Accurate Methods for Manually Marking Retinal Vessel Widths

Bashir Al-Diri[1], Andrew Hunter[1] and David Steel[2]

[1] Lincoln School of Computer Science, University of Lincoln, Lincoln, UK
[2] Sunderland Eye Infirmary, Sunderland, UK

Abstract— **This paper compares two manual measurement techniques for measuring retinal vessel segment widths: the kick-points technique and the edge marking technique. An image set of 164 clear, high-resolution segments was used. The kick-points approach uses kick points marked by observers along interpolated cross-sectional intensity profile graphs; the edge marking method allows observers to nominate the edges on a zoomed-up image, and interpolates edge positions. The edge-marking method provides more precise measurements than the kick-points method, but these are subject to more inter-observer variability; we speculate that this result is due to differing observer perceptions of the edge location.**

Keywords— **Retinal vessel, kick points, measuring vessel width, manual measurement.**

I. INTRODUCTION

This paper presents a preliminary analysis of two manual techniques for the measurement of retinal vessel widths: the edge-point marking technique (EPMT) [1] and the kick-point marking technique (KPMT) [2], showing that EPMT gives width measurements with lower variance and higher bias than KPMT. Given that variation in width rather than absolute width is important in the characterization of disease, we argue that this shows EPMT to be a superior manual measurement technique to KPMT. In addition, EPMT automatically determines the profile direction.

Both EPMT and KPMT are methods to support the marking of retinal edge vessel widths by a human observer. Manual marking is of interest for two reasons: to provide ground truths [3] to support the development of automated width measurement algorithms, and to allow the accurate study of the relationship between retinal disease and vessel geometry.

The simplest approach to manual retinal vessel width measurement is to require the observer to nominate two points, one on each edge of the vessel [1]. This requires the observer both to correctly place the points on the vessel edges, and to ensure that they lie on a single profile line – that is, a line orthogonal to the vessel direction. There are thus two possible sources of error: inaccurate edge marking, and inaccurate determination of profile direction. Given that the observer is typically limited to nominating at pixel resolution, and retinal vessels are often only a few pixels across, the approach is also prone to discretization errors, both in width and angle nomination. Accuracy can be improved by first drawing a profile line orthogonal to the vessel, and then nominating the intersection with the edges, and by averaging multiple measurements taken along a short section of the vessel, using parallel profile lines.

A more advance technique is based on the "kick point" phenomena. The blood vessels absorb some of the fundus camera light reflected from the retina, forming a relatively dark central blood column with lighter edges, the intensity falling off towards the background retinal intensity. In addition, a fraction of the light is absorbed by the vessel wall. If the image intensity is graphed along a profile line cutting across the vessel, kick points are sometimes visible [4]; see Figure 1. These slanting shoulders on the profile corresponding to the vessel wall are visible on high resolution and well-focused images, but not usually on low-resolution or blurred images, or for small vessels [2]. The distance between them is described by [4] as an accurate vessel diameter estimator that can be measured. He reported that the kick point distance is more accurate than that provided by the (automatic) Full Width Half Maximum algorithm, which was proposed by [5]. On the other hand, [6] and [7] report that the apparent diameter of the blood column is a reasonable estimator of the real intra-vascular width, even when the vessel wall is not visible.

In [1], we introduced a manual edge marking technique, EPMT, where a specially-designed tool is used to click along the vessel edges. An algorithm, described below, is subsequently used to determine the profile direction, and interpolates between click points to determine the width. This approach was used to provide the ground truth in [8].

This paper compares KPMT and EPMT. Section II describes the data set used, section III gives more details on the algorithms, and describes how they were compared; section IV gives the results of the comparison, and section V concludes the paper.

II. MATERIALS

Images were selected by a consultant ophthalmologist from the fundus image database of the diabetic retinopathy
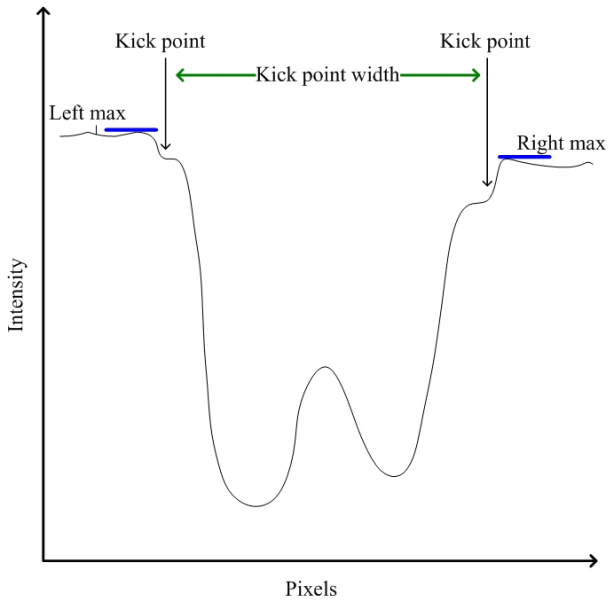
Fig. 1: An Illustration of a vessel cross-profile. The width may be defined as the distance between kick points.

clinic at Sunderland Eye Infirmary. The image set consists of 164 ground truth widths obtained from two high-resolution fundus images with a 60 degree field of view, and photographed using a Canon $60uv$ fundus camera. All 164 vessel widths were selected from large diameter non-tortuous vessel segments between bifurcations. The dimensions of the high-resolution images were 3300×2600 pixels. Figure 2 shows samples from the data set. The mark-up is time consuming, so only a few segments could be used; we have concentrated on clear, high-resolution images so that this preliminary study is carried out under ideal conditions. The image set and kick-point widths have previously been used to provide the ground truth measurements in [8]. Vessel centre lines and profile directions were determined by the algorithm described in [1].
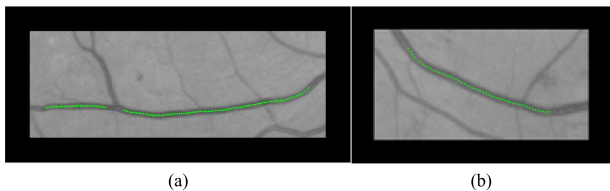

Fig. 2: Marked segments in the kick point image set.

III. METHODS

A. The Kick Point Marking Method

For KPMT, the users were presented with intensity profiles constructed by bilinear interpolation along the defined profile lines. They used a specially-developed software tool to mark the kick-points, or to estimate their position when not visible.

B. The Edge Point Marking Method

The EPMT technique uses a specially developed interactive mark-up tool. Starting from one end of a segment the observer chooses an edge and nominates edge points by clicking with the mouse until the other end of the segment is reached. The observer then returns back to the starting segment end, and similarly marks up the other edge; see Figure 3. The accuracy of this method depends on the discretization (the distance between two following points) of edge points. The tool allows the user to zoom up to super-pixel levels (in which case each pixel is drawn as a square), and then to nominate points at sub-pixel level if desired. A cubic spline is fit through the edge points, and regularly sampled: the resulting points are not discretized to pixel centers. EPMT is therefore able to extract widths to sub-pixel accuracy if the user can perceive such.
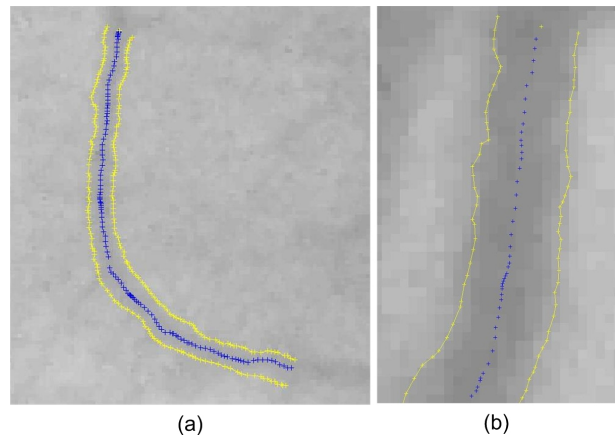

Fig. 3: EPMT marking tool. The approximate vessel centerline is displayed to show the observer which segment is to be marked.

The edge point sampled from the splines are used to construct a series of profiles and width measurement. The end points of the two edges are not necessarily located along a single profile line, so any unnecessary end sections are trimmed. The algorithm has four steps:

1. A cubic spline is fit through the user-nominated edge points, and regularly sampled (at spacing 0.2 pixels).
2. Choosing a point on one side as P_1, the nearest edge point on the other side is found, and labelled P_2. Then, the nearest point to P_2 on the same side as P_1 is located and labelled; see figure 4(a). The point P_3 is often, but not always, the same as point P_1.
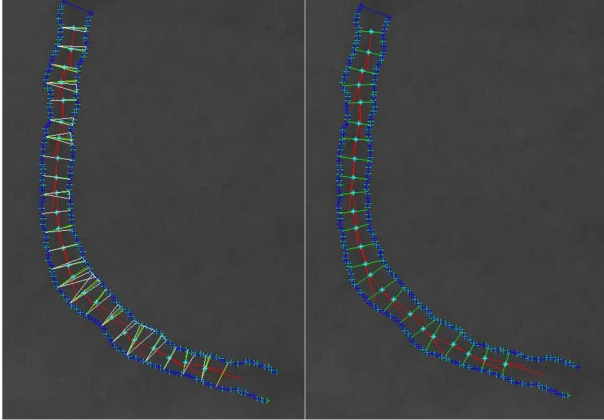
Fig. 5: Extracting vessel diameters in EPMT.

3. The local segment direction (LSD) is calculated as the mean of the perpendicular vectors on vectors $\vec{P_2P_1}$ and $\vec{P_2P_3}$; see figure 4(b).
4. The vectors between P_2 and a set of edge points from the other side, including all the points between P_1 and P_3 are calculated. The point P_4 from that set with a minimum deviation from $\pi/2$ is defined; see figure 4(c).
5. The point P_4 is shifted along a B-spline fitted to the edge points, to lie on a perpendicular profile with local segment direction (LSD); see figure 4(d). The distance between point P_2 and shifted P_4 is the local diameter.

Figure 5 shows an example of EPMT in operation.

C. Experimental Approach

The measurements for each technique were repeated by three observers (O_1, O_2 and O_3). We are interested in two issues. First, to what extent can different observers reliably produce the same results for a particular profile? We characterize this by observing the difference in the mean measurements between the observers. Second, given that there may arguably be different individual perceptions of the edge position (and there is no absolute definition of what constitutes the edge), to what extent can an individual observer reliably mark along a vessel? We characterize this by calculating the mean observer estimate ($\bar{O}$) for each methods, and then the differences between the mean and individual observers. If a technique is prone to observer bias (consistent mis-estimation), the observer means will be dissimilar. If a technique is prone to variance, the variance of the differences will be large even if the means are close together.

The KPMT technique requires a profile direction to be nominated before the width can be calculated, whereas EPMT defines the profile direction. To allow comparison of

the techniques without biasing the results in favour of either, we used a ground truth profile direction defined by the tech-
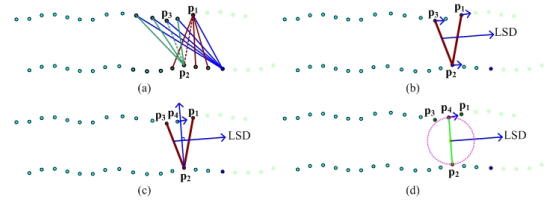

Fig. 4: Extracting width from EPMT marking: (a) shortest distances from both edges are calculated to provide two or three edge points; (b) direction vectors at edge points and the local segment direction (LSD); (c) the perpendicular direction to the LSD where point P_4 should be located; (d) P_2 and P_4 form a perpendicular profile with the local segment direction, located on the tangent of the largest circle inside the segment.

nique presented in [1]. The KPMT measurement is then taken directly along this profile direction, whereas the EPMT measurement is taken from the EPMT profile with its centre point nearest to the profile centre point, (EPMT profiles are constructed at 0.2 pixel centre point spacing). This method allows us to examine the relative performance of the methods with respect to edge position, although the EPMT method is slightly disadvantaged as observers may produce slightly different profile directions in addition to edge positions.

IV. RESULTS

The descriptive statistics of KPMT and EPMT are summarized in Table 1 and Table 2 respectively.

	Mean	Std D	Std E	95% Conf I		Min	Max
				Lower Bound	Upper Bound		
GT	7.40	0.36	0.03	7.34	7.45	6.41	8.38
O_1	7.74	0.63	0.05	7.64	7.84	5.49	9.10
O_2	7.29	0.49	0.04	7.21	7.36	6.07	7.94
O_3	7.17	0.37	0.03	7.11	7.23	6.21	8.22

Table 1: Descriptive statistics for KPMT.

Human observers are subjective and prone to inter-observer and intra-observer variability [3]. Thus a more robust approach for generating ground truth is to combine multiple human generated manual segmentations, even though the process is more costly, and there may be some uncertainty among observers. Tables 1 and 2 show that there was a greater spread in the mean measurements for EPMT than for KPMT.

Table 3 gives the standard deviations of the differences between the observers and the observer mean measurements.

	Mean	Std D	Std E	95% Conf I		Min	Max
				Lower Bound	Upper Bound		
GT	7.52	0.42	0.03	7.46	7.59	6.33	8.42
O_1	7.00	0.52	0.04	6.91	7.08	5.51	8.50
O_2	7.60	0.42	0.03	7.54	7.67	6.23	8.82
O_3	7.97	0.47	0.04	7.90	8.05	6.66	9.16

Table 2: Descriptive statistics for EPMT.

	KPMT	EPMT
	Diff SD	Diff SD
O_1	0.417	0.234
O_2	0.317	0.213
O_3	0.326	0.233

Table 3: Standard deviation of observer measurement differences in KPMT and EPMT.

The EPMT technique is more precise than KPMT, with a difference standard deviation of approximately 0.23 overall, in comparison to 0.35 for KPMT. This superior precision occurs despite the inherent disadvantage for EPMT in the evaluation technique, since EPMT measurements may be effected by variations in estimated profile direction. This variance shows that the observers had difficulty applying the kick point method consistently and accurately.

EPMT has a number of advantages compared to KPMT: the user marks the original image, not a 1D profile constructed by interpolation from the image; it automatically determines the direction of the profile line; and the vessel edges are always visible. It has one clear disadvantage: there is no absolute definition of the vessel edge, and the observer has to determine where the edge lies using his or her own judgement, bearing in mind that in fact the intensity slopes off gradually at a vessel edge and so user perception of the edge may well vary.

V. Conclusion

We have conducted a preliminary comparison of two techniques to support the manual measurement of retinal vessel widths. Such techniques are useful in providing ground truth measurements for automated measurement algorithms, and for studies relating retinal vascular geometry to diseases.

The evaluation suggests that the EPMT technique, which relies on interpolating between edge points marked on a zoomed-up image, is more precise, but more subject to individual perceptual bias, than the kick-point marking approach. The comparison has been conducted with a fairly small database containing clear, high resolution images, and so the conclusions are necessarily preliminary. As we know that kick-points are only visible under ideal conditions, we speculate that EPMT is likely to have a more marked advantage when evaluated under more challenging conditions.

In future work we will evaluate the techniques against a broader range of images, including those presenting pathologies. We will also extend the evaluation to consider the effect of the identification of the profile direction, in addition to edge position.

VI. Acknowledgements

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Author: Bashir Al-Diri
Institute: The University of Lincoln
Street: Brayford
City: Lincoln
Country: UK
Email: baldiri@lincoln.ac.uk