

A Development of Computer-Aided Diagnosis Tools of vascular retinopathy using Fundus Images

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Abstract—The identification of eye diseases in retinal images is the subject of several researches in the field of medical image processing. We developed a computerized aid diagnosis system to help specialists by displaying useful information such as the location of abnormalities in fundus images. This paper proposes three efficient approaches: for automatic detection of optic disk (OD) and exudates, and for automatic measure of vascular tortuosity in ocular fundus images. The extraction procedure of OD comprises two independent methodologies: one for automatic location of the center using an iterative thresholding flow by the PCA, and other for boundary segmentation by applying region-based-active contour model in a variational level set formulation (RSF). In exudates identification method there are two main steps. First, detection of candidates regions by preprocessing, and OD elimination. Final exudates are obtained by morphological reconstruction. Finally, we will describe an other tool for automatic measurement of vascular tortuosity while ocular disease.

Index Terms—Optic disk detection, retinal image, PCA, RSF, exudates, tortuosity.

I. INTRODUCTION

Diabetic Retinopathy (DR) is one of many eye diseases but it is the main cause of blindness in the world [6]. The DR patients do not perceive symptoms until visual loss, so the detection of this disease usually happens in the later stages when treatment is less efficient. To ensure that treatment is taken in time, diabetic patients need to flow yearly eye fundus examination, but, the problem is the high cost of this examination and the lack of specialists, on the other hand the number of diabetic patient's increase every year. Due to all these reasons, the necessity of automatic system for diagnosis of DR in early stages has been increased and many researches in this direction have been inspired. In this paper, three automated techniques help in diagnosis of DR from color fundus images. First, OD segmentation is an essential step in developing automated diagnosis expert systems for DR. It is a key preprocessing component in many algorithms designed to identify other fundus features automatically. The relatively constant distance between the OD and the fovea can be used to help estimate the location of the latter [12]. Moreover, to segment the vascular tree, an initial seed point is required using vessel tracking methods [9], [7]. Furthermore, OD detection is important for automatic diagnosis of some diseases

caused by DR. The OD region is removed before identifying retinal exudates [10], which are used to assess and grade risk of Macular Edema (ME). In addition, OD segmentation is also relevant for automated diagnosis of other ophthalmic pathologies like the most dangerous Glaucoma [11]. Thus, its segmentation and analysis can be used to detect automatically Glaucoma evidences. We present an automated OD detection system. The detection is performed by applying two independent methodologies to digital fundus images: one of them to locate a pixel in the region and the other one to obtain a circular approximation of its boundary. Exudates are among the earliest and most prevalent symptoms of diseases leading to blindness such as diabetic retinopathy. So early diagnosis of exudates has a great importance as it can help stop the progress of this disease thus keeping the sight and preventing blindness. By definition, exudates are formed by the leakage of proteins and lipids from the bloodstream into the retina via damaged blood vessels. In retinal images, exudates appear as bright yellow lesions with varying sizes, shapes, and locations. They also have a considerable contrast relative to the background. The optic disk, is the only area in the fundus images having the same brightness and color range like the exudates. So detection of exudates is needed before the elimination of optic disc area from the image. Diverse techniques have been developed for exudates detection in fundus images. Color normalization and local contrast enhancement followed by fuzzy C-means clustering and neural networks were used by Osareh et al [10]. The system works well only on Luv color space but in the case of non-uniform illumination the detection accuracy is low. Walter et al [14] proposed a method for automated identification of exudates in color fundus images using mathematical morphology techniques. Morphological operations are also used to detect the exudates and optic disc in [7]. Sopharak et al [13] proposed another method using Fuzzy-C-Means clustering which have four characteristic as inputs to obtain the result of the first segmentation. Some morphological operators have been applied to this result to refine it and obtain the final detection of exudates. An approach based on segmentation of all objects which are contrasted compared to the fundus of image, including exudates. This approach proposed by Doaa et al [15], they begin by the elimination of OD and vascular tree to obtain the first estimation of

exudates. The final estimation is obtained by morphological reconstruction. In this work, we propose a fast method for early detection of exudates. The proposed method is based on preprocessing techniques and morphological operators. To appear the candidates regions, we eliminate the OD and vascular tree and apply Sobel filter followed by thresholding to obtain the first estimation of exudates. Using morphological reconstruction to refine the first segmentation and obtain the final estimation of detection of exudates. In the same context, Tortuosity is one of the first manifestations of many retinal diseases. Quantitative measurements of retinal vascular topography have long been used as research tool to better understand the relation between the retinal microvasculature and diseases. Deformation in the blood vessel network of the retina are indicators of not only retinal pathologies but also other systemic diseases coming from cardiovascular, central nervous and endocrine-metabolic systems. Morphological features of the vascular tree are often the early symptoms indicating the onset of some retinopathies and are prognostic indicators for others. One of the first changes in vessel morphology to occur is the increase in vessel tortuosity. Quite a few techniques for tortuosity measurement and classification have been proposed, but they do not always match with the clinical concept of tortuosity. Hart et al [8] created the automated measurement using seven integral estimates of tortuosity based on the curvature of vessels. However, it failed in differentiating the tortuosity of structures that visually appear to be different in tortuosity. Dougherty and Varro [5] calculated the tortuosity using second derivatives along central axis of the blood vessels. Qin Li et al [2] have proposed an automatic system for measuring blood vessels tortuosity. The main steps of this approach were: Automatic segmentation of blood vessels and then automatic classification of tortuosity measures. Rashmi Tudor et al [3] have proposed a new approach for the quantification of blood vessels tortuosity based on the principal component analysis (PCA) technique. The proposed algorithm provides tortuosity index which is independent of the translation, rotation, and scale.

In this paper, we propose a new method for measuring vascular tortuosity. We start with the extraction of blood vessels by applying Canny filter to segment vessels, morphological dilatation and the skeletonization to appear the blood vessels in retinal image. Next, an appropriate procedure is applied for partition of vessels to simplify and facilitate the calculating. In section I, we detailed an automatic method of detection of OD. In section II, we developed the approach of detection of exudates in retinal images. The last section will be concerned for measurement of tortuosity of blood vessels.

II. METHODS

A. Detection of OD

This part is the result of previous work which was fully developed in this paper [4]. To detect OD, we applying firstly a simple clustering method on the intensity image in order to find the candidate regions where optic disk may appear. Then PCA is applied only on these candidate regions to locate the

optic disk. This approach includes three steps. Firstly, the Eigen vectors are calculated from the training images. Then, a new fundus image is projected to the space specified by the Eigen vectors. Finally, the distance between the fundus image and its projection is calculated. The following figure show threshold image and OD located in color image:

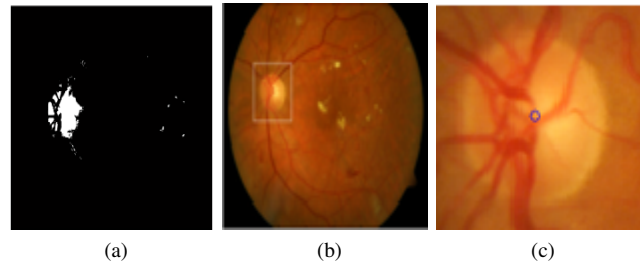


Fig. 1: Optic disc location in the retinal image:(a)Threshold image,(b) Localized optic disc,(c)Enlarged optic disc area.

After localization of the center of OD, we are still detecting its contour. The proposed method is applied on sub image RGB which delimits the region of the OD, to increase accuracy and strength of the method [4]. The adaptive model of active contour based in evolving regions: Region-Scalable-Fitting (RSF) is used to detect boundaries of OD. This model uses intensities information in the local region. For many details of this approach, we can show the paper in [1]. The result is illustrated in this figure:

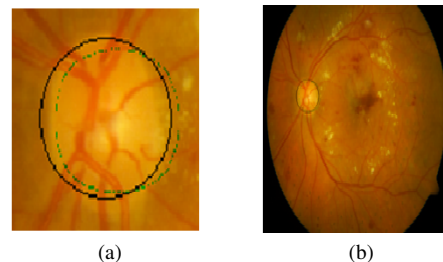


Fig. 2: illustration of obtained result:(a): manual contours superimposed with that obtained,(b):final result of detection contour by RSF

B. Detection of exudates

This method can be described on two main steps:

1) *Detection of candidates regions*: In some cases, the appearance of large exudates in the image causes the existence of larger areas than disk. Moreover, disc and exudates have the same criteria of form and contrast. Hence, the need for the elimination of the optical disc in detection of exudates as shown in Fig.3.

Blood vessels must also be removed to obtain an initial estimate of the exudate. The blood vessel tree is most contrasted in the green channel. Homomorphic filter is used to ameliorate contrast of vascular tree, it normalize the fundus and correct luminosity of retinal image. Then, matched filter followed

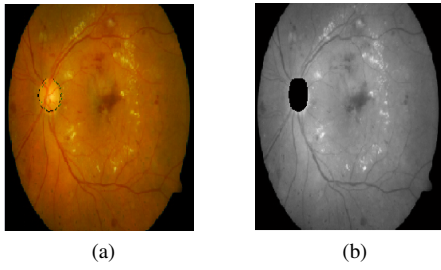


Fig. 3: Elimination of OD: (a) : detection of contour of OD , (b) :disk masked.

by an iterative thresholding are applied for segmentation of blood vessels. Finally, we must remove the boundaries of these vessels and also the noise present in image:

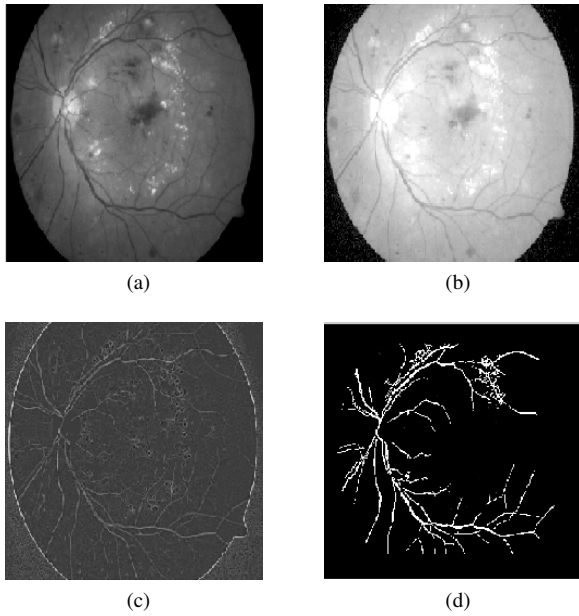


Fig. 4: Detection of vascular tree : (a) :green channel, (b) :homomorphic filter, (c) : MFR filter, (d) : vascular tree detected.

After we have first estimation of exudates, we apply Sobel filter (3*3) to detect the contour of all objects present in original image including OD and blood vessels which must be removed with pixels of outline. The result image is binarized to appear some white spots in the fundus of image , these are the candidates regions shown in Fig.5:

2) *Morphological reconstruction: fine segmentation:* The result of the previous step is only the first estimation of exudates. Fine segmentation is necessary to get final detection of exudates. This segmentation is done using morphological reconstruction by dilatation of two images: the marker image and the mask image.The reconstruction is given by the iterative formula given by this equation:

$$h_{k+1} = (h_k \oplus b) \wedge I_{in}. \quad (1)$$

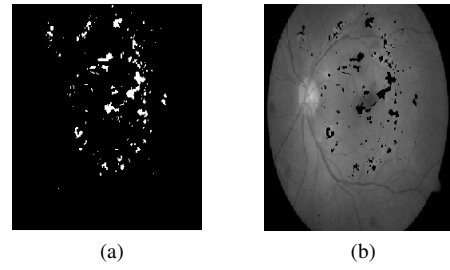


Fig. 5: First estimation of exudates:(a): White spots , (b): Candidate regions overlaid with the original image

where h_k is the marker image in k iteration, therefore h_1 is the image of the initial estimate superimposed on the original image, b is the structuring element and I_{in} is the input image in gray level.This process is iterative, it must be repeated until there is not any change in the image h (marker image). In our case, we took the original image in gray scale as a mask image, and the resulting image of the first segmentation which contains the first estimate of the detection of the exudates, such as an image marker.

The final iteration result is then subtracted from the input image to get the final estimate of exudates in I_{out} as give by:

$$I_{out} = I_{in} - h_{final}. \quad (2)$$

The following figure shows reconstructed image and difference image (I_{out}):

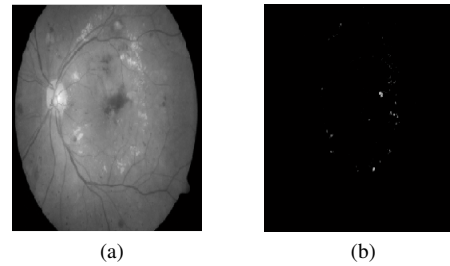


Fig. 6: Reconstructed image and the difference image.

Then a fast thresholding is performed on the final image (I_{out}), so the pixels which have intensity greater than the threshold is considered such as final detection of exudates:

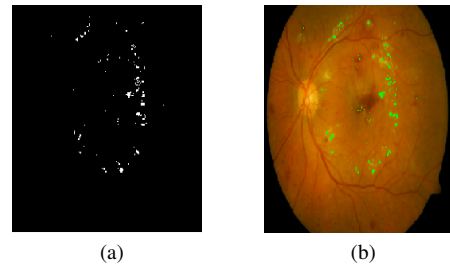


Fig. 7: Final detection of exudates.

C. Quantification of retinal vessel tortuosity

Theoretically, there is no formal clinical definition of vessel tortuosity measures; however there are some intuitive notions of tortuosity, which a reasonable index must satisfy. A tortuosity measure should provide good predictive performance which help specialist in diagnosis. The proposed method is divided into three main parts.

1) *Extraction of Vessels*: We use image in gray scale in vessels segmentation because vessels are well contrasted. Firstly, we remove noise by applying the mask of original image. Then, we use Canny filter to detect not only boundaries of blood vessels but also outline which its pixels are set to zero. Subsequently, a morphological dilation, which the structuring element is a disc of dimension $8 * 8$, is applied to the contour image to connect different contour pixels. Finally, skeletonization is necessary that simplify after the work.

2) *Vessel Partitioning*: The compute is performed on vessels, so it's necessary to partition vessels into segments in order to simplify and facilitate measure of tortuosity of all vascular tree. Thus, we detect different branch points presents in vascular tree, then "AND" operation between the image of branch points and the skeleton. This operation divides vessels in segments separated by the branch points as shown in the following figure:

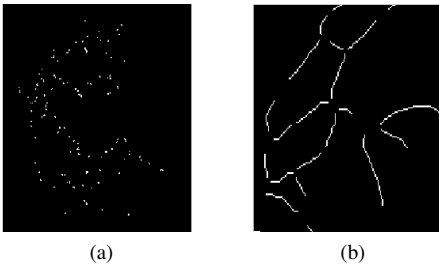


Fig. 8: detection of branch points and image result of AND operation.

Finally, we remove all small segments which can neglect.

3) *Measure of tortuosity*: There are many methods to calculate tortuosity, we choose one of them which define tortuosity as the ratio of the length of the arc by the distance between its two end points: $T = L / F$. Calculation is performed on a single segment and it is generalized in all segments of blood vessels:

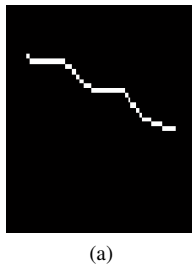


Fig. 9: vessel segment.

The length of arc of vessel segment is defined as the half of

its perimeter, then we detect the end points of segment and calculate the distance between them, so tortuosity is the result of the ratio of this two values. Then we got the tortuosity of each segment. So, we can know if the image is affected or not affected seeing the number of segments whose tortuosity exceeds the critical value that we put in 1.1. The following figure illustrates the result of measure of tortuosity of vessel segments:

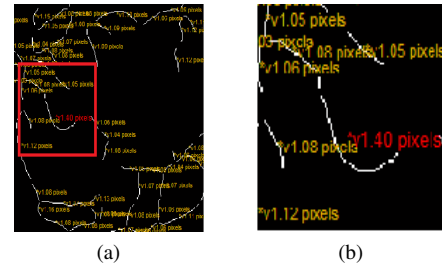


Fig. 10: Measure of tortuosity

III. EXPERIMENTAL RESULTS

A. Detection of OD

PCA method is applied to each pixel in the largest cluster of the brightest pixels of the input retinal image. The pixel with the minimum distance E in all the candidate regions and among is located as the center of optic disk. Compared with the location of optic disk as the centroid of the largest cluster of brightest pixels, the proposed algorithm achieves more accurate result. Illustration can be seen in Fig. 11:

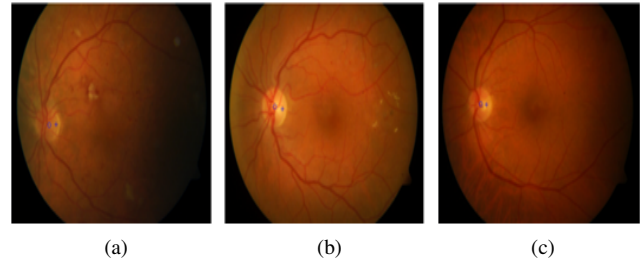


Fig. 11: Comparison of the location of optic disk by PCA method with centroid of the largest cluster. o indicates the location of optic disk by PCA method and + presents the location by the centroid of the largest cluster of the brightest pixels.

The proposed method improves the precision of the automatic location of optic disk in the color retinal image. This allows the accuracy and robustness of locating the OD to be increased. The result from this step is quite successful; the algorithm can locate the OD with 88.76 % accuracy compared with manual OD location from a test set of 89 images. The simulation tests were conducted on DIARETDB1 databases. The failed outcomes resulted from poor image quality or very blurred and unclassifiable OD. Once the vascular structures are removed based on the gray scale morphological closing

operation, the boundary detection operation is carried out. To fit active contour onto the optic disc the initial contour must be near to the desired boundary otherwise it can converge to the unwanted regions. In order to automatically position an initial contour, the approximate center of optic disc obtained in the localization method is used. The boundary thus detected is compared with the manually marked optic disc. Fig.12 shows the hand labeled optic disc boundary and automatically detected optic disc boundary overlapped on the ground truth image in different color:

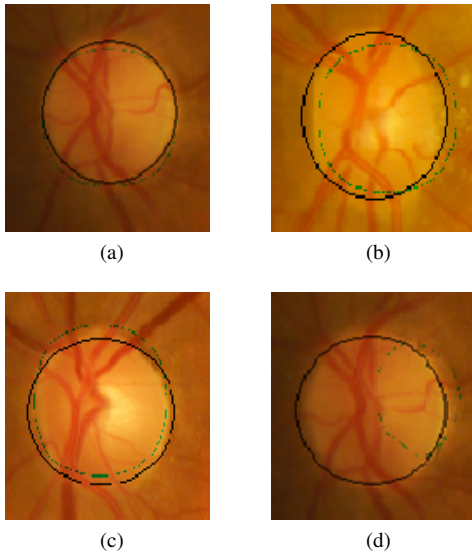


Fig. 12: Detected OD is mapped to the original subimage :(a),(c): Automatically RSF detected boundaries (green colour) overlapped on corresponding hand labeled images. (b),(d): Automatically ACM detected boundaries (green colour) overlapped on corresponding hand labeled images.

Fig.12 indicate that the overlapping area between ground-truth OD segmentations and those obtained by RSF models is higher than those obtained by ACM. All optic disk pixels were set to white, and all non-optic disk pixels were set to black. The new image was saved as a ground truth which will be used for comparison. All the OD which are automatically detected by our system are then compared with the hand-drawn ground truth.

Sensitivity S_n and specificity S_p are used to evaluate the performance of the methods as follows:

$$S_n = \frac{T_p}{T_p + F_n}, \quad S_p = \frac{T_n}{T_n + F_p} \quad (3)$$

Where T_p , T_n , F_p , and F_n are true positives, true negatives, false positives, and false negatives, respectively.all results are shown in this table:

TABLE I: Performance de dtection de contour du disque optique

Nombre des images	Sensibilit	Spfcicit	Prcision
89	90.33%	99.77%	95.05%

B. Detection of exudates

In order to test the proposed approach, we was applied the algorithm to our data base DIARETDB1.From 89 retinal images , we found 47 that contains exudates in different patterns and degrees. The robustness of our algorithm is shown in this figure where is a full detection of exudates inspite of the small sizes of the exudates regions:

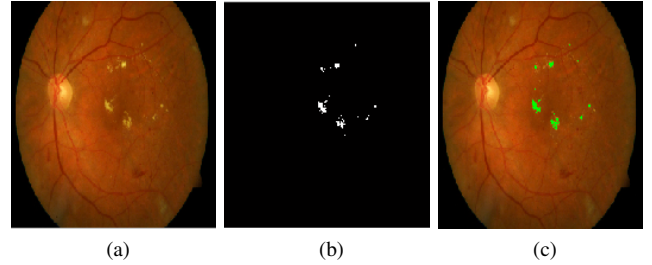


Fig. 13: Full detection of exudates:(a) original image, (b) extracted exudates and (c) detected exudates

A good result of exudates detection is shown in Fig.14 which is an image containing hemorrhage and very early exudates and again the detection is typical:

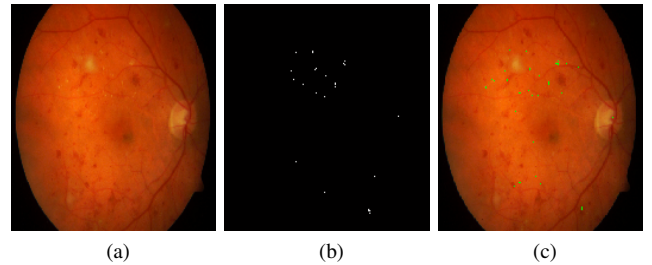


Fig. 14: detection of exudates in the presence of hemorrhage:(a) original image, (b) extracted exudates and (c) detected exudates .

This robustness could also be noticed from the detection of exudates in Fig.15 .Inspite of the low quality of the image, the algorithm well detects the exudates:

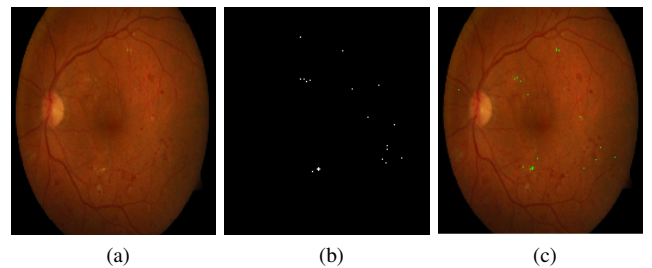


Fig. 15: detection of exudates in image of low contrast: (a) original image, (b) extracted exudates and (c) detected exudates.

C. Tortuosity Measurement

Sixteen images were used to test the performance of the proposed method. All the images were sent to an ophthalmologist in order to classify those images as a tortuous or non tortuous. Classifications are divided into two levels. The first level is vessel level which doctor classified each segment of vessel from vessel tree as tortuous or non-tortuous. Another level is frame level; the doctor decided which image is tortuous by looking at the whole vessel tree as one structure.

Tortuosity of the whole vascular structure T is obtained by the average of tortuosity values of each sub-vessel in the image.

We calculate tortuosity of the whole vascular structure by sum of tortuosity values of each sub-vessel and take the average. We mention here that we ignore also sub-vessel that has arc-length less than 20 because it is too short to take into account. The result from training set is shown in Table II. From the training, we obtained threshold that is used for classification of the retinal images into two classes. we calculate the mean of the maximum tortuosity value of normal retinal image and the minimum tortuosity value of tortuous retinal image. So this training set produced threshold equal to 1.1. This threshold is used to classify sub-segment as tortuous or non-tortuous. The experiment with 6 images is shown in Table III.

TABLE II: Training Set

No	Total Tortuosity	Ground Truth
1	1.071	Normal
2	1.085	Normal
3	1.11	Normal
4	1.089	Normal
5	1.101	Normal
6	1.233	Tortuosity
7	1.098	Normal
8	2.298	Tortuosity
9	1.13	Tortuosity
10	1.074	Normal

TABLE III: Classification

No	Total Tortuosity	Ground Truth	Prediction
1	1.062	Normal	Normal
2	1.045	Normal	Normal
3	1.012	Normal	Normal
4	1.25	Tortuosity	Tortuosity
5	1.032	Normal	Normal
6	1.042	Normal	Normal

IV. CONCLUSION

We have proposed for automatic detection of OD two methodologies: one to locate the OD based on a PCA and another one to segment its boundary based on RSF. Then, early detection of exudates is very important in the diagnosis of ocular diseases, so we have proposed an approach which combine coarse and fine segmentation to obtain final

detection of this kind of abnormalities. Finally, another type of computerized tools in automatic diagnosis of fundus images, we developed an automatic method of retinal vessel tortuosity measurement.

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