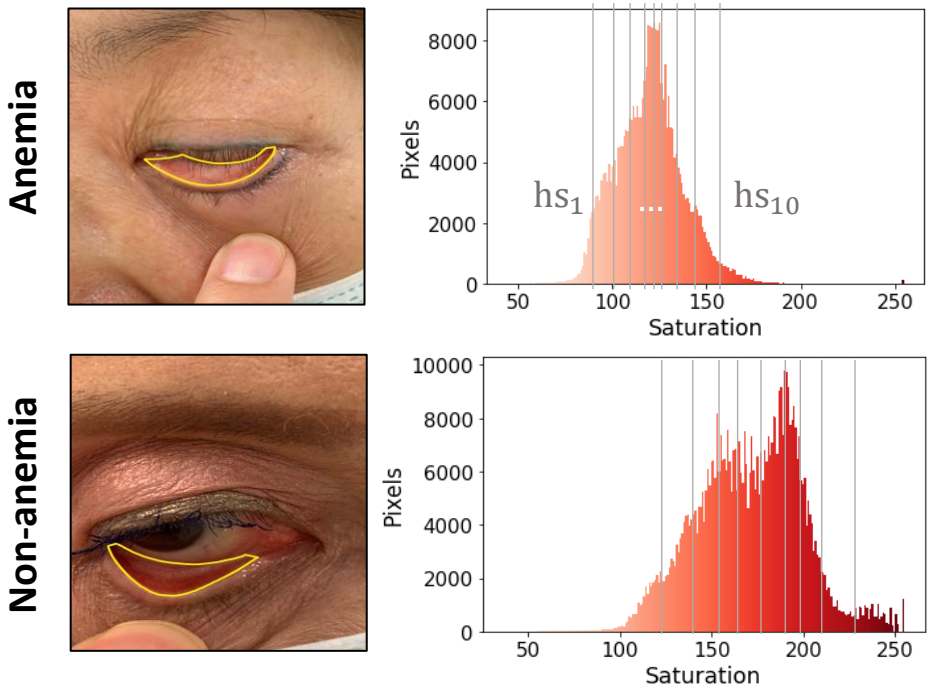


Fig. 10: HSV color space



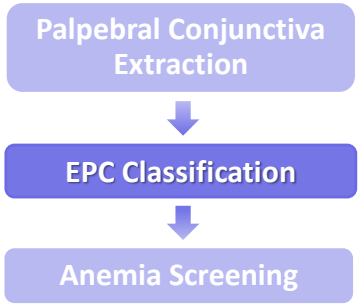
- Saturation distribution centered around 125
- Feature vector < $hs_1, hs_2, \dots, hs_{10}$ > has saturation values between 75 and 175

- Saturation distribution centered around 175
- Feature vector < $hs_1, hs_2, \dots, hs_{10}$ > has saturation values between 100 and 250

Fig. 11: 10-tuple vector computed from the HSV distribution

Supervised Classification

- k-Nearest Neighbors (k-NN) vs. Support Vector Machine (SVM)
  - k-NN with k ∈ {3, 5, … , $\sqrt{n}$}
  - SVM with C ∈ {0.001, 0.01, 0.1, 1, 10, 100}, gamma ∈ {0.0001, 0.001, 0.01, 0.1, 1},
  - Kernel functions: RBF, linear, polynomial, sigmoid



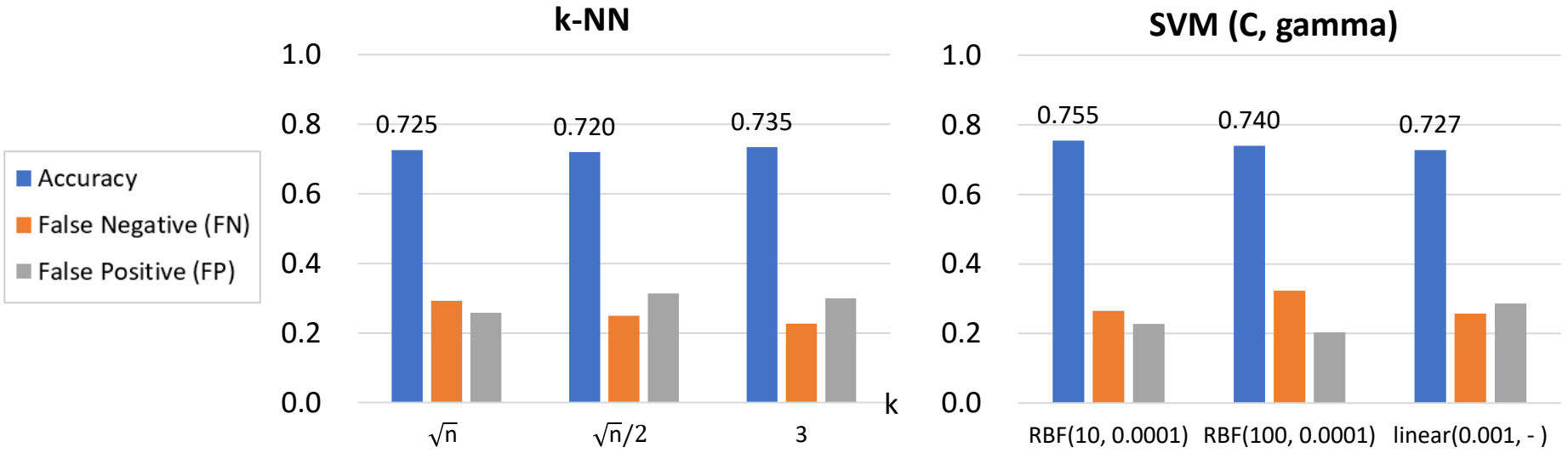


Fig. 12: Acurracy of EPC classifications

- Best Result:
  - 3-NN: Accuracy=0.735, FN=0.300, FP=0.227
  - SVM(RBF, C=10, gamma=0.0001): Accuracy=0.755, FN=0.228, FP=0.265

Anemia Screening Criteria

- Screening Criteria:

Single Image 1 Eye (SI1E)

$P(i) \mid \exists\, i \in (I_L + I_R)$

Single Image 2 Eye (SI2E)

$P(i) \mid \exists\, i \in (I_L)\ and\ P(i) \mid \exists\, i \in (I_R)$

Majority Rule 1 Eye (MR1E)

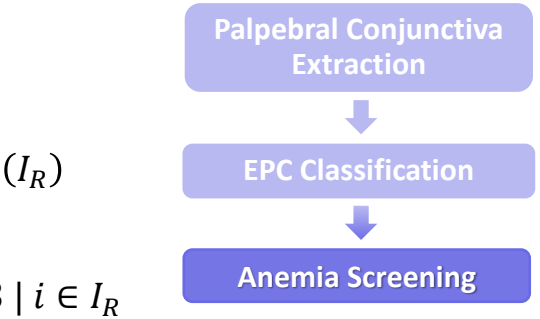
$\Sigma P(i) \geq 3 \mid i \in I_L\ or\ \Sigma P(i) \geq 3 \mid i \in I_R$

Majority Rule 2 Eye (MR2E)

$\Sigma P(i) \geq 3 \mid i \in I_L\ and\ \Sigma P(i) \geq 3 \mid i \in I_R$

Majority Rule Image Set (MRIS)

$\Sigma P(i) > 5 \mid \ \forall\, i \in (I_L + I_R)$



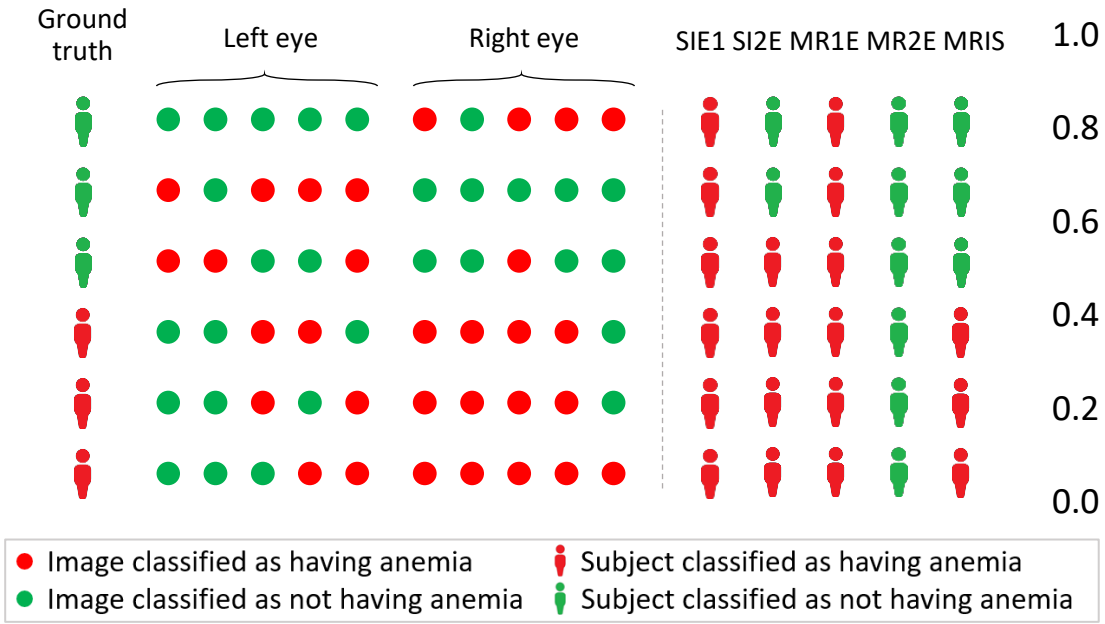


Fig. 13: Examples of applying screening criterion to classified EPCs

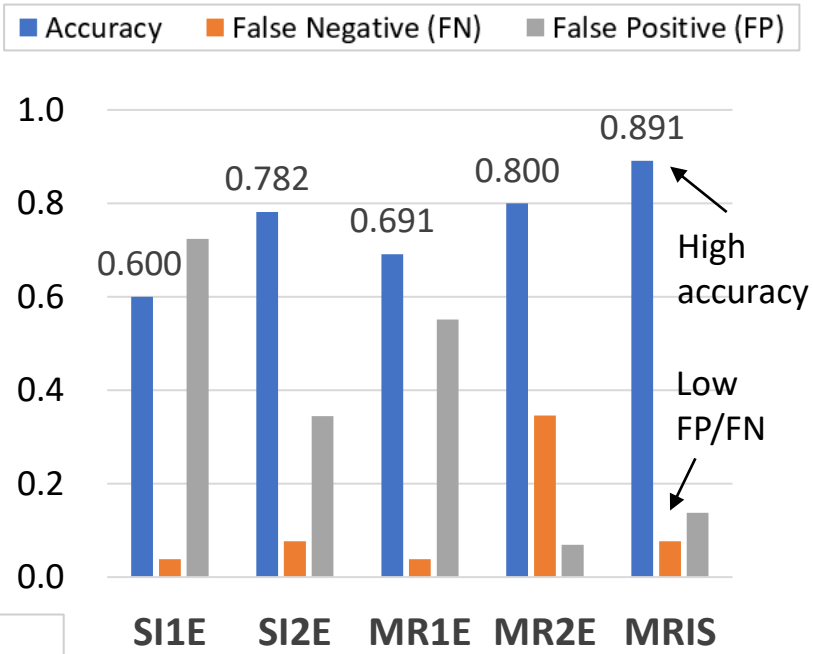


Fig. 14: Screening accuracies

Anemia Screening Results

Table 3: Female, male and overall experimental results

Female (Acc.=0.880)		Male (Acc.=0.900)		Overall (Acc.=0.891)	
TP = 0.909	FP = 0.143	TP = 0.933	FP = 0.133	TP = 0.923	FP = 0.138
FN = 0.091	TN = 0.857	FN = 0.067	TN = 0.867	FN = 0.077	TN = 0.862

TP: True Positive TN: True Positive FP: False Negative FN: False Negative

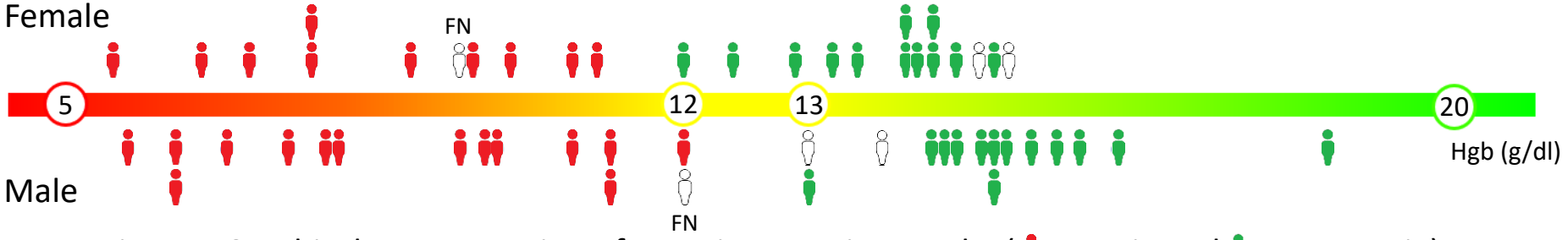


Fig. 15: Graphical representation of anemia screening results (anemia and non-anemia)

- High accuracy (TP, TN) and low FN and FP for both female and male groups.
- Two FN cases (Fig. 16) both have EPC with high IoU, but EPC mostly classified as non-anemia.

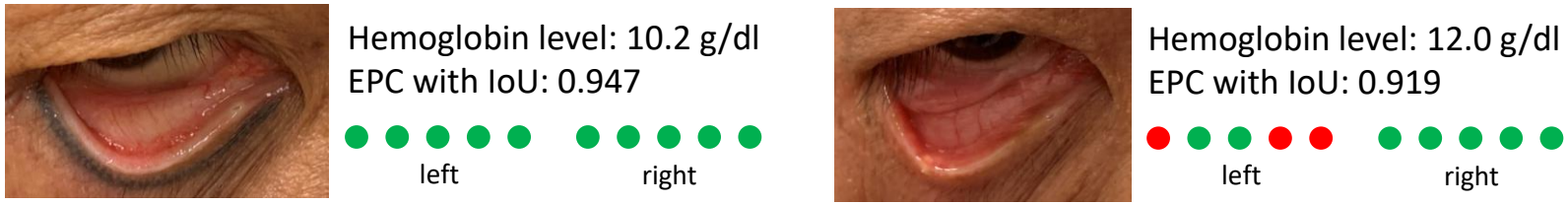


Fig. 16: Two subjects with false negative anemia screening result

Conclusions

- This research proposed an **efficient conjunctiva based anemia screening** method.
- The proposed method has anemia screening accuracy that is **10%~20% better than earlier researches**, and with much lower false positive and false negative rates.
- An anemia screening sensor can be made based on this research for use at clinics or at home.
  - To lower the false positives diagnosis and to prevent wasting medical resources
  - To facilitate early detection and early treatment before symptoms deteriorate

Accuracy = 0.891
False Negative = 0.077
False Positive = 0.138

References

[1] Collings, S., et al. Non-invasive detection of anaemia using digital photographs of the conjunctiva. *PLoS One.* **2016**;11:e0153286.

[2] Iglovikov, V., et al. TernausNet: U-Net with VGG11 encoder pre-trained on ImageNet for image segmentation. **2018**.

[3] Mazzu, T., et al. Mobile health (mHealth) and advances in noninvasive diagnosis of anemia: an overview. *Intern J Nutrol.* **2020**;13:42-47.

[4] Park, S.M., et al. mHealth spectroscopy of blood hemoglobin with spectral super-resolution. *Optica.* **2020**;7:563-573.

[5] Sheth, T.N., et al. The relation of conjunctival pallor to the presence of anemia. *J Gen Intern Med.* **1997**;12:102-106.

[6] Strobach, R.S., et al. The value of the physical examination in the diagnosis of anemia correlation of the physical findings and the hemoglobin concentration. *Arch Intern Med.* **1988**;148:831-832.

[7] Tamir, A. et al. Detection of anemia from image of the anterior conjunctiva of the eye by image processing and thresholding. ***2017*** *IEEE Region 10 Humanitarian Technology Conference*; 697-701.