Image Mosaicing of Neonatal Retinal Images

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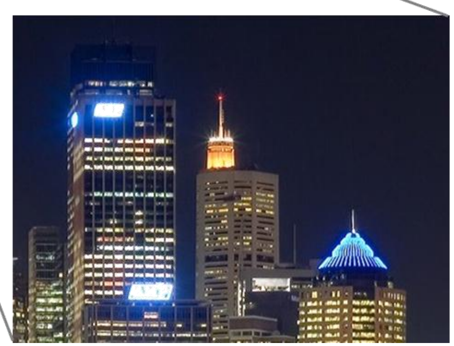
Image Mosaicing

Image mosaicing:

- *A technique used to combine multiple images of overlapping field of view and create a single high resolution image (**mosaic**)*
- *It is employed to fuse the information and extend the field of view*

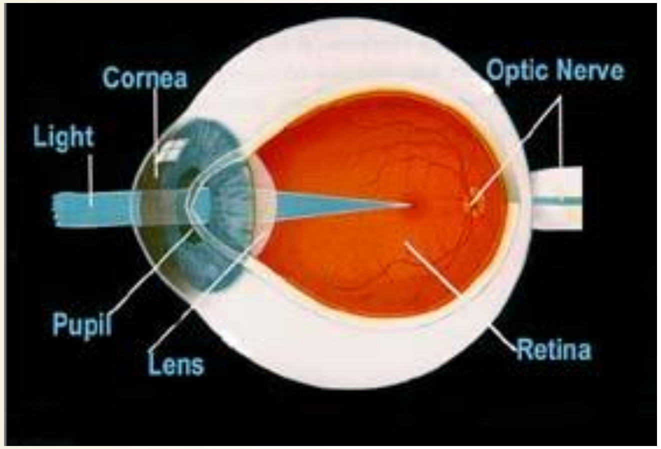


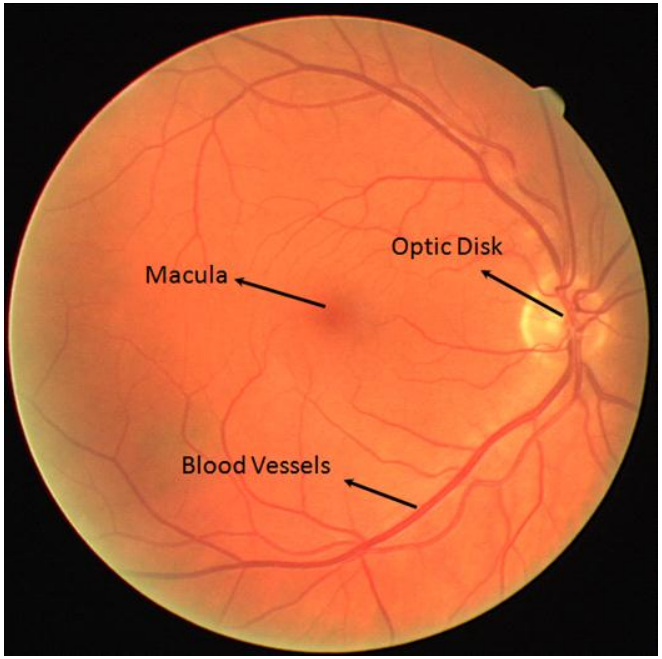
A sample Mosaic (Inset Showcasing High Resolution of mosaic)

Motivation: Retinopathy of Prematurity

Retina:

- A thin layer of membrane at the back of the eye is called 'Retina'
- Contains light receptors which converts the light rays into electrical impulse
- Major Structures: *Optic Disk, Macula, Blood Vessels*



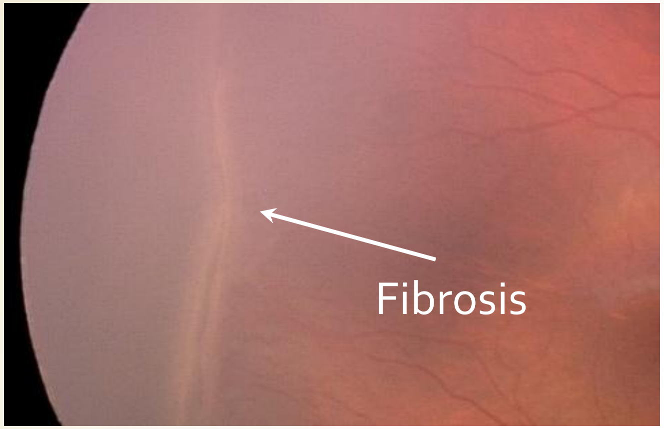


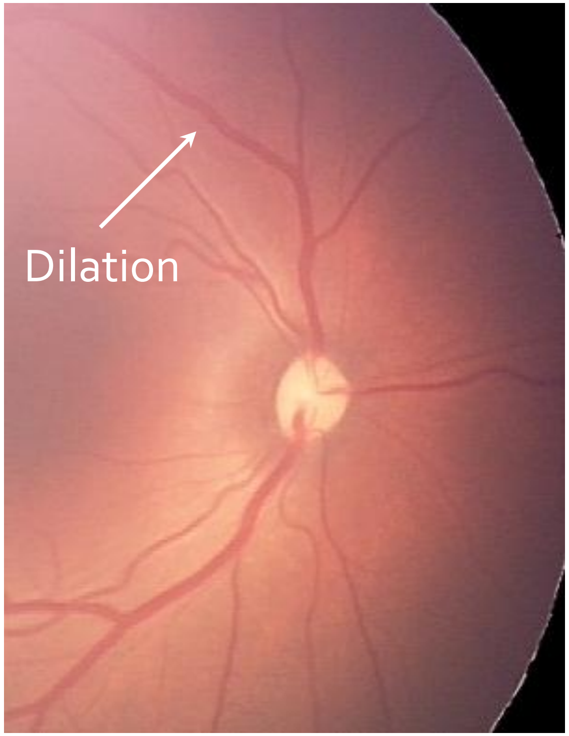
Retinopathy of Prematurity

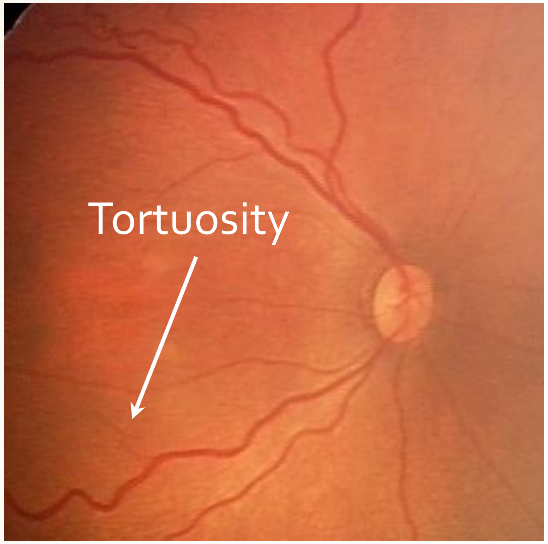
- Retinopathy of prematurity (ROP) is an eye disease that affects ***premature babies***
  - Common cause of blindness in babies
  - Characterized by abnormal vessel growth and fibrosis in peripheral retina

- The key information for diagnosis is the presence of plus disease and the extent of vessel growth in periphery
  - Plus disease represents abnormal levels of tortuosity and dilation of posterior blood vessels

Abnormality in ROP



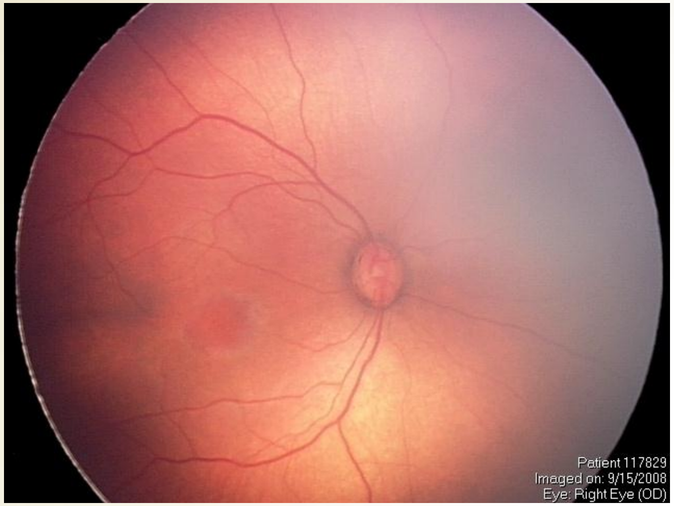


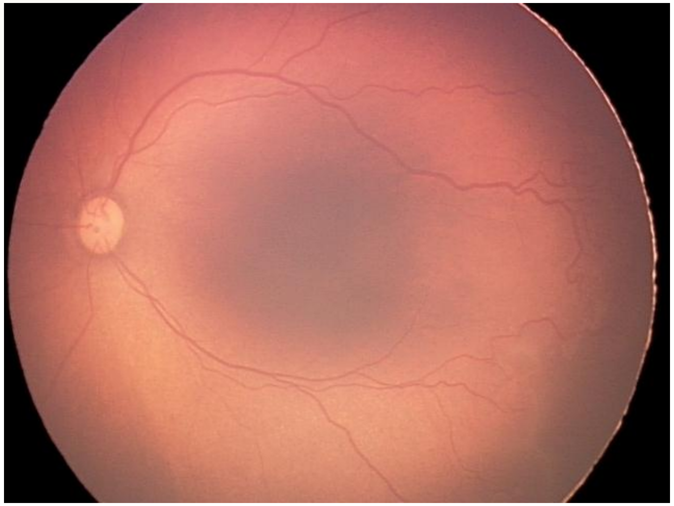


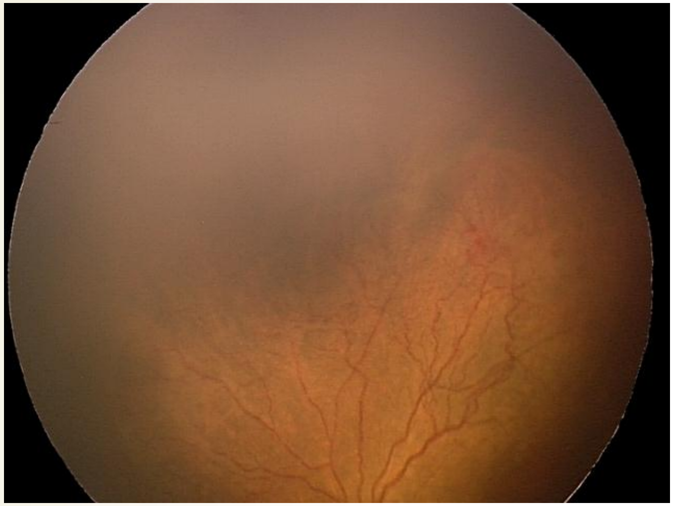
Why mosaicing ?

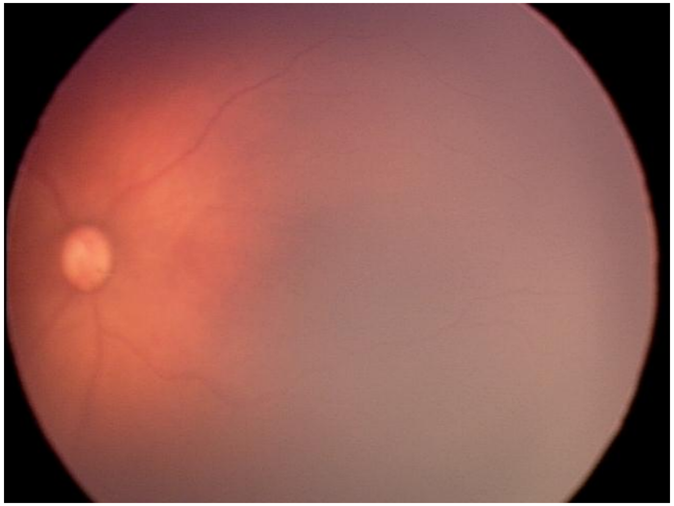
- Due to its spherical nature, multiple images are required to capture the complete retinal surface.
- Using a standard fundus camera, it is difficult to capture the extreme periphery of retina
- RETCAM, a wide-field fundus camera which is designed mainly for retinal imaging in infants, is used.

Sample Retcam Images









Objective

- Existing work towards ROP tries to detect plus disease and derive tortuosity measure that correlates with experts
- These require a good quality image of the central region of retina (limiting their use when such an image doesn’t exist)

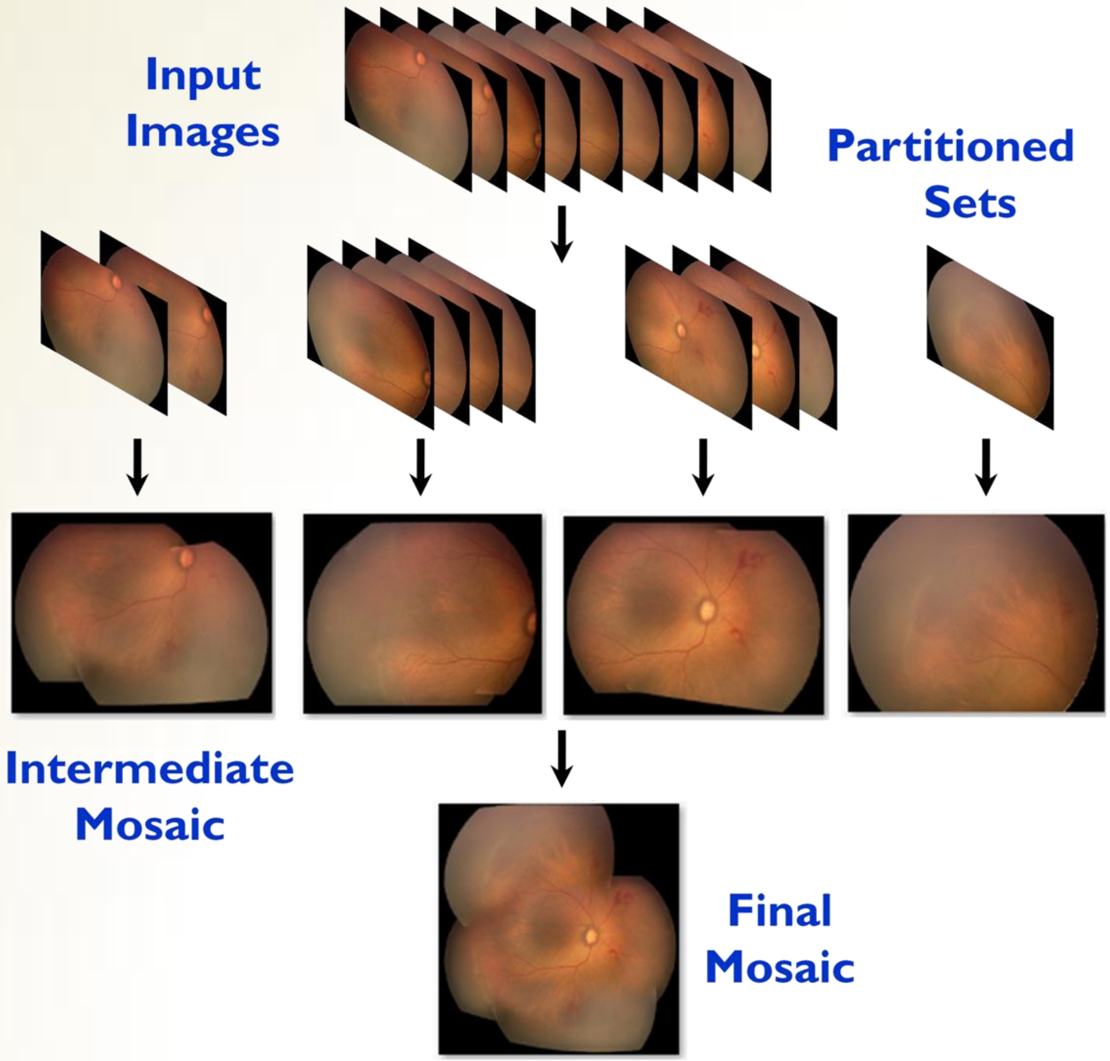
- **Goal**: To create a single good quality mosaic of the complete retina using a set of retinal images taken from different view points

- The mosaic would be helpful for doctors for manual diagnosis and can be used by the existing computer systems

Challenges

- Low quality images with uneven illumination and various degree of blur
- Images of low pixel resolution (640x320)
- Large set of non-sequential images with few containing either no information or redundant information
- Existing approaches designed for good quality adult retinal images cannot be directly used

Hierarchical Approach



Mosaicing algorithm

1. Partition the given set S: $\{S_k\}$ based on OD location
2. Choose an anchor frame for each S_k based on image quality
3. Register the remaining images in S_k to the anchor
4. Discard the images which did not register accurately
5. Blend the registered images in S_k to create an intermediate mosaic
6. Register and blend the intermediate mosaics to create a complete mosaic using steps similar to 2-4.

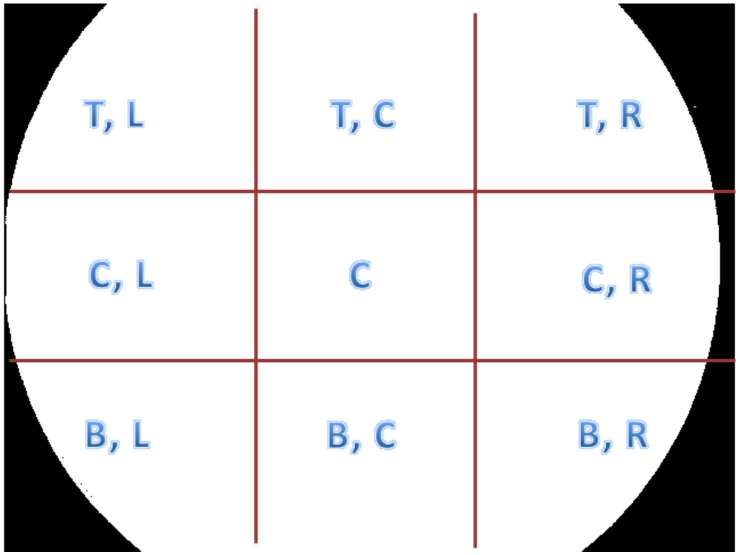
Partitioning

- Given set of images $S = \{I_n: n=1,2,N\}$ is partitioned into S_k:k=1,2,..K
  - where each S_k correspond to a distinct region of retina
- Aim of such grouping is to achieve maximum overlap among images in a set (for accurate registration)
- This is achieved by using the domain knowledge about the inherent structure of retina
  - Based on location of optic disk and peripheral vessels

Partitioning

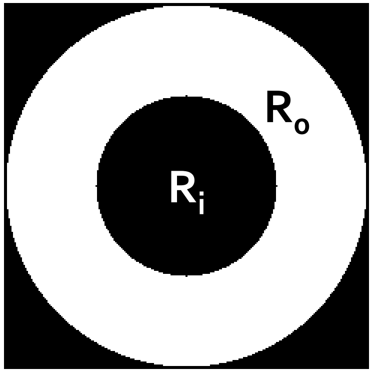
Images are partitioned into 5 sets as follows:

- S1 : OD centric images (C)
- S2 : OD positioned in the left (L)
- S3 : OD positioned in the right (R)
- S4 : OD positioned in the top (T)
- S5 : OD positioned in the bottom (B)



Membership Based on OD

Optic Disk Detection



Optic Disk Detection: We try to capture the color discontinuity at the boundary of OD

Observation:

- OD consists of uniform color => color distance among OD points would be low

- Color change at boundary => color distance between points inside OD and boundary would be high

Optic Disk Detection

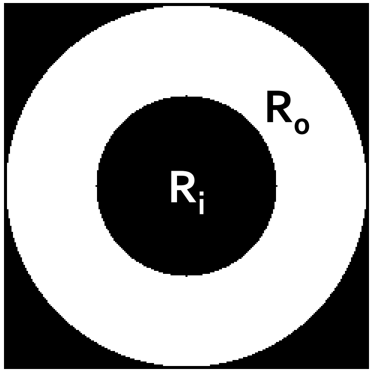
- An annulus shaped template with Ri and Ro is constructed
- A every point p, local maxima (Cp) is computed within Ri
- The color variations in Ri and Ro with respect to Cp

$$O(p) = \sum_{r \in R_o} \|I(r) - C_p\|$$

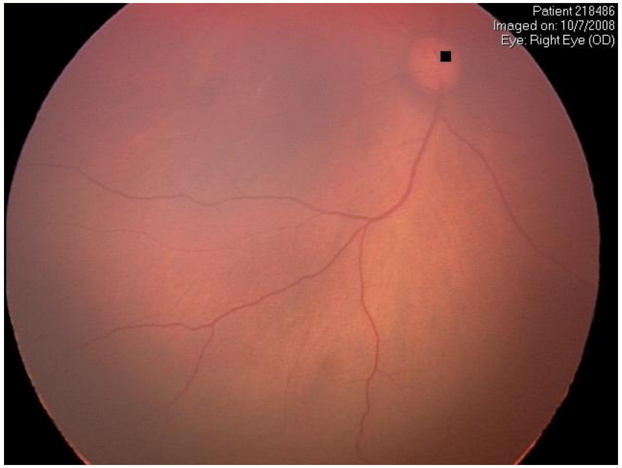
$$I(p) = \sum_{r \in R_i} \|I(r) - C_p\|$$

- The location where the difference is maximum is taken as OD

$$H(p) = O(p) - I(p)$$



OD Detection Results



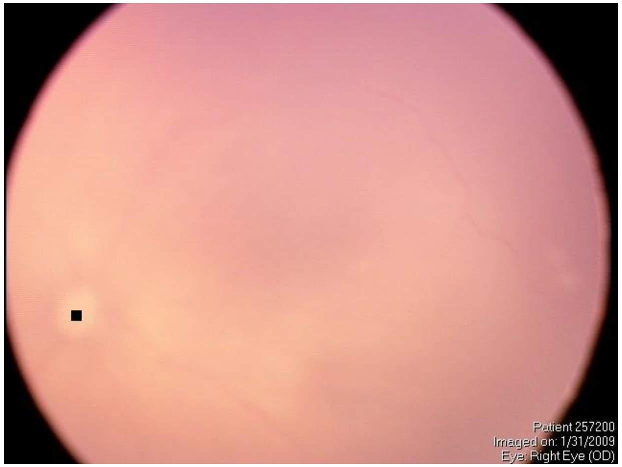
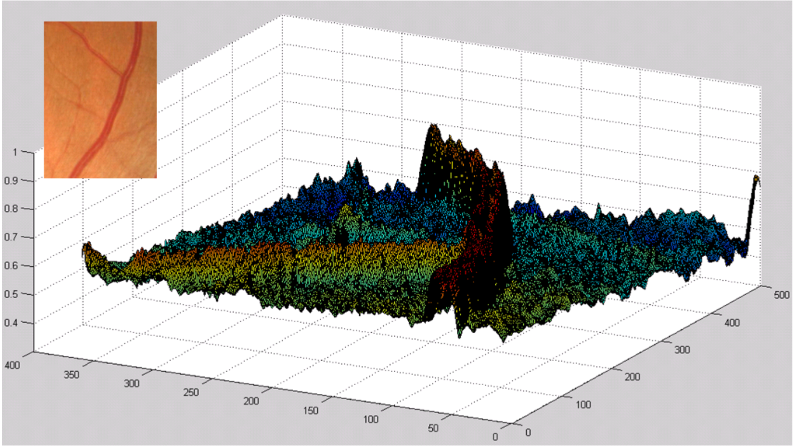


Image Quality Assessment

- After partitioning, images in each set need to be registered
- An anchor image is needed in each set as a frame of reference which is chosen based on image quality
- Image quality depends on the object of interest which in this case are blood vessels
- The specific features of interest are the sharpness and contrast of vessels

Image Quality Assessment

- Blood vessels can be visualized as ‘ridges’ considering image as a surface map



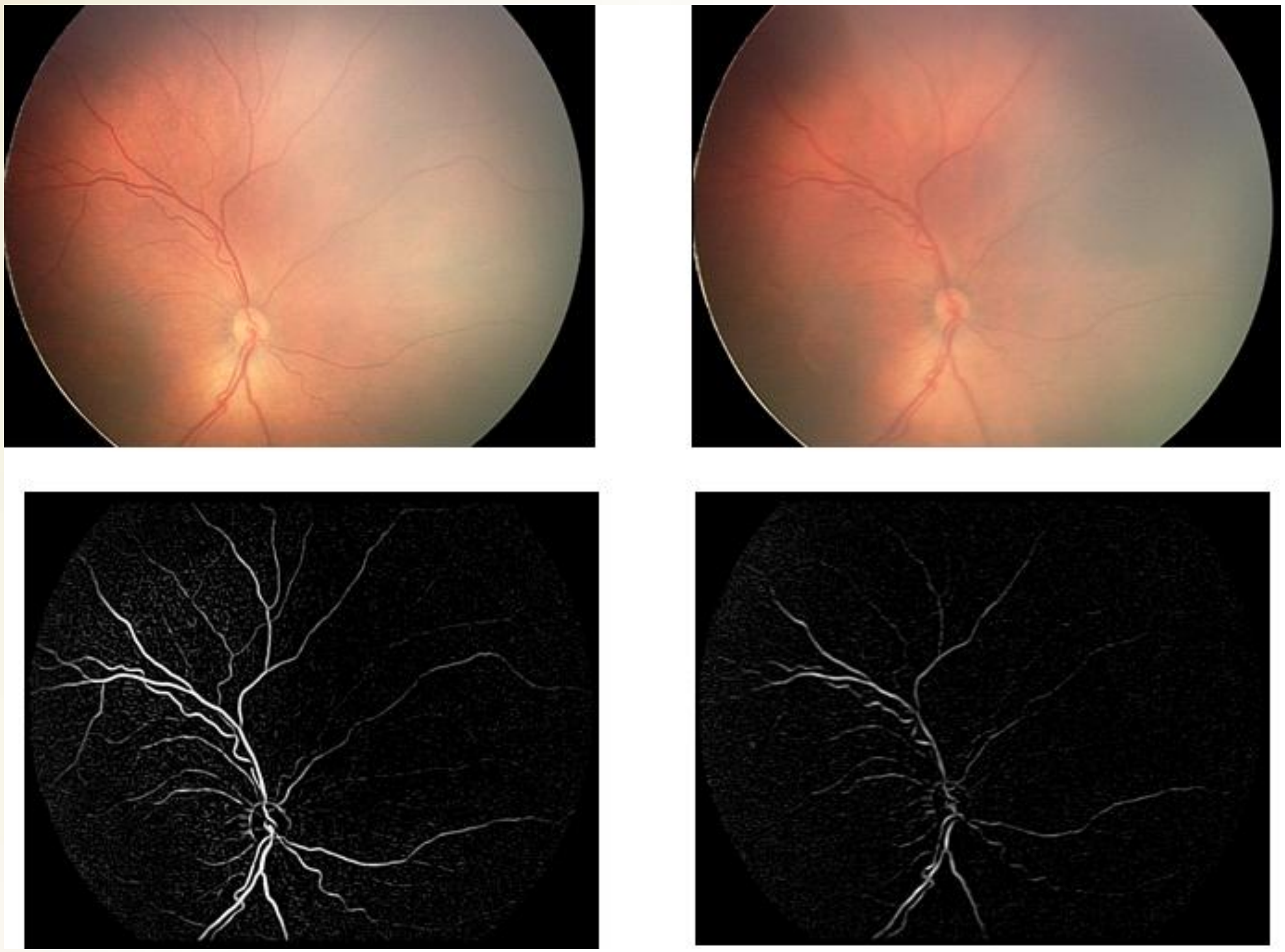
- We use a multi-scale ridge strength measure based on Hessian

$$H = \begin{bmatrix} L_{xx} & L_{xy} \\ L_{yx} & L_{yy} \end{bmatrix}$$

$$R_S(x, y, s) = (L_{uu}^2 - L_{vv}^2)^2$$

$$R(x, y) = argmax_s R_S(x, y, s)$$

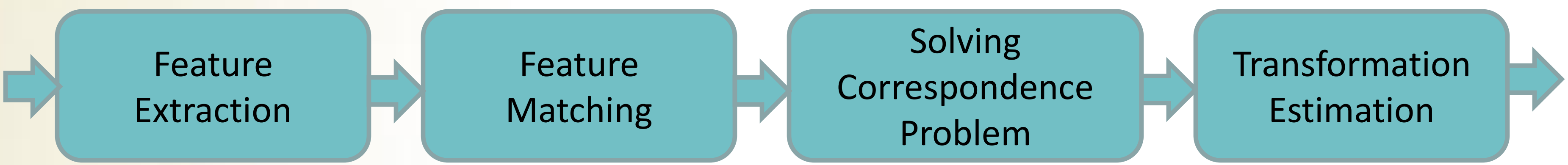
Image Quality Assessment



Two views of the same region of retina with corresponding vesselmaps

Pair-wise Registration

- Partitioned images need to be spatially aligned to a single co-ordinate system
- As a frame of reference for each set, an anchor image is chosen based on quality
- All images are individually registered to the corresponding anchor image



Feature Extraction

Feature Detection:

- A interest point detector based on Determinant of Hessian (DOH) is used
- DOH is computed at multiple scales and scale-space maxima is thresholded
- A dense set of high curvature points near the blood vessels are detected

Feature Description:

- A radon transform based descriptor is used to represent the information around the interest points
- Radon transform is based on projections widely used to describe the shape of objects

$$R(r,\theta) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} I(x,y)\delta(xcos\theta + ysin\theta - r)\mathrm{d}x\mathrm{d}y$$

Feature Matching

- Obtained descriptors need to be matched for correspondence
- Since a dense set is constructed, a rigorous ‘bilateral matching’ technique is employed
- For all features, best match is computed in the other set based on Euclidean distance
- In bilateral matching, only matches which are two way are considered

Solving the Correspondence Problem

- Based on transformation model, the matches are refined resulting in accurate correspondence
- RANSAC is used for model fitting and estimating the parameters of the model
- This is a popular estimator which is used when data consists of significant no.of outliers
- A quadratic transformation model (DOF : 12) is chosen for fitting spherical retinal structure

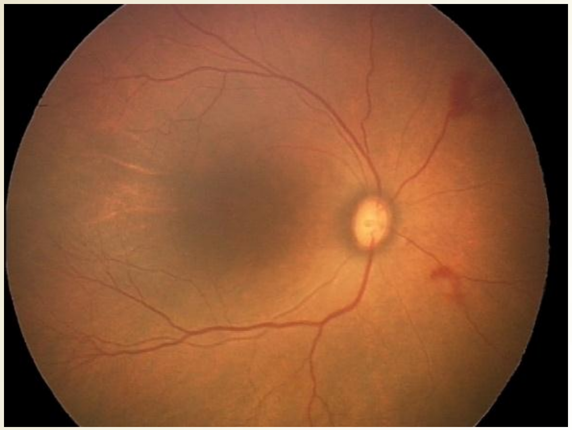
Solving the Correspondence Problem

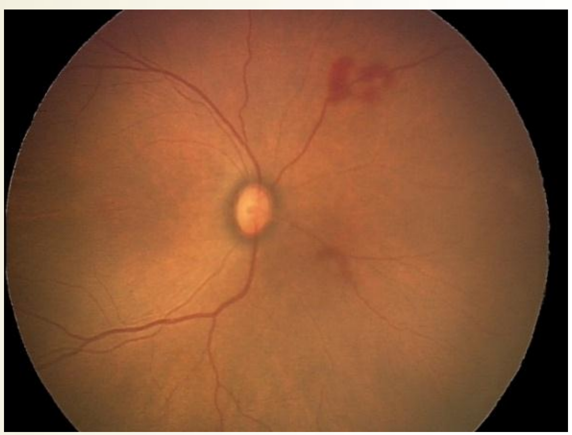
- An affine transformation model is first assumed to refine the initial matches
- The matches are further refined by fitting the quadratic transformation

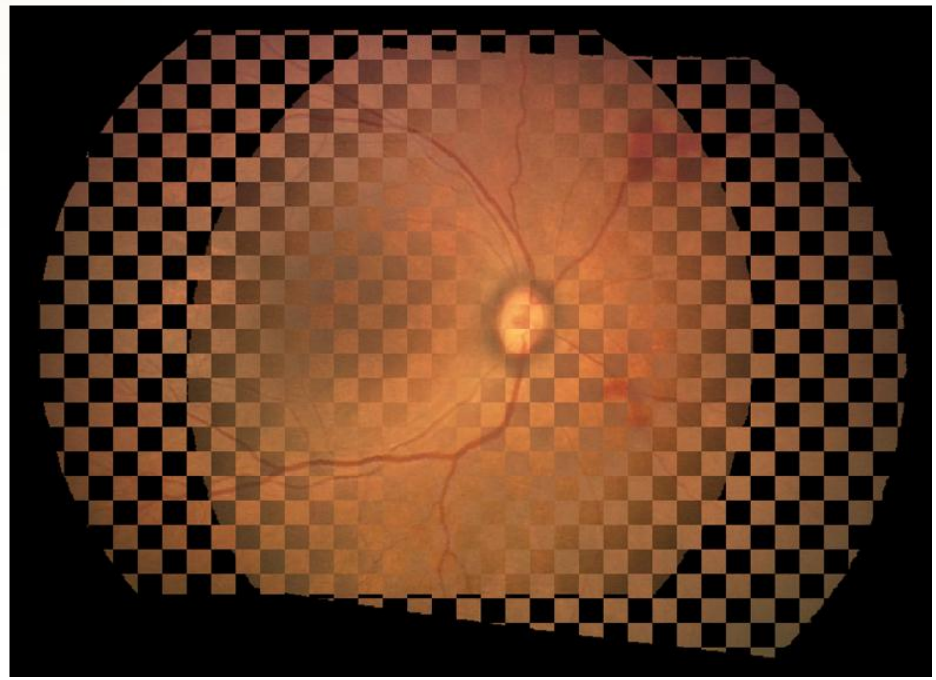
Transformation Estimation

- The obtained set of accurate matches are spatially localized using normalized cross-correlation
- A guided matching strategy is applied around a small windows to obtain the final accurate correspondence

Registration Results







Checker board pattern showing alternate blocks of registered images

Image Blending

- Once images in each set are registered to anchor image, they need to combined using blending to obtain seamless images
- A multi-band blending based on Laplacian pyramids is used to combine the registered images.
- Idea is to combine high frequencies over a small spatial extent and low frequencies over large extent

- The key step in this approach is to obtain the blending masks
- Blending mask dictates which region to be included in the composite image

$$LS[i,j] = GR[i,j] * LA[i,j] + (1 - GR[i,j]) * LB[i,j]$$

Image Blending

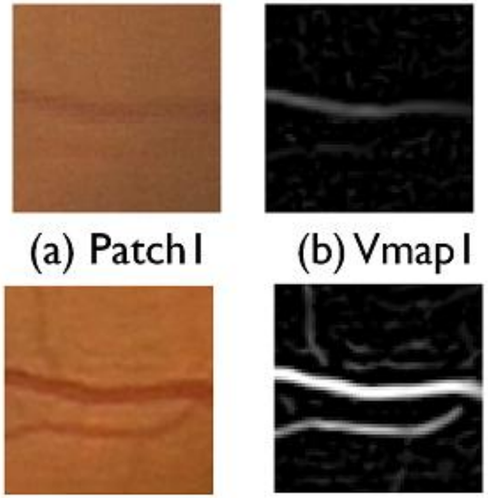
We apply the blending multiple times

First Pass:

- Information is exchanged among the images based on the patch level vessel quality measure
- Aim is to equalize the vessel quality in all the views

Second Pass:

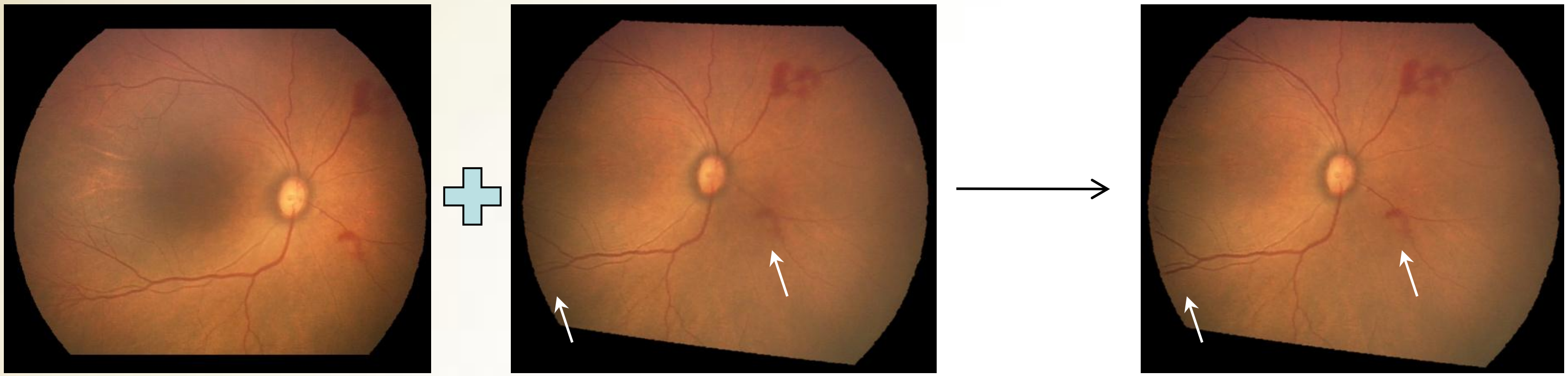
- The modified images are blended to eliminate the seam at the junction



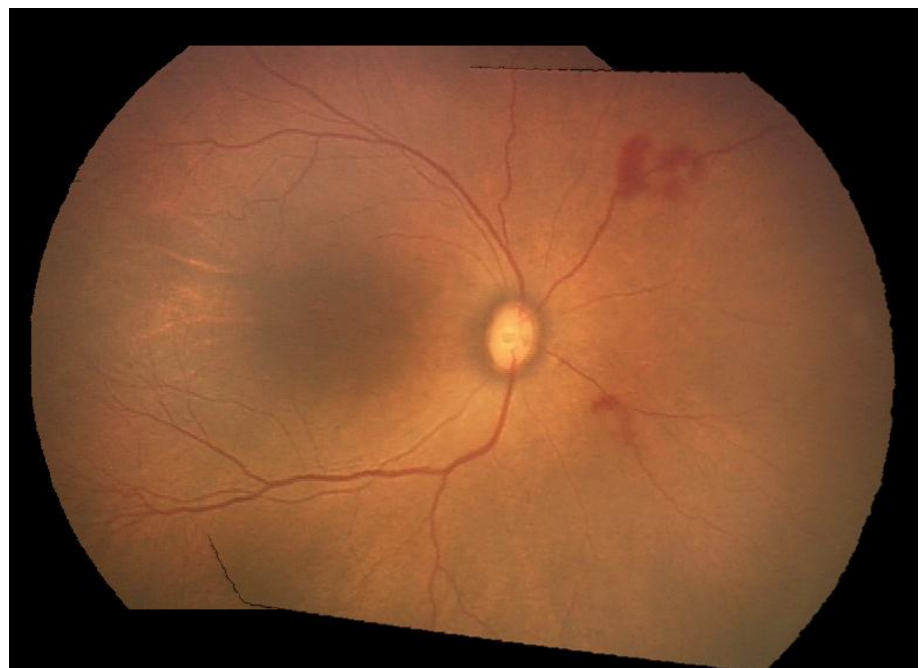
(a) Patch1 (b) Vmap1 (c) Patch2 (d) Vmap1

Blending Results

Adding Information:



Final blended Image



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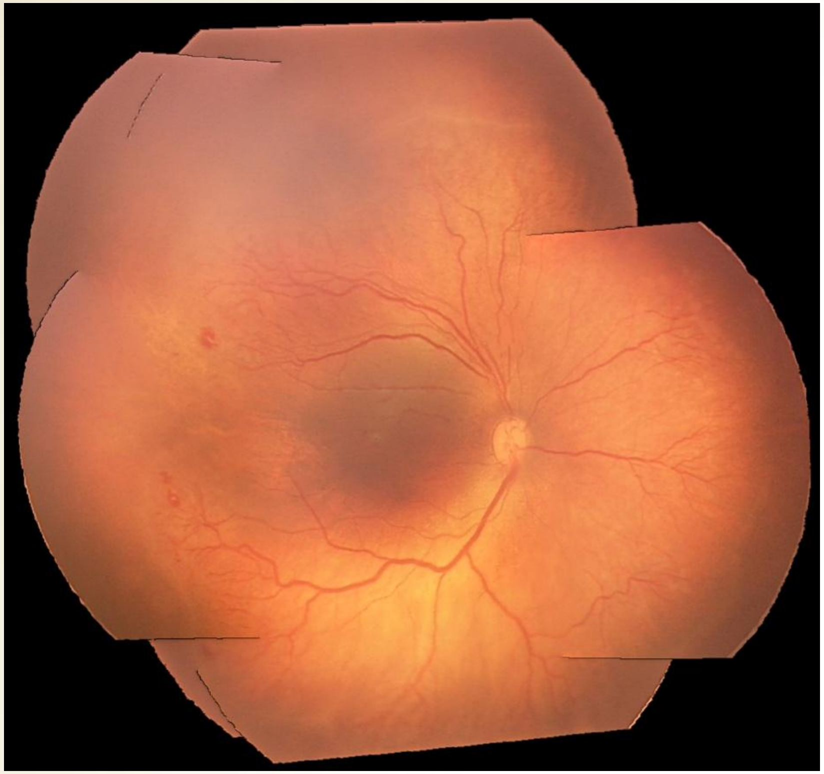
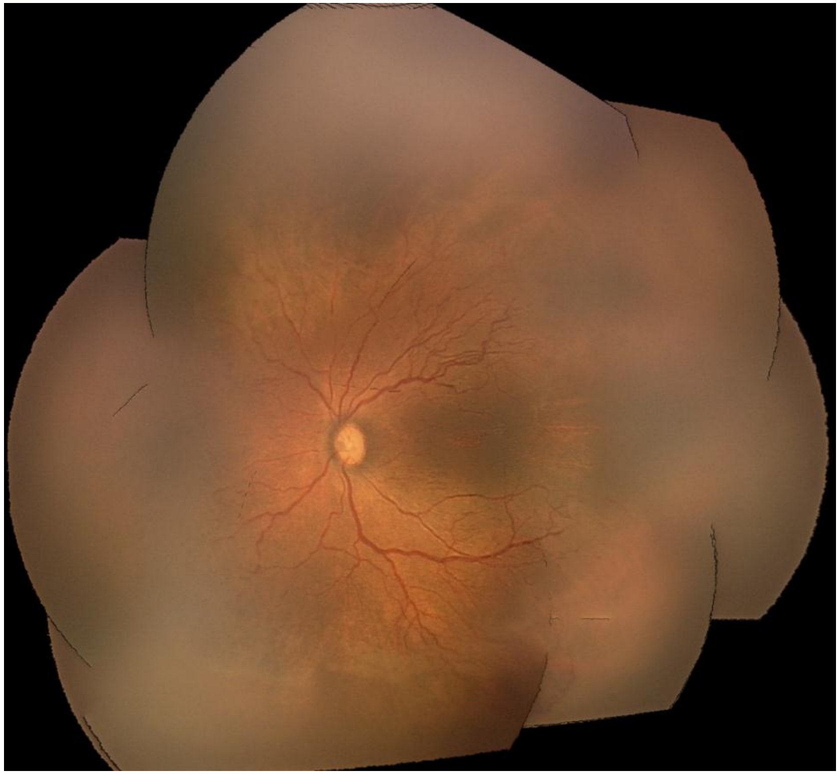
Generated Image Mosaics

Two sample cases:



(a) Combining 7/12 images



(b) Combining 8/12 images

Assessment

Major Components:

- Optic Disk Detection
- Pair-wise registration
- Image Blending

Quantitative Assessment

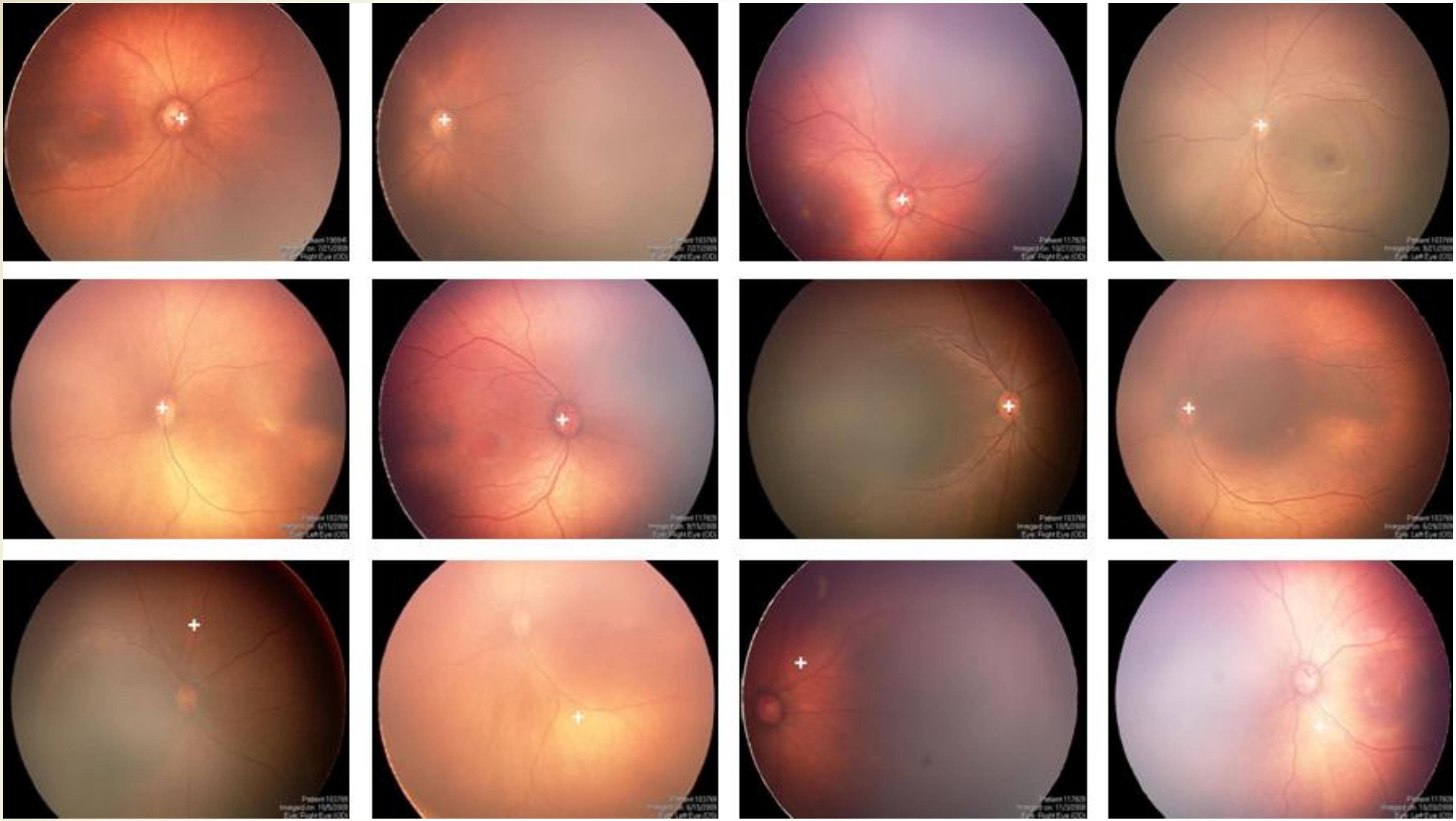
Qualitative Assessment

Results: Optic Disk Detection

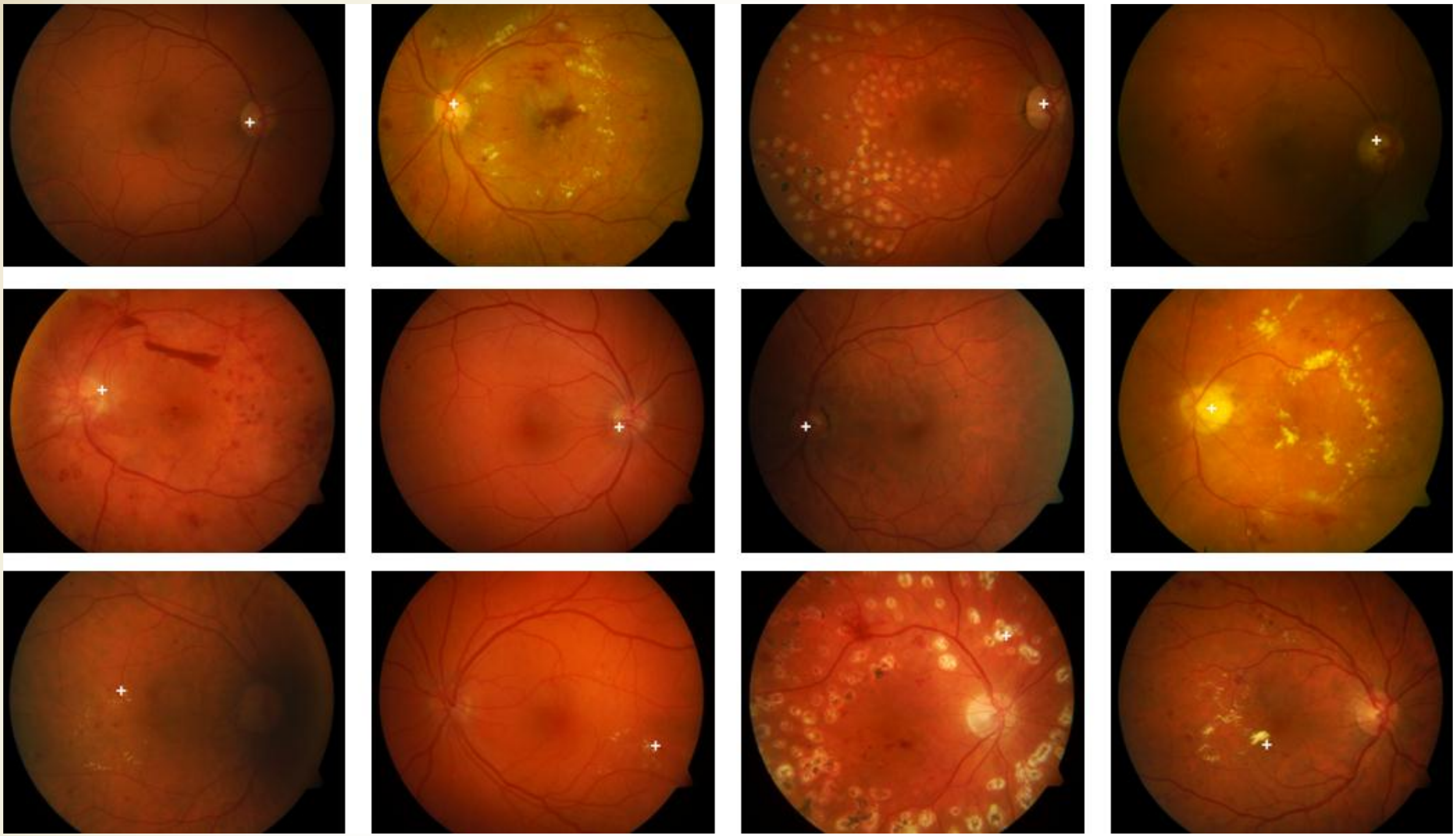
Dataset	Drive	Diaretdb0	Diaretdb1	ROP1	ROP2
Number of Images	40	130	89	75	50
OD detected	40	125	87	74	45
Success Rate (%)	100	96.2	97.8	98.7	90
Computation time (secs)	0.30	1.05	1.05	0.32	0.32

- Drive, Diaretdb0, Diaretdb1 : Public Benchmark Datasets
- ROP1, ROP2: Consists of neonatal retinal images. ROP2 consists of challenging cases

Results: Optic Disk Detection



Results: Optic Disk Detection

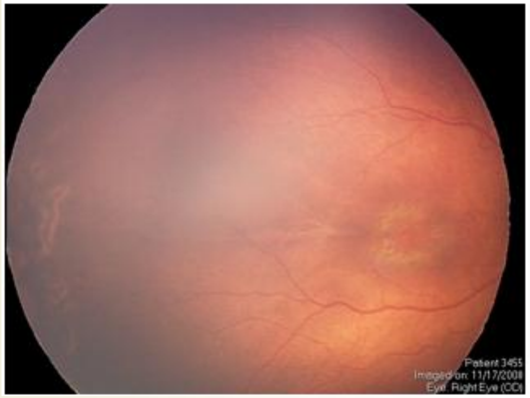


Results: Pair-wise Registration

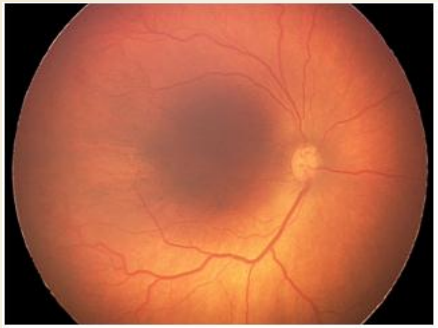
Method	Dataset	Accurate	Adequate	Failure
Our method	REG1	22	14	4
GDBICP[1]	REG1	16	13	11
Our method	REG2	11	10	4
GDBICP[1]	REG2	6	9	10

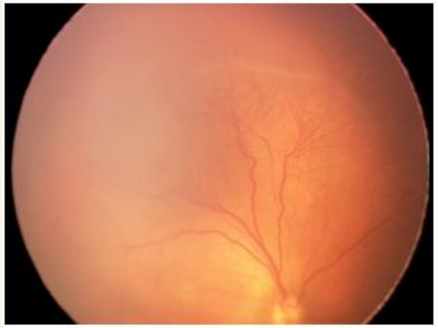
- REG1, REG2: Pairs of neonatal retinal images obtained using RETCAM. REG2 consists of challenging cases.

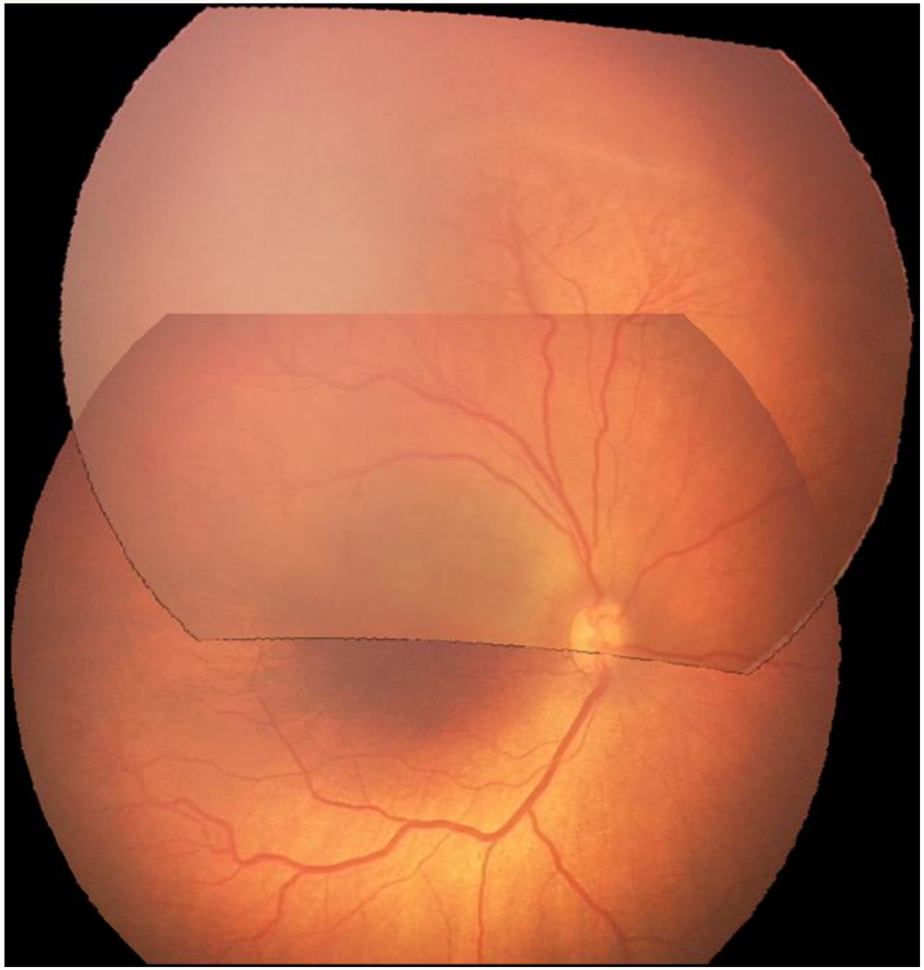
Results: Pair-wise Registration



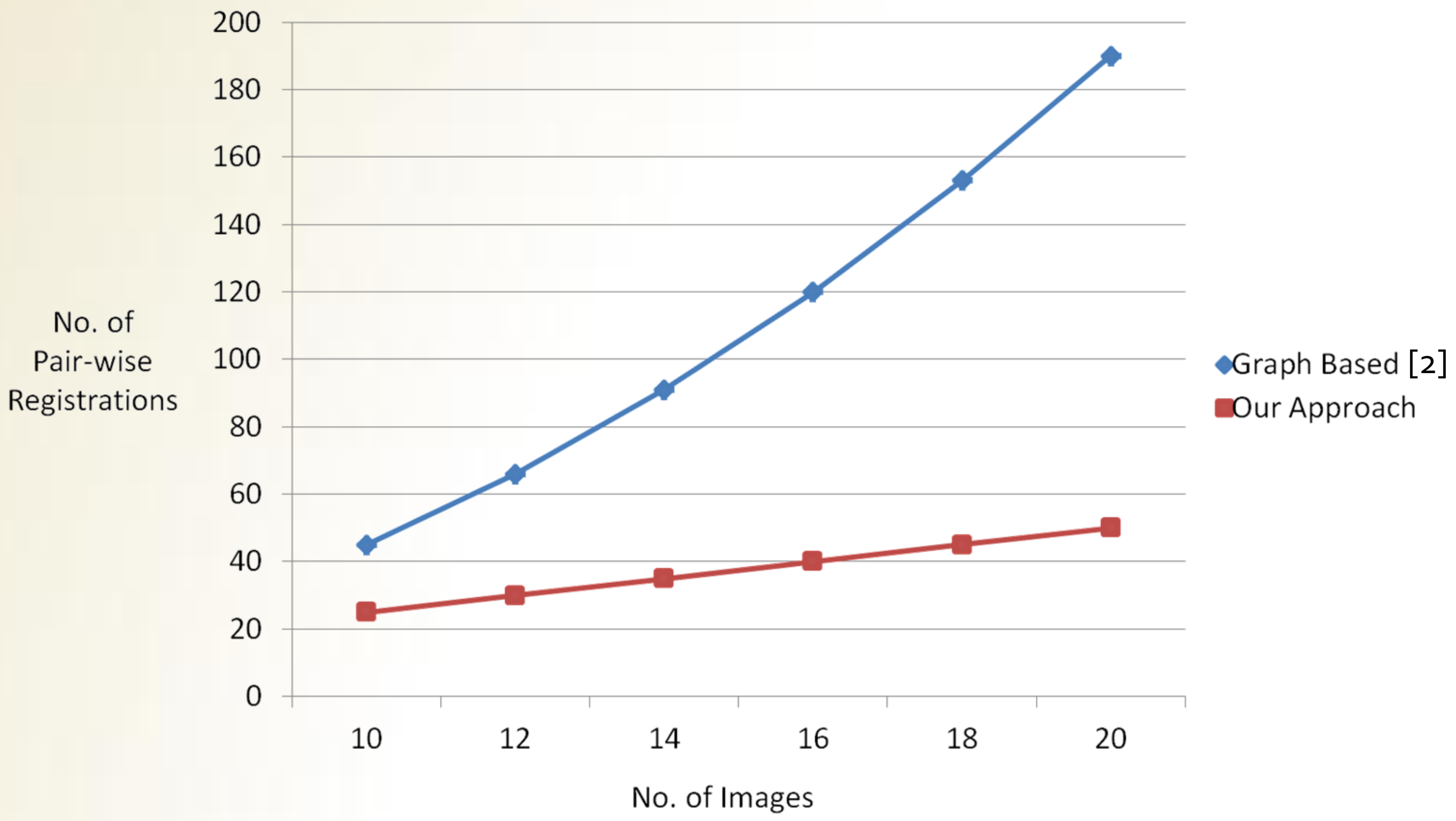
Results: Pair-wise Registration



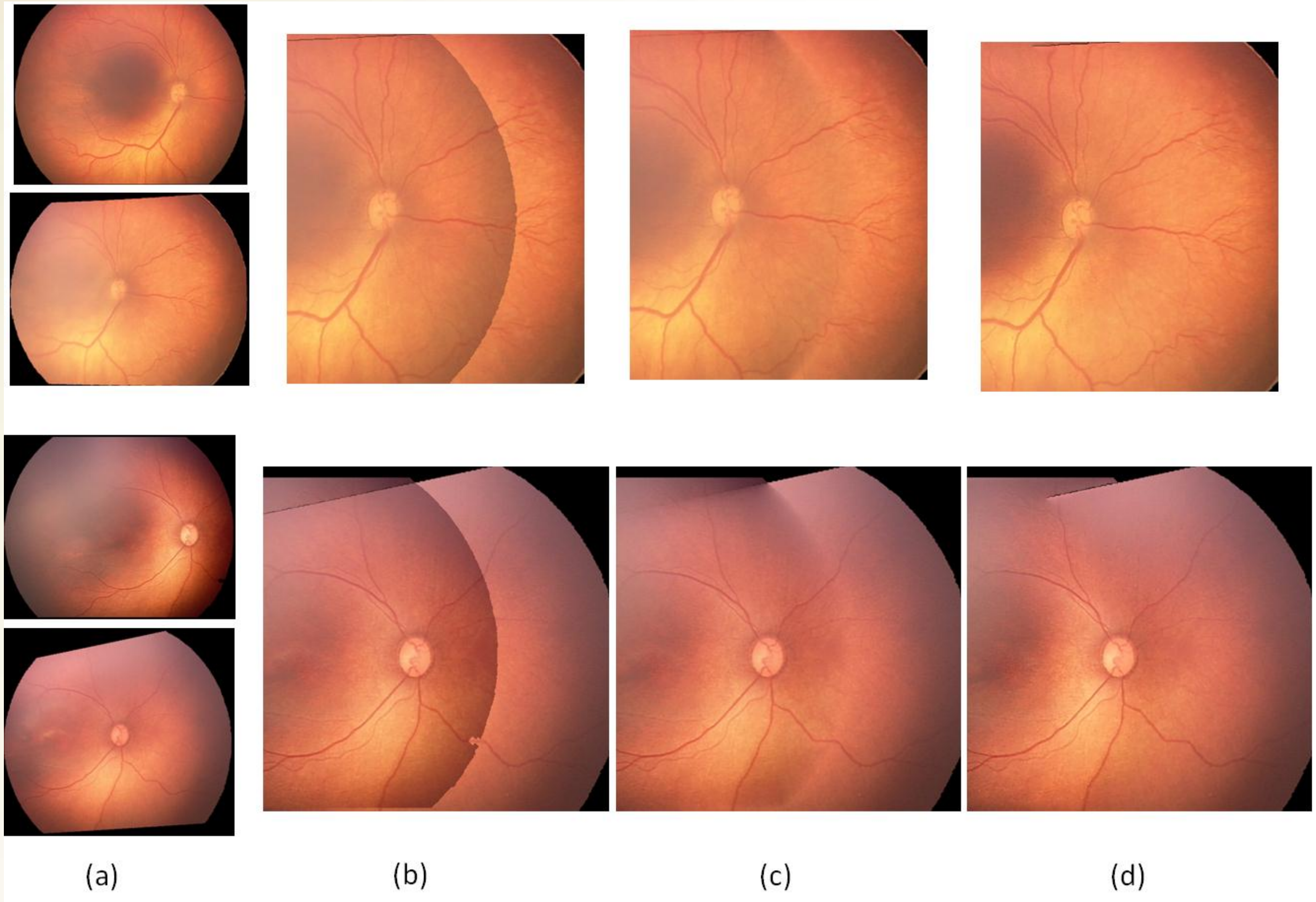




Cost of mosaicing

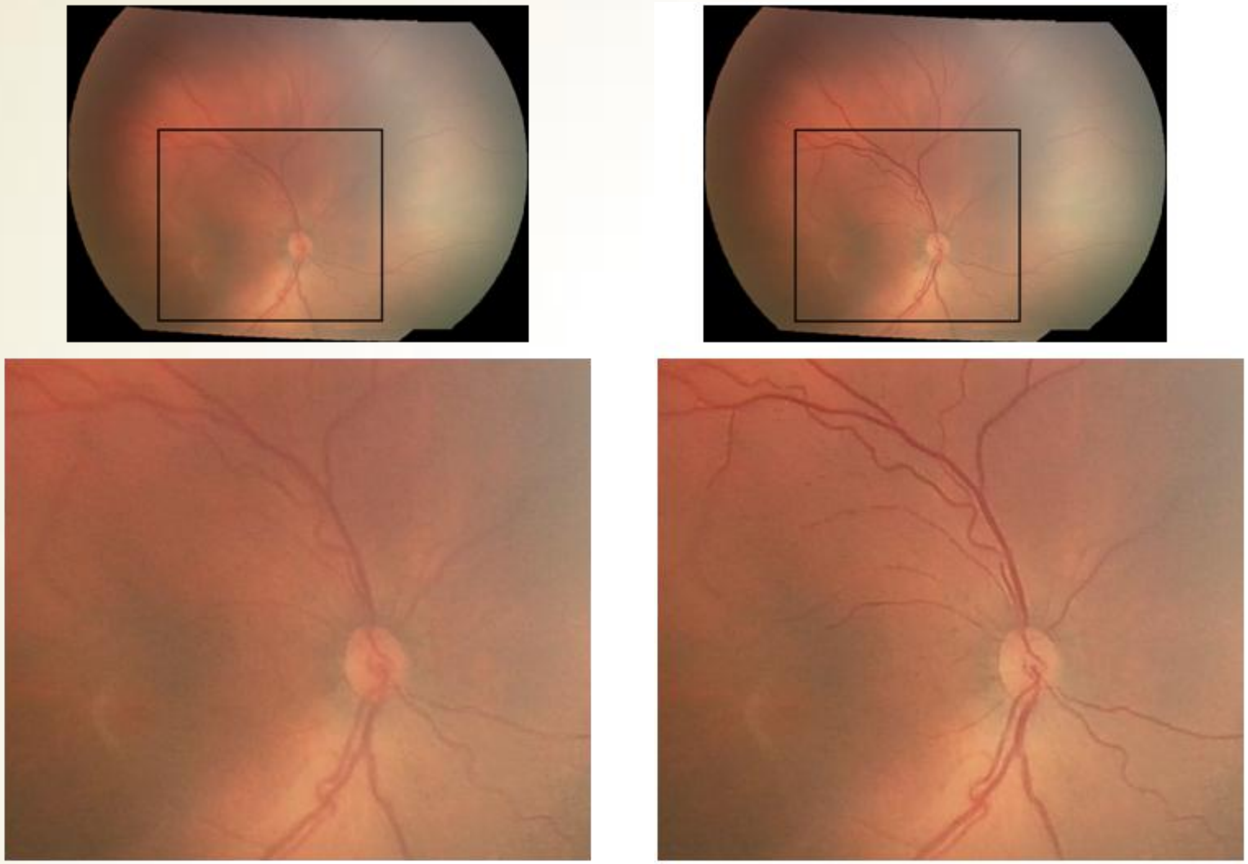


Results: Image Blending



(a) Input Image (b) Simple Averaging (c) Alpha Blending (d) Proposed Method

Results: Image Blending



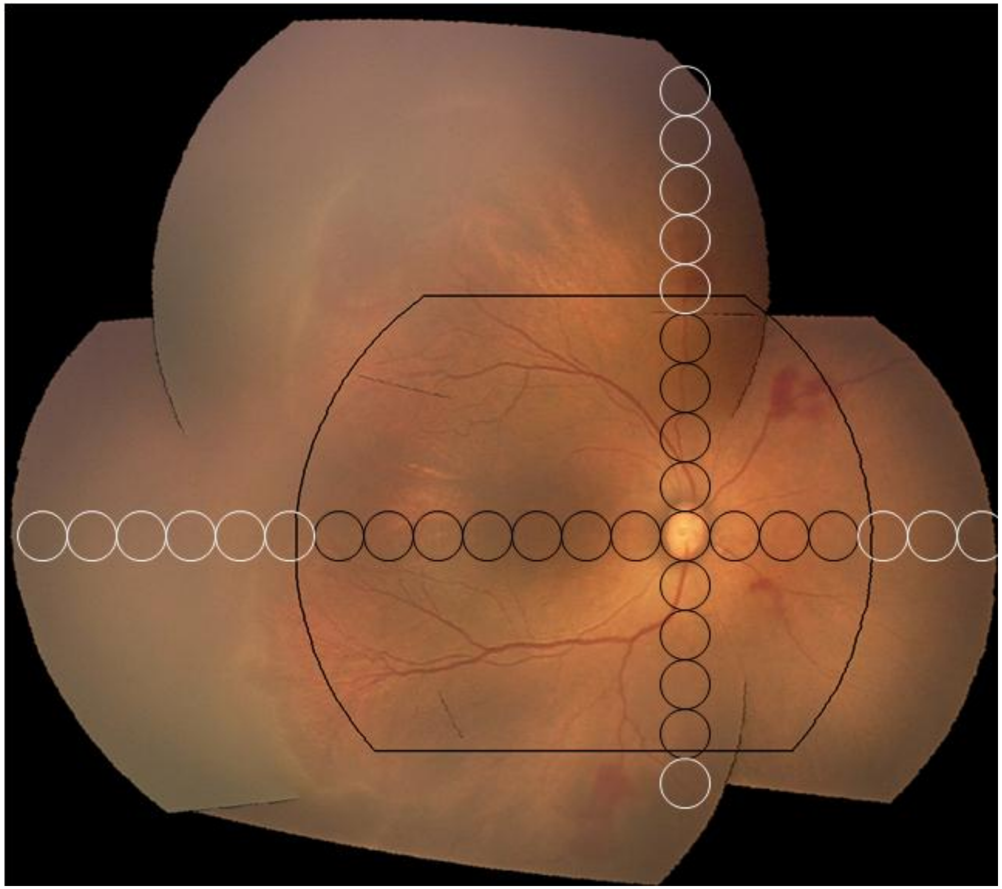
(a) Using Original multi-band method [3]

(b) Proposed Method

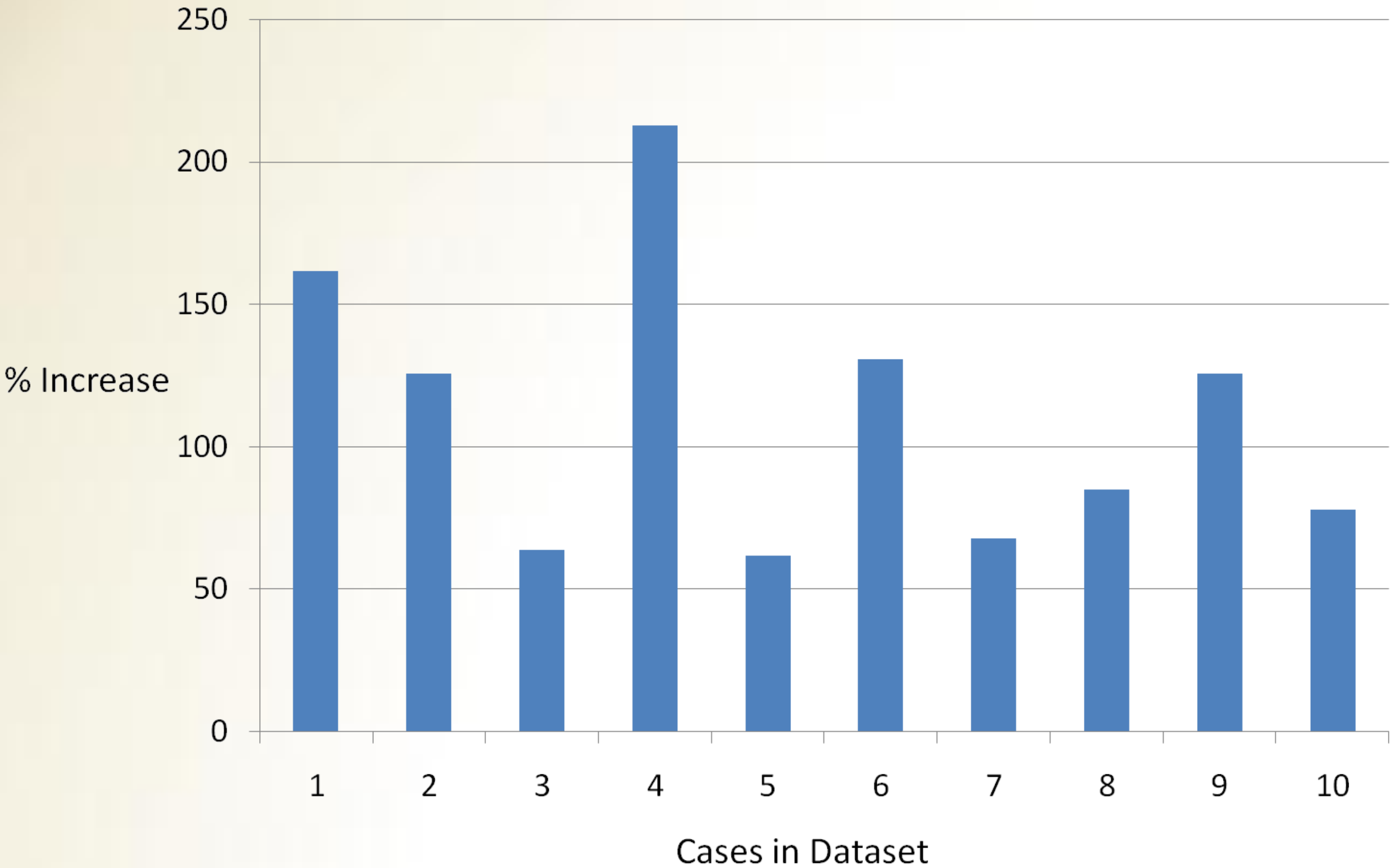
Quantitative Assessment

- Increase in the field of view, in each of the four directions (in terms of OD diameter)

	Left	Right	Up	Down
Base	7	3	4	4
Mosaic	13	3	9	5
% Increase	85%	100%	125%	25%

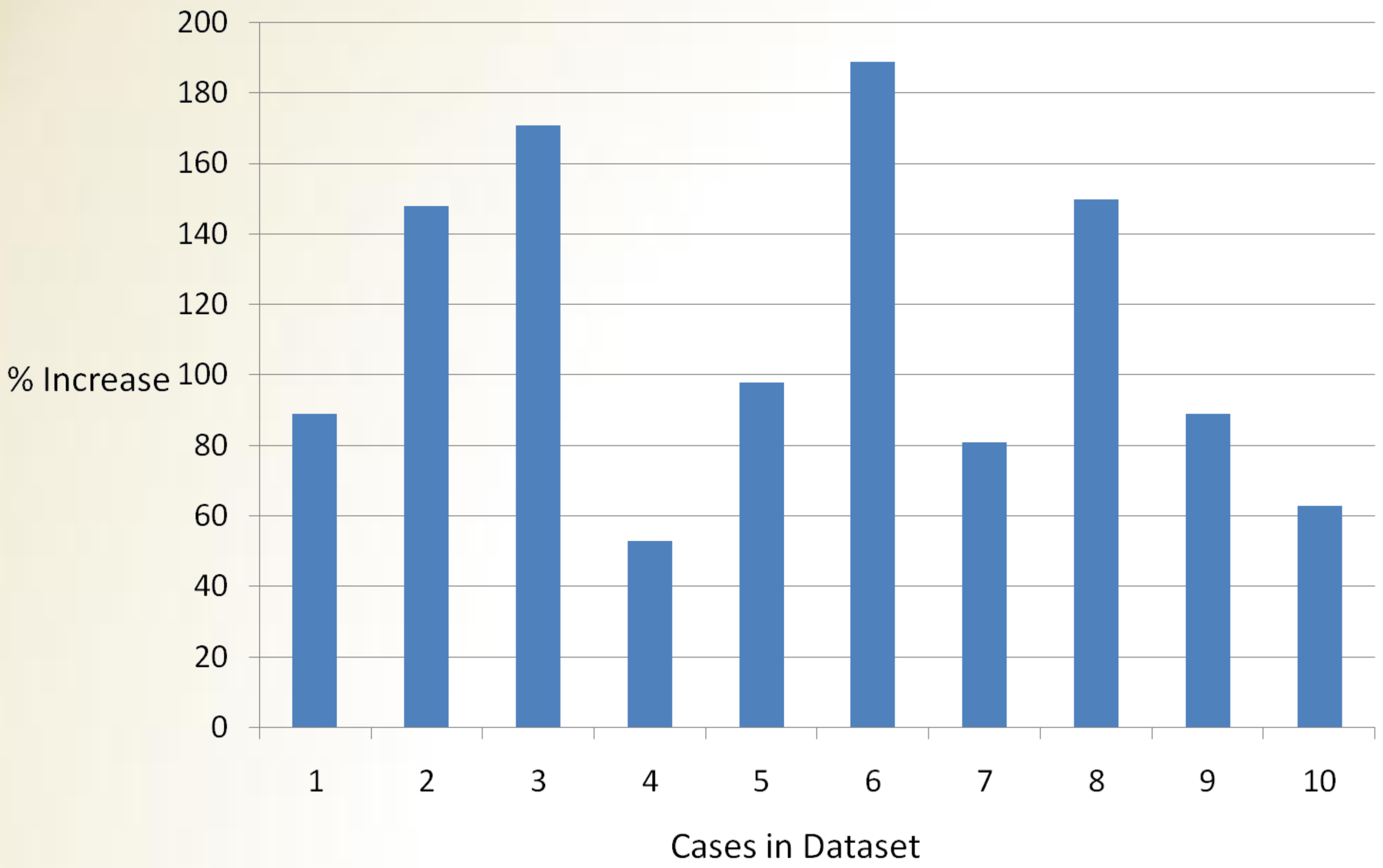


Quantitative Assessment



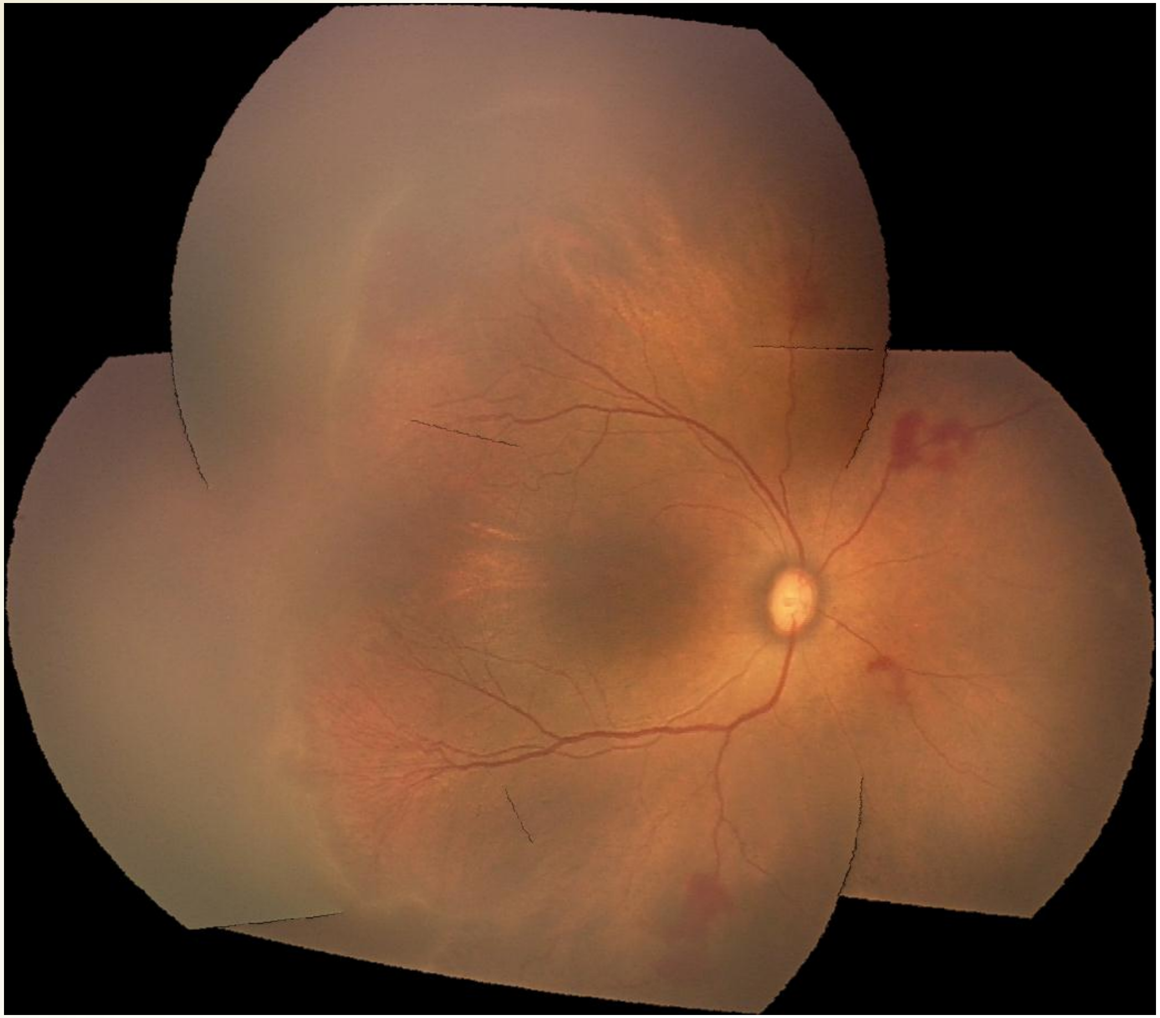
% Increase in number of pixels

Quantitative Assessment

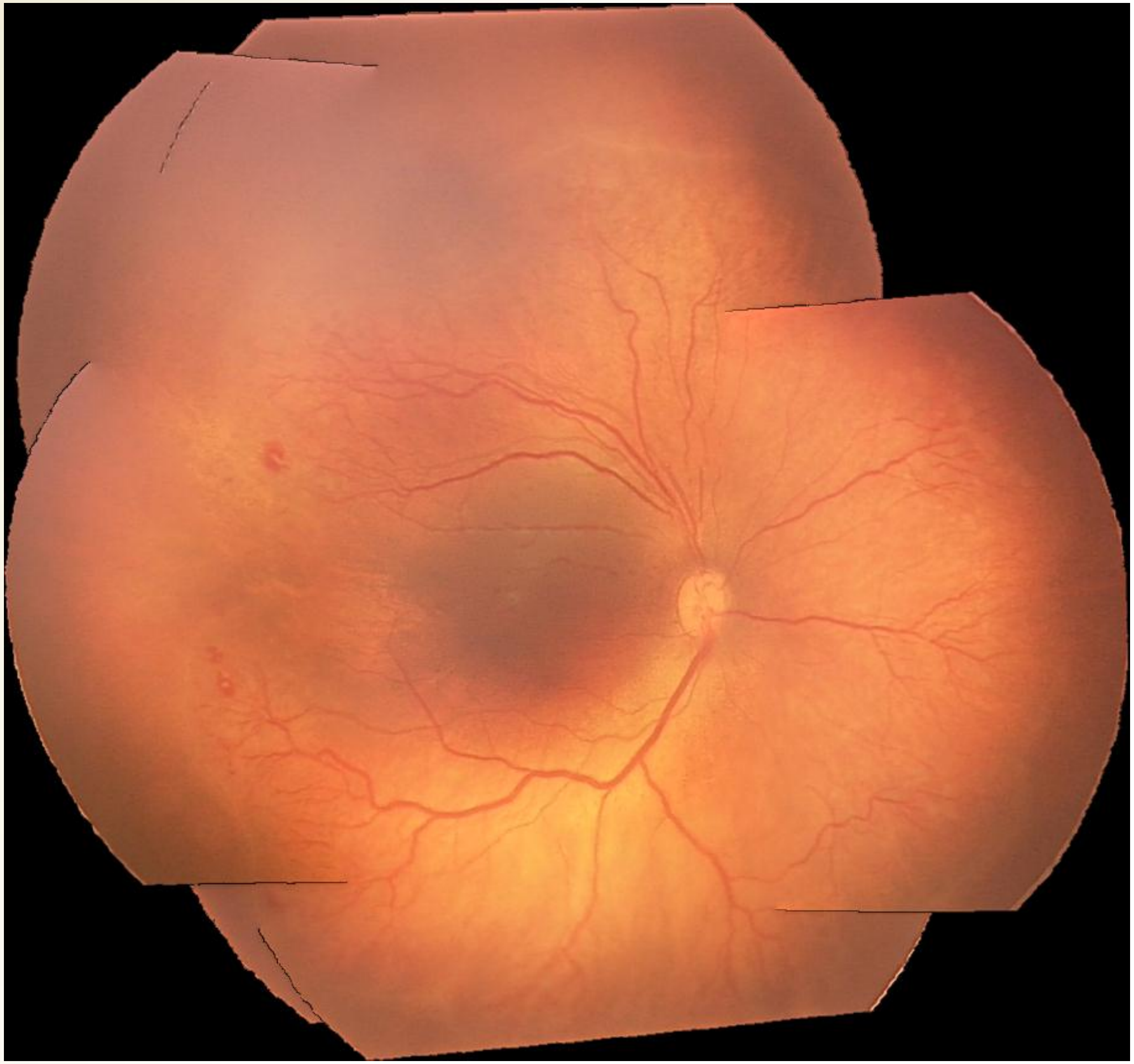


% Increase in vessels deteted

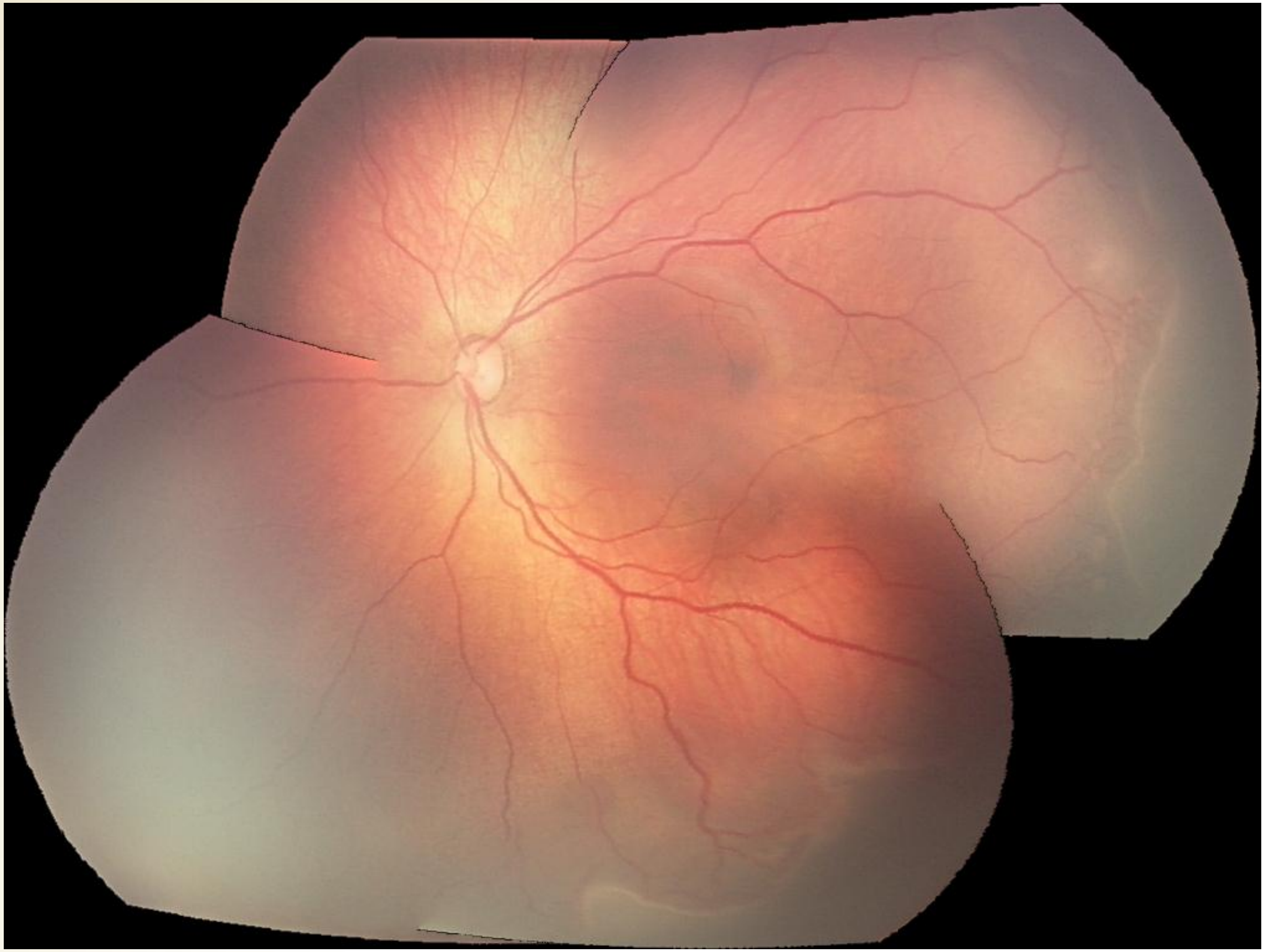
Qualitative Assessment



Qualitative Assessment



Qualitative Assessment



Conclusion

- Presented an image mosaicing system for generating single high quality image of the complete retina

- The generated mosiacs have been validated by the experts to be sufficient for diagnosis

Future Work:

- Along with mosaicing, super-resolution technique can be used for fusing information
- Better data fusion for non-vessel structures like Optic Disk, lesions etc can be investigated
- Computational time can be reduced by parallelizing the algorithm

Related Publication

Akhilesh Bontala, Jayanthi Sivaswamy and Rajeev R Pappuru, "*Image Mosaicing of Low Quality Neonatal Retinal Images*", IEEE International Symposium on Biomedical Imaging (ISBI), 2012.

References

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2. YB Xie, P. Yang, and Y. Gong. *On the graph-based panorama construction for 2d large-scale microscope images*. int. Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 2008.
3. Peter J Burt and Edward H Adelson. *A multiresolution spline with application to image mosaics. ACM Transactions on Graphic*

Question ?

From Reviews:

Regarding obtaining continuous video stream of infants eye

- Due to the challenges in acquisition. As the patient is an infant only few sparse snapshots from the video are useful containing required information

Thank You