Acquisition Time and Image Quality Improvement by Using HDR Imaging for Finger-vein Image Acquisition

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***Abstract*—Finger-vein images are a powerful biometric, which could replace fingerprint images in the future. In this paper, a method is proposed for capturing uniformly lit finger-vein images, which does not make use of a controllable light source. The method implies taking several images with differing shutter times, and combining them into a single image in which the finger is lit uniformly. The total capture time of the images taken using the proposed method is decreased drastically compared to methods using a controllable light source, and is independent of the imaged finger. The image quality using the proposed method is mostly improved, but still dependent on the imaged finger. A modification is proposed to set the appropriate shutter times for different finger types. The main question to be answered is whether finger-vein imaging devices can be built without a controllable light source which can use the method without decreasing image quality.**

***Keywords*—Biometrics, HDR imaging, Vascular pattern images**

I. Introduction

Finger-vein pattern images are a promising biometric, due to the good spoofing resistance, and a user convenience that is equal to that of the widely accepted fingerprint recognition. Finger vein pattern images are generally made by placing the finger between an infrared light source and an infrared sensitive camera. The infrared light is absorbed by the blood in the veins, but mostly transmitted by other parts of the finger, causing veins to show up as dark regions in the captured image.

The transmittance of infrared light is not uniform across the finger. This causes veins in thicker parts of the finger to be less distinguishable compared to veins in thinner parts of the finger. Several solutions to this problem have been proposed in [1, 2], where the light source is modified to increase the uniformity of the finger illumination. These methods have the disadvantage that the time to capture the image is not constant, and dependent on the finger that is imaged.

In this paper a method is proposed to increase the uniformity of the light intensity across the finger without controlling individual LEDs. The method uses a High Dynamic Range (HDR) imaging technique to improve the captured dynamic range of the finger-vein pattern image, and increase the illumination-uniformity of the finger. The advantage of this method is that the light source can maintain a constant intensity regardless of the finger to be imaged. This can reduce the costs for the light source. Another improvement over the previous methods is that the acquisition time using the proposed method is not dependent on the captured finger.

II. The proposed method

The proposed method will use a constant light source. The method will take three pictures of the finger with differing shutter times, and combine these into a single image containing a higher dynamic range. The dynamic range will then be reduced again, by decreasing the apparent illumination of bright parts of the image, and increasing the apparent illumination of dark parts of the image.

A. Source image acquisition

The previous methods for image acquisition from [1, 3] would not always illuminate the fingers with the maximal luminance of the LEDs, because the method would find the optimal LED illumination for a fixed shutter time. In case the imaged finger is so thin that the LEDs are used at less than their full brightness, the shutter time is higher than necessary, and the light levels could be increased to decrease the shutter time, and have a higher chance of a sharp image. Since HDR techniques will be used to prevent saturation of bright areas, the lighting intensity can be increased, to increase the SNR at the camera.

The method makes use of three images, which will be called I_-, I_0 and I_+, where I_- is an underexposed image of the finger, I_0 a correctly exposed image of the finger, and I_+ an overexposed image of the finger

B. Image processing

The goal of the image processing algorithm is to turn the three captured images I_-, I_0 and I_+ into a single HDR image I_{HDR} in which the finger is lit uniformly.

The algorithm makes use of the fact that the transmission of the finger is mostly independent of the Y position (distance across the finger), and varies only with the X position (distance along the finger), following the coordinate system as seen in Fig. 1. It is assumed a slice if the finger along the width of the finger (Y axis) is imaged in one pixel column of the image. The algorithm will therefore affect individual columns, and change them to make the apparent illumination equal at every X position. A column of an image is a vector denoted as $\mathbf{I}_t(c)$, where t denotes the exposure ($-$, 0 or $+$), and c the column number of the image.

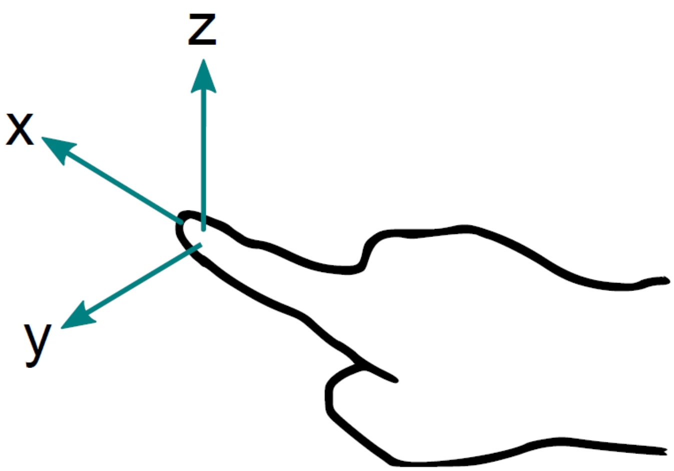


Fig. 1: Used coordinate system of the finger, figure from [1].

1) Image normalization: Since only the finger should be affected by the HDR algortihm, and not the background, the first step is to isolate the finger from the background. Afterwards, the uniformity of I_- and I_+ can be increased using equation 1 and 2

$$M_t(c) = \mathrm{mean}(\mathbf{I}_t(c)) \tag{1}$$

$$\mathbf{N}_t(c) = \mathbf{I}_t(c) - M_t(c) \tag{2}$$

Where t denotes the affected image, M the mean of all pixels in a column, and **N** the normalized image.

Equation 2 causes the normalized image columns to have a mean column value of zero, and both positive and negative pixel values.

2) Image blending: After the normalization of the short and long exposures, the middle exposure is used to determine for each pixel column whether most detail is available in the short or the long exposure. This is done using $M_0(c)$, the mean value of each column in the middle exposure. The goal is to achieve a weighting for both images. If the illumination of a column is low in the short exposure, the column should have a low weighting, since the SNR of the column is much worse than that of the column in the long exposure image. The long exposure should have a low weight at a high illumination, since the signal in the image column has a high chance of being distorted due to saturation.

For certain columns the data is present without distortion or excessive noise in both source images, in which case the data from both images can be used to reduce the amount of noise in the image. To calculate the weight of each image in each column, a cumulative normal distribution can be used, as can be seen in equation 3. The weight of the short exposure W_- should be high when the mean value of the column is high, and the weight of the long exposure W_+ should always be $1 - W_-$. A normal distribution is used because it is a smooth function, decreasing the chance of visible lines at places where the blending factor changes.

$$\begin{aligned} W_-(c) &= \Phi(M_0(c)|\mu,\sigma) = \int_{-\infty}^{M_0(c)} \frac{1}{\sqrt{2\sigma^2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \mathrm{d}x \\ W_+(c) &= 1 - W_-(c) \end{aligned} \tag{3}$$

The columns of the final image can be built up from the normalized images and their weights using equation 4.

$$\mathbf{N}_{\mathrm{HDR}}(c) = W_-(c)\mathbf{N}_-(c) + W_+(c)\mathbf{N}_+(c) \tag{4}$$

These columns still have mean values of zero, and pixel values above and below zero, so the data needs to be mapped back into a normal range for pictures using equation 5.

$$\mathbf{I}_{\mathrm{HDR}}(c) = n\frac{\mathbf{N}_{\mathrm{HDR}}(c) - \min(N_{\mathrm{HDR}})}{\max(N_{\mathrm{HDR}}) - \min(N_{\mathrm{HDR}})} \tag{5}$$

Where n is the maximum value to which the image is mapped.

III. Performance Analysis

To test the method, the method has been implemented using the device built by B. Ton in [1], where the software from P. Jing from [3] has been supplemented with functions to take HDR images using the method described in this paper. Also, for every picture taken using the software, a quality score would be calculated which is described in section III-B below.

A. *Test setup*

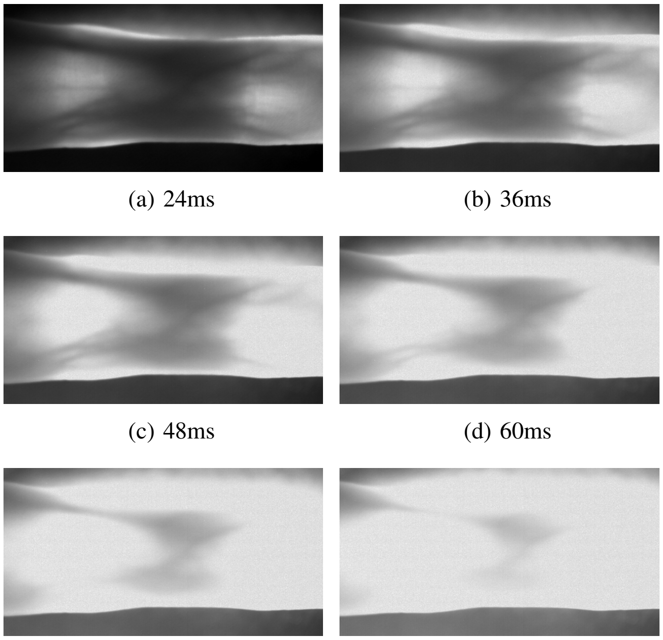
The device used to verify the method consisted of 8 IR LEDs in a row, which shined trough the finger. A C-Cam BCI-5 camera with an infrared filter acts as the imaging device.

Since the C-Cam BCi5 camera uses a different ADC for the even and odd pixel columns, the picture would contain alternating bright and dark columns if the calibration is wrong. To fix this issue without needing to calibrate this part of the camera a 1D image filter was applied with kernel $H = \begin{bmatrix} 0.25 & 0.5 & 0.25 \end{bmatrix}$. Another way in which the alternating bright and dark columns could be removed is by determining the offset between the even and odd columns, and remapping the even or odd columns accordingly. This would maintain the resolution accross the rows of the image equal, since no blurring effect will take place due to the image filter.

The shutter times used for the implementation were chosen after taking several test pictures, which can be seen in Fig. 2. Since the images with a shutter time longer than 48 ms do not reveal extra detail in the image, the images with the shutter times not higher than 48 ms were chosen, which were shutter times of 24, 36 and 48 ms. This means that $I_- = I_{24}$, $I_0 = I_{36}$ and $I_+ = I_{48}$.

The finger is isolated using the function lee_region from [4]. As can be seen in Fig. 2., the contrast between foreground and background is the strongest in the exposure of 24 ms. Therefore, the finger-edge detection is run on the 24 ms exposure with the parameters $\mathrm{mask_h} = 4$ and $\mathrm{mask_w} = 20$.

For the constants in equation 3, $\mu = 160$ and $\sigma = 10$ were chosen from the plot which can be seen in Fig. 3. The plot



(a) 24ms (b) 36ms

(c) 48ms (d) 60ms

(e) 72ms (f) 84ms

Fig. 2: Author's left middle finger captured using various shutter times

shows the standard deviation of an entire column against the mean of the column for three different exposure times of the same finger. The 48 ms lobe in the top right still contains detail, because it has a high standard deviation, so should still be included in the final image. This lobe matches with the top right lobe of the 36 ms exposure at a mean value of 180. It can also be seen that the same information is in the 24 ms exposure at a mean value of 140, which should not be used in the final image due to higher noise. The mean μ of the distribution in equation 3 (where both images contribute the same amount) was chosen exactly between these two points at 160. The value of the standard deviation σ in equation 3 was set at 10 so the critical points of a mean of 140 in the 24 ms exposure and a mean of 180 in the 48 ms exposure were both two standard deviations from the mean of the normal distribution.

It can be seen from Fig. 3. that the standard deviation in the bright columns of the 48 ms exposure is lower than the standard deviation of the same lobe in the 24 and 36 ms exposures. This is caused by the fact that the 48 ms exposure has several parts of the column that are saturated, especially at the edge of the finger. this makes the standard deviation a poor classifier of the amount of detail in these parts of the images when pixels become saturated. All desired data (in the dark parts of the 48 ms exposure) is still available, as seen in Fig. 2c.

The parameter n in equation 5 was set to 1.

The final outcome of the HDR image made from the images seen in Fig. 2. can be seen in Fig. 4.

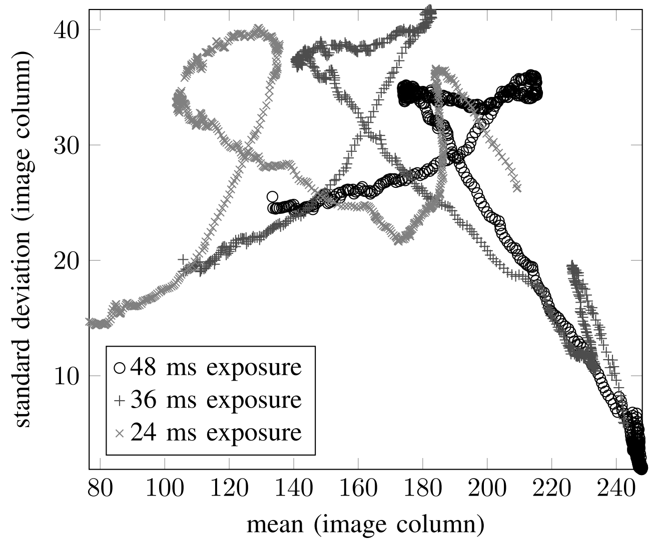


Fig. 3: Image mean value vs image standard deviation for each pixel column in all three exposure of author's right ring finger

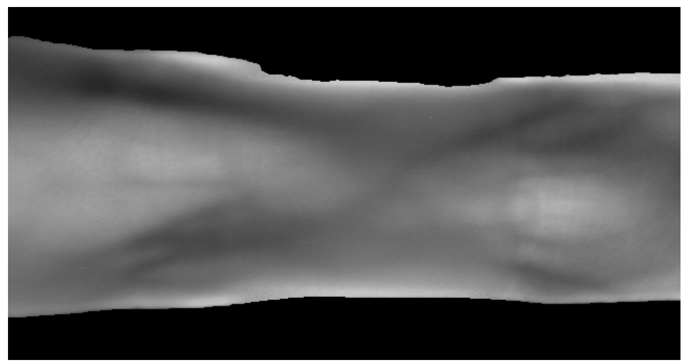


Fig. 4: HDR image made from the source images in Fig. 2.

B. Quality Analysis

To quantify the quality differences between the HDR images, the HDR source images, and the images created using the original method from [1], the finger vein image quality assessment from [5] has been used. The method subdivides the image into small segments, and uses the curvature of the radon transform of each segment to quantify the amount of detail that has a high probability of being a vein.

1) Quality assessment implementation: The quality assessment by H. Qin et al. has been implemented with a few modifications. The score calculated using the method in [5] is depicted as S_{Qin}. The parameters used for the quality assessment function can be seen in the table I.

The W and H values were set to 60 and 30 respectively to have the image split up into an $11{\times}11$ grid. This amounts to more segments than in the $8{\times}9$ grid that was used in the original research. This was chosen because parts of the images used in this research contain just background, or a part of the

TABLE I: Parameters used for the quality assessment from [5]

Parameter	description	Value
W	Segment width (pixels)	60
H	Segment height (pixels)	30
K	Amount of radon transform angles	16
τ	Prominence threshold	$0.12/255$

background. These will not be used for calculating the quality score of the image, since noise in the background could falsely be picked up as vein-detail, and the edge of the finger could falsely be detected as a high contrast vein.

The K parameter indicates the amount of angles at which a radon transform is identified. In the original research this value was set at 8. 16 was used in this research because the resolution of the segments used in this research is higher, and this allows for more accurate quality scores if the veins are at angles that are not sampled if the amount of angles is 8.

The τ parameter was increased from 0.06 to 0.12, since quality scores would often be zero with the parameter set to 0.06, even though a lot of vein detail was visible in the image. The value also had to be divided by 255, since the scores are calculated on images with pixel values ranging between 0 and 1, instead of 0 and 255.

Since the quality score scales linearly with the amount of curvature in the radon transform, it also scales linearly with the illumination of the finger. Because it was desired to test the quality of the HDR source images as well, a quality score that's independent of overall illumination intensity is necessary, which can be achieved by dividing the quality score by the mean of the entire picture. This score is depicted as S_{eq}.

TABLE II: Average quality scores for all images taken using the proposed method (first 4 rows) and images taken using the method proposed by P. Jing in [3].

Image	avg. S_{Qin}	avg. S_{eq}	min. S_{eq}	max. S_{eq}	# Samples
I_{HDR}	1,870	4,461	2,215	8.088	41
- I_{24}	*1,417*	*2,346*	*1,539*	*3,176*	*41*
- I_{36}	*1,672*	*2,185*	*1,459*	*3,001*	*41*
- I_{48}	*1,776*	*2,065*	*1,464*	*2,824*	*41*
I_{Jing}	1,498	3,027	1,904	4,353	45

C. Time Analysis

Since the proposed method is a static program, that does not rely on feedback during the acquisition process, the time it takes to scan and process a finger is always equal. For the system used during this research the acquisition time was 2.6 seconds.

The current method for acquiring Finger-vein images relies on a system using a feedback loop. This causes the acquisition time to be dependent on the finger that is captured. Two implementations of the method have been measured in several use cases by P. Jing in [3]. He measured the time it took to complete the lighting for thin, normal and thick fingers.

TABLE III: Average combined lighting- and acquisition time for three different implementations. B. T. Ton results from [3]

Finger Size	B. T. Ton method Total time (s)	P. Jing method Total time (s)	Proposed Method Total time (s)
Thin	4,5	4,3	2,6
Normal	5,4	3,9	2,6
Thick	13,5	4,9	2,6

In that research, a method was proposed that decreased the acquisition time drastically, but sometimes had to fall back to the old method. The average time for each type of finger and for each implementation can be seen in table III.

IV. Discussion

As seen in table III the method always works quicker than the previous methods. The minimum gain compared to P. Jing's method is a reduction of 32% for a normal finger, and 47% for a thick finger. It should be noted that in the implementation used for this experiment, a pause of 0.2 seconds was used between the captures of several images, because the camera would not use the updated shutter time if the pause was shorter. This means the total capture time for the HDR method could be reduced to 2.2 seconds if this problem is solved.

From table II it can be seen that the quality scores of the HDR images are on average better than the quality scores obtained using the old method. Both the minimum and maximum score are increased as well.

It should be noted that in some of the images taken for the data in table II and III there were no veins visible. This could have several causes: The finger could have been held at the wrong spot in the capture device causing the vein patterns to be out of focus, the finger might have moved during the acquisition causing motion blur, or the veins might be deep inside the finger, causing them to be invisible using this capture technique.

During the capturing of the finger vein images, it was found out that the shutter times chosen for the images were not suitable for every finger, since some fingers were too thin. An image of a finger with the right size where the shutter times were suitable can be seen in Fig. 5. An image of a finger that is too thin for the shutter times used can be seen in Fig. 6., where it can be seen that all source images are partly overexposed. There were no cases where the shutter times used were too short.

The program could be changed to account for the difference in finger thickness, while still only taking three images to use for the HDR image. For thick fingers, the shutter times should stay 24, 36 and 48 ms, but this could be changed to 18, 24 and 36 in case the imaged finger is thin. This is possible without further time delay by having the picture sequence of 24, 36 and 48 ms respectively, or 24, 36 and 18 ms respectively. After the capture of the 24 ms image, while the 36 ms image is captured, the mean of the 24 ms image can be calculated, and a threshold can be used to determine whether the third picture taken should have a shutter time of 48 or 18 ms. An example

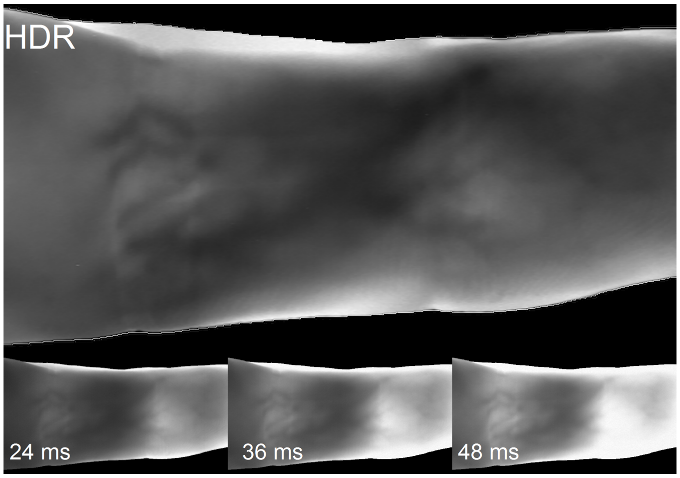


Fig. 5: Example of high quality HDR image with suitable shutter times in the source images.

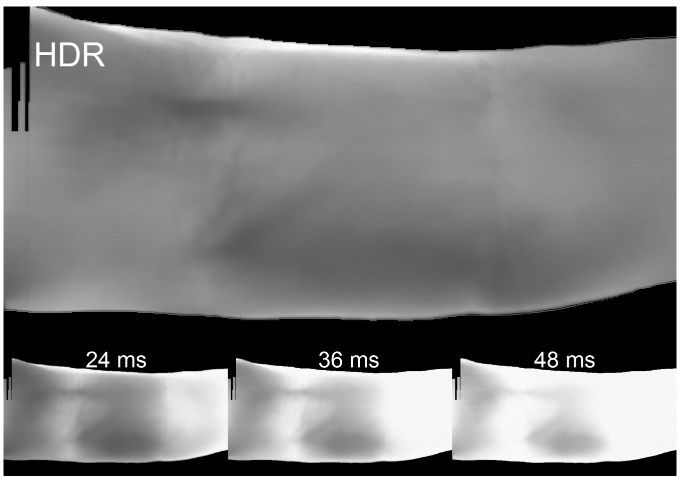


Fig. 6: Example of low quality HDR image with too long shutter times in the source images, and improper background removal

of an HDR picture using an image with a shutter time of 18 ms instead of 48 ms can be seen in Fig. 7. The imaged finger is the same finger as seen in Fig.4. and it can be seen the contrast is increased in the image created using lower shutter times.

Another observation that can be made is that in a lot of the HDR images is that the veins in the bright parts of the finger have less contrast compared to veins in the darker parts. This could be due to the longer exposure having more motion blur, which is shown only in the parts where the longer exposure is used. Another reason could be that the image was already saturated in the long exposure.

The shutter times used for the images to use with this method are of course dependent on the device used for image capturing device, where the necessary shutter times are a function of the light intensity of the light source, the aperture size of the used lens, and the sensitivity of the camera. The

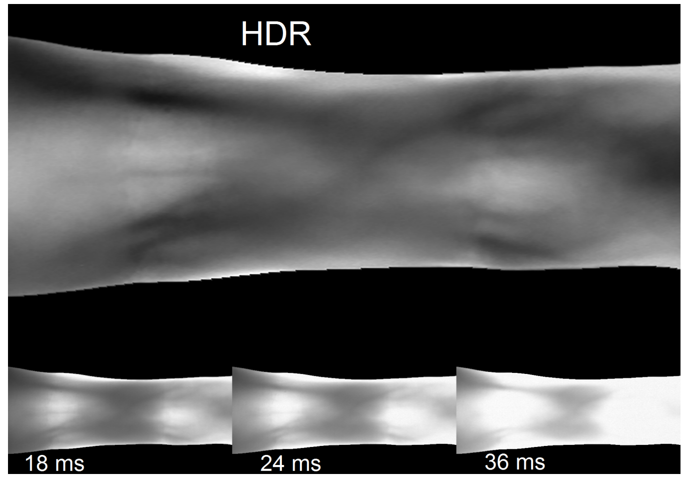


Fig. 7: Example of HDR image using shorter exposure times, to keep detail in thin fingers.

Algorithm with the used parameters will work with all images, given that the shutter times of the images are t, $1.5t$ and $2t$. If different shutter time relations are to be used, the weight function in equation 3 should be modified accordingly.

V. Conclusion

In this paper, a method has been proposed for taking uniformly lit finger-vein images using a non-controllable light source. The method has been analysed using a small data set, and it has been shown that the speed of the acquisition has improved up to 47% using the proposed method. The quality of the pictures has been improved as well. These results show the method could be used to design finger-vein scanners without a controllable light source, which could reduce the costs of the device.

VI. Further research

The implementation used to do the performance analysis of the method has not been thoroughly worked out. The parameters chosen for the system were always chosen depending on the images taken from one finger. The system could likely be improved by using more data to choose parameters to use in the implementation.

Another aspect of the method that could be improved is how the images are used. In the current proposed method, the data in the middle exposure is essentially valid data that could be used in the HDR image as well, but is only used to determine weights. Using this image in the weighted sum as well would increase the amount of data used in the HDR image, and therefore increase the SNR of the HDR image.

Finally, the method could be improved by modifying it so the light parts of the finger will have the same amount of contrast as the dark parts of the finger.

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