

## Semi-manual Rectangle mark-up Technique

The algorithm was designed using the MATLAB software package. It consists of two steps; labelling and marking of retinal bifurcations.

### **Step one: Labelling of retinal bifurcations.**

The analysed retinal image is presented within the MATLAB system. The image could be viewed in either full coloured mode, red free or contrast enhanced mode with the facility to toggle between the three viewing modes. The operator selected clear and / or relatively evaluable arterial and venous bifurcations in each image, where the vessels at the vicinity of the junction were not grossly masked by any distracters such as dense haemorrhages or exudates plaques. Following selection, the type of bifurcation was manually identified whether it is arterial or venous.

The system displayed a list of the nominated bifurcations; each bifurcation was defined by its vertical and horizontal pixel location. Once the process was completed, the labelled image was saved to be ready for marking in the next step.

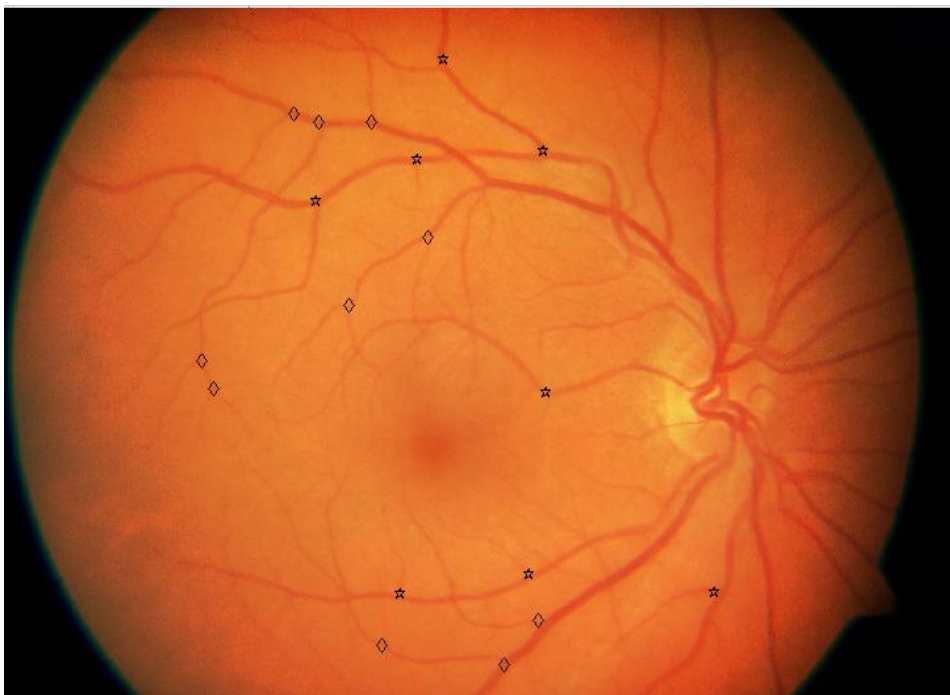


Figure 1 Labelled retinal fundus image

### **Step two: Marking labelled retinal bifurcations**

The objective of this next step was to measure the bifurcation angle and diameters of the vascular segments around the bifurcation to determine its various geometrical parameters.

The pre-labelled images are presented within the MATLAB application as before, with a list of the nominated vascular bifurcations.

## 1. Estimation of Bifurcating angle:

- a) The diameter of the parent vessel is roughly calculated as the linear distance between two points placed at the vessel' opposite edges, in a plane perpendicular to its axis. The parent vessel diameter roughly estimated at this stage is utilised only for determining the arms' length of the "Y" model as described later.
- b) The provisional location of the bifurcation apex point is defined by placing an intersection point by the operator within the vicinity of the bifurcation.
- c) The parent and the daughter vessels' mid-points are identified by clicking at a point along an imaginary center line for each vessel running along its longitudinal axis.
- d) The intersection point is joined by the system with the three vessel mid-points to form a "Y" shaped model, each of its arms measures three times the predetermined parent vessel diameter.
- e) The location of any of the four points can be moved or adjusted at any stage, till the arms of the "Y" figure coincide with the central longitudinal axis of the parent and daughter vessels, and parallel to the vessel wall edges, or the tangent to central line in case of curved vessels. This is irrespective to the position of the junction point in relation to the geographical center within the bifurcation junction. In all conditions, the length of the "Y" model arms is unaltered.

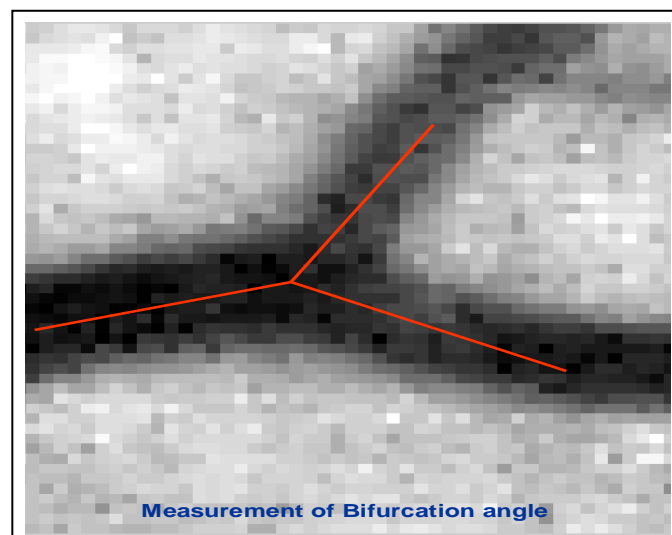


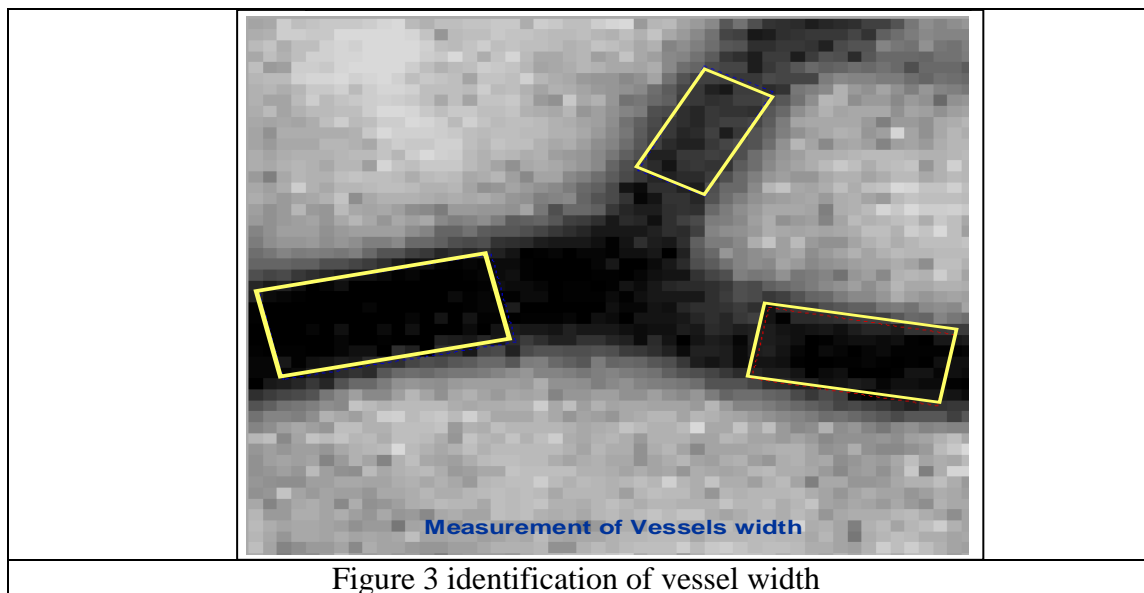
Figure 2: identification of bifurcation apex

- f) Once the ideal position is achieved, the points' position is saved to the system and used for calculation of the bifurcating angles.

## 2. Determination of blood vessel diameters

The developed technique involved the observer aligning a rectangle over each vascular segment. The rectangle width determines the diameter of the vessel.

- a) For each of the parent and two daughter vessels, a segment which appears fairly uniform in thickness is selected where the vessel course runs relatively straight. The vessel segments are selected at approximately uniform distance - equivalent to the provisional predetermined parent vessel diameter in previous step - from the bifurcation point for each individual vascular bifurcation wherever possible. Two points are placed by the operator along the axis of the center-line of the selected segment to determine the orientation of the rectangle's longitudinal axis. A third point is placed at one of the vessel segment lateral boundaries to define its edge where the pixels appear uniformly darker than its immediate surroundings.
- b) The algorithm uses the information regarding the three points' locations to construct an aligned rectangle; the width of which is calculated in pixels as double the distance between the lateral boundary point and the central-line predetermined by the two midpoints. The rectangle's length is oriented along the axis of the two center points and calculated as twice the estimated width.



- c) The observer may then click to either side of the rectangle to adapt its width and can click around its corners to adjust its direction. This process of adjusting the rectangle parameters could be repeated until the observer is satisfied with the rectangle alignment and width overlying the selected segment. The rectangle would always maintain the length: width ratio at all times.

The advantage of using a fitted rectangle for width detection is to average out and “smooth” the estimated vessel width across a “region” of the selected vessel rather than a point. This in turn helps to reduce the errors resulting from locating individual pixels only at opposite vessel edges as described with other previous techniques. Accurate orientation of the rectangle’ longitudinal axis also ensures that the estimated vessel width is obtained at a precise plane perpendicular to the vessel axis at this region. Other semi-manual or semi-automated previously described methods that suffered from problems with plane orientation of the cross sectional profiles can be used by taking advantage of the rectangle orientation.

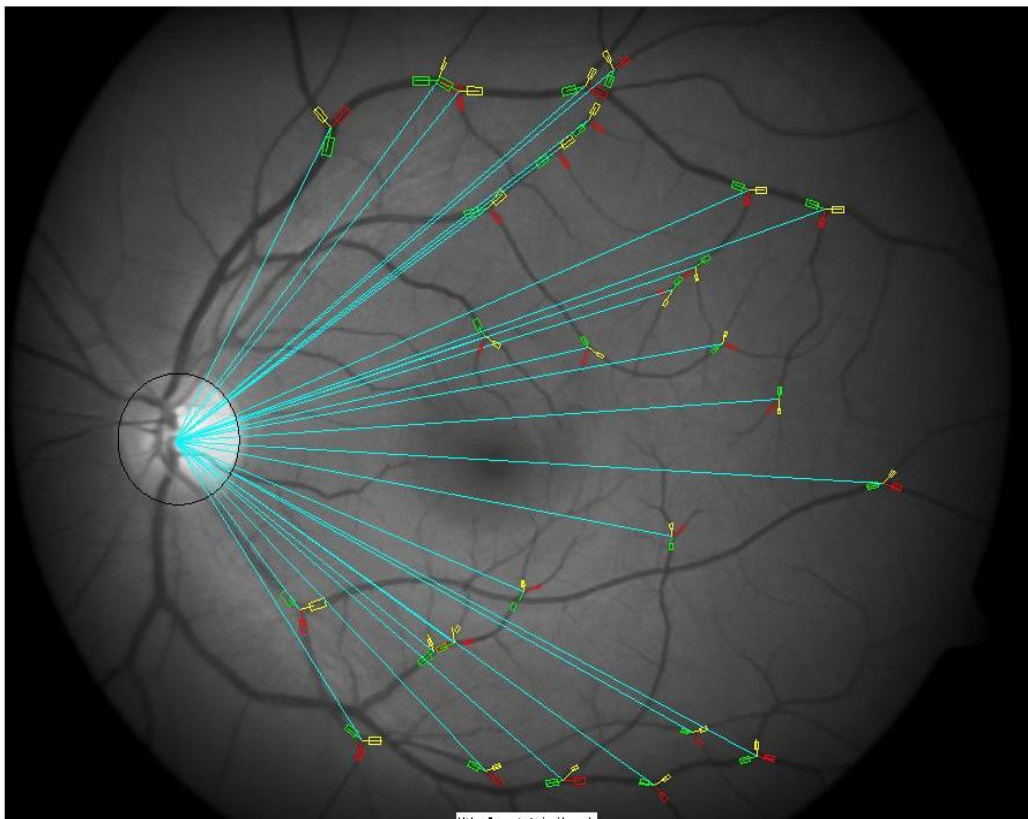


Figure 4 An example of a marked image with labelled and marked selected bifurcations, vascular segments are colour coded for each bifurcation, and distance from optic disc center is measured.