# EXTENSION OF VESSEL MODEL FOR THE VALIDATION OF RETINAL VESSEL ANALYSIS

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**Abstract: Aim of this work is the extension of a numeric retinal vessel model to validate measuring algorithms for measuring retinal vessel diameters. With this extension the fill factor and the offset will be simulated and its influences on the vessel profile and on the result of the measurement will be investigated.**

## Introduction

Since a physical model describing the optical properties of the retinal vessels can only be realised with great difficulty, a numerical model was created to simulate retinal imaging. This model includes the imaging process of the retinal vessels to a pixel image. A numeric vessel model developed by Vilser and Münch was used as the base of this work. Their model is based on an extinction approach according to the Lambert-Beer‘s law. This allows the calculation of the brightness gradient perpendicular to the vessel path [1].

Based on a Model grid of 1µm, the vessel profile is represented by this brightness gradient, every pixel has a brightness value from this profile. This profile is distorted during the optical transmission through the eye and the camera. This distortion was implemented in the model by averaging the area of optical resolution. The two-dimensional vessel path was then modelled by taking into account the slope and curvature of the vessel. The brightness image was digitized with the grid of a CCD camera. The brightness value of a pixel was calculated from the average of the brightness across the pixel area. The noise of the CCD camera was calculated and included in the model as a random value. In this manner the pixel brightness values were calculated and fed into a measurement algorithm. The effect of several modelling parameters on the measurements was investigated [2].

This model was extended in order to include the specific properties of the CCD sensors and to export generated vessel images. By means of this extension of the model, the size and position of the light sensitive area of the CCD sensors (fill factor) and the position of the vessel in the grid (offset) were simulated. This allowed the more precise simulation of the application of those sensors. The images were saved, which made it possible to load them into various measurement systems and to compare the results.

## Materials and Methods

The model was reprogrammed in Matlab for increased flexibility in order to examine the influence of the parameters on the profile in every modelling stage

The fill factor – the sensitive area over the overall area of a pixel (Equation 1)– was simulated. The pixel consists of the light sensitive area of the photo diodes, which produces the electric charge, as well as other electric components needed to read the collected charges of the pixels.

In CCD sensors fill factor can range from 0.2 to 1.0. One way to increase the fill factor is the application of micro lenses. The CCD micro lenses assure that the incoming light is focused only on the light sensitive area instead of on insensitive sections within the pixel .

In the CCD matrix image, the dimensions $N_x$ and $N_y$ as well as the distances $\Delta x$, $\Delta y$, X and Y were used as variable parameters for the sensitive area of the pixel (Fig. 1) in order to arbitrarily determine the size and position of the light sensitive area of the pixel.

$$FF = \frac{N_x \cdot N_y}{X \cdot Y} \qquad (1)$$

with X und Y as the pixel dimensions.

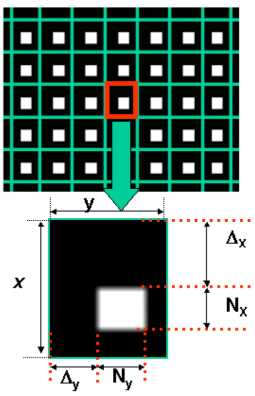
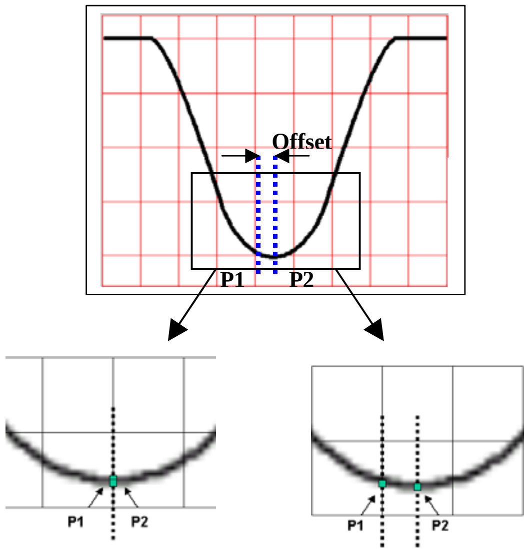



Figure 1: Modelling of the fill factor


ISSN: 1727-1983 

The second new parameter is the offset. Figure 2b shows this as the distance between the vessel centre (P2) and the right boundary of the pixel column adjacent to the vessel centre (P1).




a: offset = 0 b: offset > 0

Figure 2 : Modelling of the offset

The offset ranges from zero to one pixel in size. The vessel profile was modelled in a way that the two pixels have the same grey value at the middle of the vessel centre. If the offset is zero (figure 2a) or equal to the pixel size, the digitized profile will be symmetrical because the pixel boundary lies exactly between these two pixels and each of the opposing pixels reveals the same brightness value at the vessel centre.

In order to allow the movement of the vessel within the designated grid area, the distance (P2 – P1) was programmed as a variable parameter for the offset (figure 2b). The offset in Y-direction was also simulated in case of a horizontal vessel. In this extended model the generated vessel images can be saved as TIFF images. Intentionally no compression – as for example with JPEG images – was performed in order to not change the modelled brightness gradients.

The extended vessel model was used to analyse the influence of errors. It calculates the grey value profile, then produces a model image of a vessel section that is passed through an automatic measurement algorithm. This algorithm utilizes the model image in order to determine the vessel diameter ($D_m$) as a measurement value. The following simulated systematic error influences were defined according to their impact on the measurement (Equation 2):

$$\Delta D_m = D_m(x) - Dm_0 \qquad (2)$$

with $Dm_0$ being the reference measurement value, e.g. at a fill factor of 1 or an offset of zero and with $D_m(x)$ being the measurement value given at the simulation of the influence of an error.

The relative errors can be calculated from the absolute errors as seen in equation 3:

$$\Delta D_m[\%] = 100 * (D_m(x) - Dm_0) / D_0[\%] \qquad (3)$$

## Results

The changes in the fill factor influence the digitized profiles. To disable the influence of the offset, the sensitive area will be modelled symmetrical to the pixel centre. Profile changes are given by the changes of the correlation coefficient. If the two compared profiles are identical, the coefficient's value is 1. The vessel profiles changed by various fill factors were compared to the unchanged profile (fill factor of 1) and the correlation coefficient was calculated.

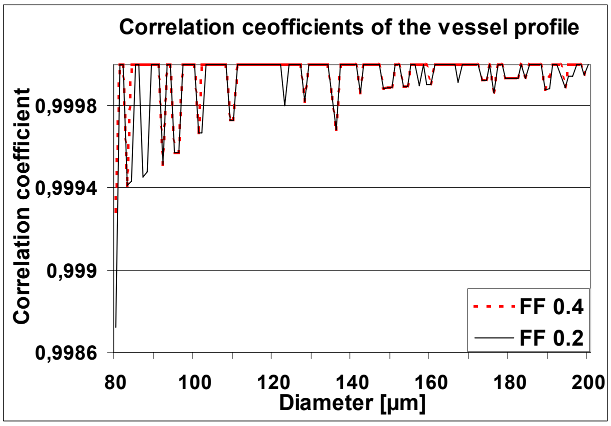



Figure 3: Correlation coefficient of the changed profiles

Figure 3 shows that the fill factor influence tends to decrease as the vessel diameter increases. Figure 4, for example, shows the vessel profile where the fill factors induces the minimum correlation coefficient or the greatest changes (Ds =80 µm and fill factor of 0.2).

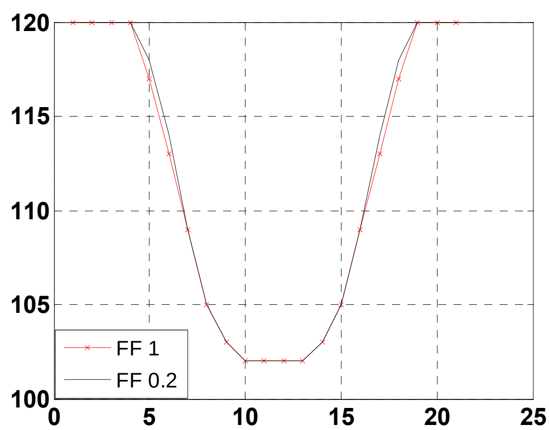



Figure 4 : Influence of the fill factor on the vessel profile at the point of greatest changes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The vessels changed by the fill factor were measured by a measurement algorithm and the relative measurement errors were calculated. Based on these vessels, the measurement errors for the simulation results were less than 1% (figure 5).

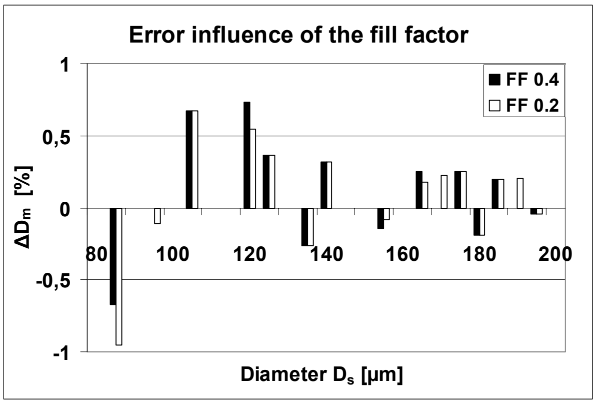


Figure 5 : Relative measurement error at different fill factors (FF)

Also, the influence of the offset on the vessel profile as well as on the measurement results was examined. The offset changed the digitized profiles as well. These changes were also verified by the correlation coefficient. The reference is the profile with the offset of zero. Profiles changed by an offset were compared to this reference and the correlation coefficient was calculated. Here the correlation coefficient was calculated without taking the shift into account (figure 8). Both profiles – with and without offset – were shifted by ±2 pixels in order record the maximum correlation coefficient, where the profiles are most similar (figure 6).

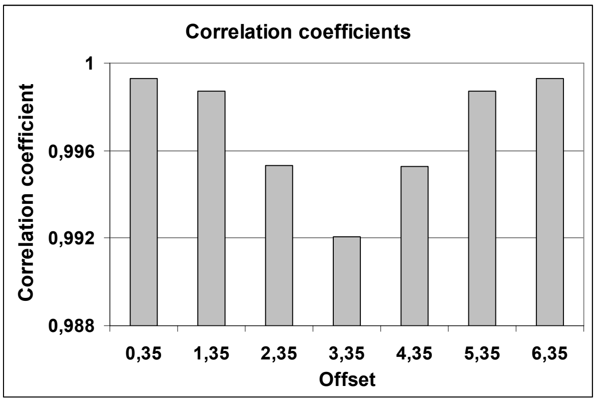


Figure 6: Correlation coefficients

The offset 3.35 (half of a pixel) shifts the pixel boundary by half of the pixel size and that changes the profile strongest.

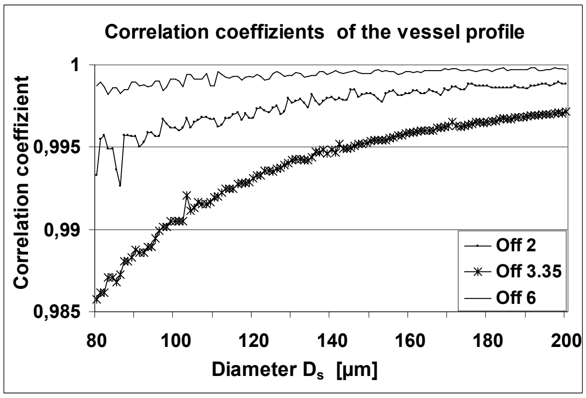


Figure 7: Correlation coefficients of profiles changes by an offset

The offset influence tends to decrease as the vessel diameter increases (figure 7). The greatest changes to the vessel profile occurred at the offset of 3.55 and the vessel diameter of 80µm as shown in figure 8.

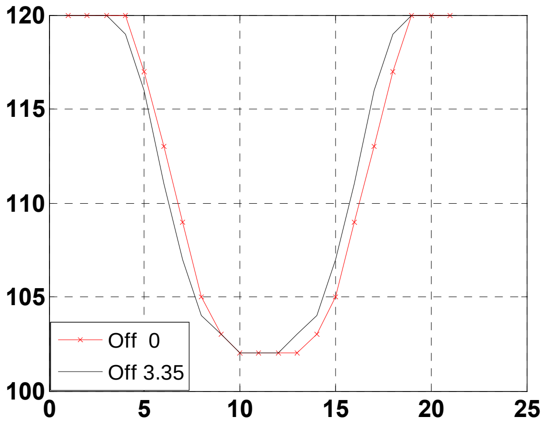


Figure 8 : Changes in vessel profile at the point of greatest changes

The changes in offset caused relative errors in the measurements of the vessel diameter. Figure 9 shows that the errors in the considered measurement range are less than 1.1%, based on simulation results.

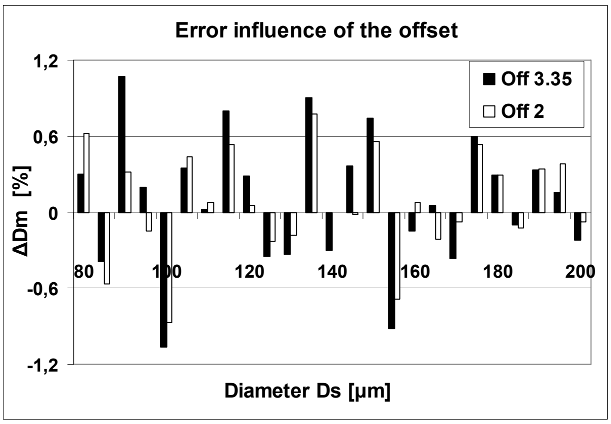


Figure 9: Relative measurement error at different offsets.


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These results were achieved for a set of input parameters, e.g. a pixel size of 6.71×6.71µm² applied to the retina, an optical resolution of the fundus camera and the eye of 20µm, a surrounding brightness of the vessels of 120 grey steps, and in the absence of noise caused by the CCD sensors.

## Discussion

The influence of the fill factor and the offset was revealed in the extended model. The presented simulations are only valid for a pixel size of 6.71×6.71µm² and for single images. Changes of the fill factor caused a systematic error that can be neglected. Changes of the offset cannot be avoided due to changing viewing conditions of the retina caused by eye movements in the single images. Errors caused by the offset have to be considered with regard to the measurement range and the input parameters.

## Conclusions

The extended model allows a good approximation of real imaging conditions and the analysis of the influence of several parameters on the measurement result. To get minimum error influence, the device parameters have to be optimised for example pixel geometry. The influence of errors could be analysed by arbitrary measurement methods of simulated TIFF images of the vessels

## Acknowledgements

German Academic Exchange Service (DAAD).
OIT-OpthalmoInnovation Thuringia, granted by BMBF-13N8521

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